ADVANCING
INDUSTRIAL ENGINEERING IN NIGERIA
THROUGH
TEACHING, RESEARCH AND INNOVATION

A BOOK OF READING

Edited By
Ayodeji E. Oluleye
Victor O. Oladokun
Olusegun G. Akanbi

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(A Festchrift in honour of Professor O. E Charles-Owaba)

Professor O. E. Charles-Owaba

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FOREWORD

It gives me great pleasure writing the foreword to this book. The book was written in recognition of the immense contributions of one of Nigeria's foremost industrial engineers, respected teacher, mentor, and lover of youth – Professor Oliver Charles-Owaba.

His commitment to the teaching and learning process, passionate pursuit of research and demonstration of excellence has prompted his colleagues and mentees to write this book titled – Advancing Industrial Engineering in Nigeria through Teaching, Research and Innovation (A Festschrift in honour of Professor O. E Charles-Owaba) as a mark of honour, respect and recognition for his personality and achievements.

Professor Charles-Owaba has written scores of articles and books while also consulting for a medley of organisations. He has served as external examiner to various programmes in the tertiary educational system. The topics presented in the book cover the areas of Production/Manufacturing Engineering, Ergonomics/Human Factors Engineering, Systems Engineering, Engineering Management, Operations Research and Policy. They present the review of the literature, extension of theories and real-life applications. These should find good use in the drive for national development.

Based on the above, and the collection of expertise in the various fields, the book is a fitting contribution to the corpus of knowledge in industrial engineering. It is indeed a befitting gift in honour of erudite Professor Charles-Owaba.

I strongly recommend this book to everyone who is interested in how work systems can be made more productive and profitable. It represents a resourceful compilation to honour a man who has spent the last forty years building up several generations of industrial engineers who are part of the process to put Nigeria in the rightful seat in the comity of nations. Congratulations to Professor Charles-Owaba, his colleagues and mentees for this festschrift.

Professor Godwin Ovuworie
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CHAPTER 1

Quantitative Approach to Organisational Design in Project Management Office

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Abstract

In a competitive and dynamic business environment, project management is an efficient framework to ensure flexibility and to manage beneficial change. In the design of a project organisation structure, the use of a quantitative approach to model contingency variables and human dynamics challenges have received limited attention. In this chapter, the basic concepts of projects, organisation design and structure, and Project Management Office (PMO) was discussed. Thereafter, the applicability of operations research paradigm to structure a PMO using the methodology developed by Professor Charles-Owaba were highlighted.

Keywords: Project, Project management, Organisation structure, Project-based organisation, Modeling, Charles-Owaba.

1. Introduction

An organisational structure is rooted in different organisational design theories and provides the required platform to drive organisation strategic goals. Although different organisational structure exists, the effect of competition and an uncertain business environment often leads to organisational restructuring. In this chapter, the applicability of quantitative methods in project organisational structure will be discussed from sections 1.1 to 1.6.

1.1 Projects and Project Management: Concepts and Definitions

As agents of beneficial change, projects are conceptualised and executed within the established schedule, resource and performance parameters to achieve organisation strategic goals. Therefore, in a dynamic and competitive environment, the pace of change offered by projects is one of the ways to remain relevant. Projects constitute 30% of the world economy as commented by Anbari *et al.* (2008). Projects are characterised by their uniqueness, temporary and transient nature, urgency, unitary, resource usage, novelty, complexity, integration, level of risk, flexible structure, modularity of design, and predefined objectives (see Bard et al., 1994; Atkinson, 1999; Turner & Muller, 2003; Bredillet, 2007; Reiss, 2007; Gray & Larson, 2008, p.100; Moleli, 2012; Project Management Book of Knowledge (PMBOK) Guide, 2017, p.4; Odedairo & Olenloa, 2021). These inherent attributes of projects differentiate it from another business process; for example, the transient nature of projects refers to different stages in the project management processes. Hence, project management is an efficient framework to ensure flexibility and handle changes.

Project Management (PM) as defined by Association of Project Management (APM) is "a process by which projects are defined, planned, monitored, controlled and delivered such that the agreed benefits are realized" (APM Book of Knowledge, 2006, p.2). Project Management Institute (PMI), view PM as the "application of knowledge, skills, tools and techniques to project activities to meet the project requirements" (PMBOK, 2017, p.10). While the core of PM methodologies is adaptable and universal, an effective project life-cycle ensures smooth transformation from vision to reality. Project life-cycles can be characterised along level (i.e. degree) of change and delivery frequency. A project life-cycle is agile if it offers a high degree of change and high delivery frequency, while the predictive, iterative and incremental life-cycles lies within these two extremes. The project management team (or the organisation) must identify the peculiarity of the project before selecting the preferred life-cycle. Also, the project organisational structure and needs (e.g. time, resources, communication links, etc.) should be appraised continually during the life-cycle.

1.2 Organisations: Design and Structure

An organisation is developed "whenever the pursuit of an objective requires the realization of a task that calls for the joint effort of two or more individuals" (Hax & Majluf, 1981 p. 417). In essence, organisations can be characterised based on type and size. Greenwood and Miller (2010) commented that most organisation types are confronted with arrays of design and decision challenges. Eames (1969) defines design as a plan for arranging elements effectively to accomplish a purpose. Most design efforts present flexibility to gather multiple choices and offer opportunities to compare alternatives. Organisational design is an approach that holistically integrates people, processes, structure and other core organisation elements to enable an organisation to actualise its strategic goals. Any organisational design method should be responsive to the ability to adapt to new strategies and future changes. This responsiveness will enable the organisation to respond to disruption arising from the environment, political and economic pressure, technology, and culture.

Organisation design has rich and established literature on different design frameworks such as classical, neoclassical and modern theories (Charles-Owaba, 2002; Greenwood & Miller, 2010; Van de Ven et al., 2013; Food and Agriculture Organisation). However, the complexity and malleability inherent in almost all types prohibit a "one-size-fits-all" organisational design framework. Although, an in-depth discussion of these design theories is beyond the scope of this chapter; however, a summary will be provided. The components of the classical theory are Taylor's scientific management (scientific selection, management and training of workers), Weber bureaucratic approach (structure, specialization and democracy) and administrative theory by Fayol (discipline, unity of command, and equity). The neo-classical approach consists of human relation and decision-making theories. The modern theories include the following approaches: (i) system-view (ii) socio-technical and (iii) contingency or situational. Irrespective of the design theory adopted, a carefully designed organisation is expected to reduce confusion in the choice of a structure.

Organisation structure (OS) rooted in organisational design theories is one of several elements in any business. OS provides the necessary platform to conceptualise and drive the strategic plan. Some of the elements to consider in the selection of an OS include decision positions and levels, supervisory positions, cost, physical locations, operation positions, communication lines, and span of control (Charles-Owaba (2002); PMBOK, 2017 p.46). An efficient structure provides an enabling environment for rapid transformation of decisions into actions. Usually, to arrive at an acceptable structure, a trade-off among several elements is unavoidable. Since organisation structure is expected to work in tandem with organisation design, some of the constraints associated with the preferred design theory have to be addressed before a working structure can be achieved. An organisation may adopt more than one structure across its business functions e.g. the sales/fulfilment function may require a different structure from the purchasing function. Once the design and structure of an organisation support its business objectives; ultimately, organisational effectiveness will be actualized. In Table 1, different structures are compared along with several factors.

Table 1 Comparison of some organisation structures

	Factors	Structure type				
		Functional	Divisional	Matrix	Network	Cluster
1	Strategic goal	Specific	Multiform	Reactive	Innovative	Competitive
2	Environmental conditions	Stable	Heterogeneous	Complex	Volatile	Fast-paced
3	Division of Labour	By inputs	By outputs	Inputs and Outputs	Knowledge	Skills and knowledge
4	Co-ordination / Reporting	Hierarchical	By division-General manager and Corporate staff	Dual purpose	Cross-functional teams	Centralised

5	Decision making	Centralised	Separated	Shared	Decentralised	Internal
6	Boundaries	Core	Dual-Internal/ external	Multiple	Unstable	Multiple
7	Mode of authority	Functional/ Positional	Management Skills and responsibility	Required negotiating skills	Use of knowledge	Combination of expertise and resource usage
8	Resource usage	4	1	2	3	4
9	Time usage	1	3	2	4	4
10	Responsiveness	1	2	3	4	4
11	Adaptability	1	3	2	3	3
12	Accountability	3	4	1	3	3
Legend: 1-Poor, 2-Moderate, 3-Good, 4-Excellent						

Source: Adapted from Guide to Organisation Design (Stanford, 2007, p.66)

1.3 Organisation Structure in Project Management

The term 'temporary organisation' is one of the characteristics of a project. Lundin and Söderholm (1995) highlighted the difference between a permanent and temporary organisation using the concept of task, time, team and transition. Permanent organisations are preoccupied with goals (rather than tasks), the need to survive (not time-based), functioning organisation (not a team concept) and continuous production (rather than a transition). The question 'what is the most suitable organisation structure in project management is somehow complicated due to inherent characteristics of projects. A project organisation structure (POS) is expected to support, maintain and ensure balance among the following criteria: resource allocation, authority, division of work, communication lines, etc. Invariably, a poor POS can result in a failed project; for example, a report submitted in 2011 by the presidential projects assessment committee in Nigeria revealed a huge number totalling 11,886 of ongoing and abandoned federal infrastructural projects (Premium Times Newspaper, 2012). Lack of direction in project management was cited as one of the several reasons for the problem. Usually, a good direction in project management aligns the selection of the project, organisation structure/culture, and the project management process with corporate strategy. Similarly, Dai and Well (2004) suggested that while project failure rates are on the increase, more research into improved organisation structures such as the Project Management Office (PMO) should be encouraged.

1.3.1 Typology of Project Organisation Structure

In organisation theory, based on environmental conditions (i.e. internal and external factors) surrounding an organisation the need for typology arises. Project-based organisation (PBO) has its mixture of design choices and contingency features. The idea of developing a generalised typology will be useful in modelling different types of organisations. In literature, researchers have discussed project organisation by multiple nomenclatures as presented in Table 2.

Table 2. Typology of Project Organisation Structures

	Authors	Description/ Characteristics	Nomenclature/ Names
1	Hobday, 2000; Pemsel and Wiewiora, 2013;	Description: Project is the primary unit of production, innovation, and competition. Characteristics: Standalone, subsidiary of a big corporation and role defined by the parent organisation	1. Project-Based Organisation (PBO)
2	Oliviera, 2017; PMBOK, 2017; Babaeianpour and Zohrevandi, 2014; Kerzner, 2003; Hurt and Thomas, 2009.	Description: (i) An organisation unit with the responsibility of coordinating projects in a PBO. (ii) PMO is implemented to standardise, improve, administer and control project management processes. (iii) PMO may be in stages depending on the maturity of an organisation. (iv) PMO referred to as Project Office Characteristics: Diverse, transient (can be created and closed when not needed), an organisation within an organisation	1. Project Management Office (PMO). 2. Project Office 3. Organisational project office

3	Monteiro et al (2016)	(i) Identified 47 PMO models (ii)Number of models sharing the same name reduced to 25. (ii) Common nomenclature across models reduced to 4	1.Enterprise PMO 2. Project Management Centre of Excellence (PMOCE) 3. Project Office 4. Project Support Office

1.3.2 Project Management Office

In recent years, several organisations have embraced PMO as a formal organisational structure to ensure a good direction in project management, eliminate trial and error in project administration and efficient resource management. A PMO (also called the Centre of Excellence or Center of Expertise) is a governance strategy and a control layer between an organisation and its project management efforts. Project management institute defined a PMO as:

> an organizational structure that standardizes the project-related governance processes and facilitates the sharing of resources, methodologies, tools, and techniques. The responsibilities of a PMO can range from providing project management support functions to the direct management of one or more projects (PMBOK, 2017, p.48).

In the third edition of its PMBOK (2004), PMI highlighted other nomenclature for PMO as "project office" or "program office". Some of the functions of a PMO includes: storing of proprietary information, defining and maintaining project standards, facilitating and provision of resources, consulting and knowledge sharing, and to conduct training.

Ward and Daniel (2013) consider a PMO as an organizational entity designed to offer supports on strategic decisions and proper implementation of project management principles; to project managers, project and management teams. As an entity, Montero et al (2016) commented that a PMO could be a unit or department in a matrix or PBO. Babaeianpour and Zohrevandi (2014) identified the project office, basic PMO, standard PBO, advanced PMO and centre of excellence (CoE) as stages a PMO may transform through in an organisation. Just like projects, PMOs are complex and due to variability in different project management firms, their design may be difficult. However, Hobbs and Aubry (2008) through their rigorous empirical study proposed three (3) classifications for PMOs using three variables; namely, number of projects (NP), number of project managers (NPM) and level of decision-making authority (DMA). The three classifications are (i) PMOs with many NP and NPM with considerable high DMA (ii) PMOs with few NP, few NPM with less DMA and (iii) PMOs with few or zero NPM with a moderate level of DMA.

1.4 Organisation Design and Project Management Structure: Current Issues

Miterev et al. (2017) commented that despite limited studies on the interaction between project management and organisation design, PBO presents promising research opportunities. The contingency features and human dynamics challenges of elements such as decision positions and levels, supervisory positions, cost, physical locations, operation positions, communication lines, and span of control in a PBO is worth researching.

1.5 Organisational Design Approaches in Project management Office

Several organisation models (e.g. Galbraith's Star Model, 7-S model) derived from different organisational design theories form the basis of many organisational structures. Hax and Majluf (1981) identified three forms of organisational structures widely used. These are the functional, divisional and matrix derived from well-proven design theories. The advantages and disadvantages of these design structures are widely published. For example, the matrix structure is mostly preferred in project management; however, its use is characterised by conflicts bothering on authority, reporting and resource management (Thiry, 2007).

1.5.1 Quantitative methods

With quantitative research design, it is possible to observe, assess, diagnose, generate a hypothesis, and estimate interaction among system components. Quantitative methods emphasize the mathematical and numerical analysis of data to enhance better communication. Hax and Majluf (1981) suggested the use of operations research (OR) paradigm in organisational design. OR methods can evaluate and determine optimal choice among several courses of action. Charles-Owaba (2002) not only accepted the idea of studying the applicability of OR in organisational design, the author further suggested the adoption of the engineering design process in organisational design. The author highlighted 24 benefits of using engineering design methodology in organisational design studies to show that OR methods can handle mechanistic tendencies in different organisation design theory. Some of the benefits include (i) adoption of quantitative procedures for the design (ii) ability to mathematically model an organisation structure (iii) quick modification of an organisation structure (iv) provision for comparative evaluation of different types of structure (v) combination of suitable design tools from mathematics, physical sciences, social sciences, industrial and systems engineering opportunities (vi) ability to choose appropriate design criteria (vii) identification of design variable and parameters required to define an organisation structure, etc.

1.6 Modeling PMO with Personnel Utilisation as the organisational design objective

An organisational design problem using OR approach will aim to optimise a pre-defined design objective such as personnel utilisation, redundancy and their associated cost; subject to the satisfaction of a set of organisation design variables and constraint functions parameters within sets of variables limiting values (Charles-Owaba, 2002). Since the organizational design of PMO using quantitative approach is an emerging research area, the design methodology proposed and developed by Charles-Owaba (2002) will be adopted. Consequently, an employee utilisation design approach to PMO and the relevant solution procedure to ensure an optimal business organisational structure will be highlighted further in the next section.

1.6.1 Notations and Terminologies

The basic notations and their definitions are presented in Table 3.

Table 3. Notations and Definitions

Notation	Definition	Notation	Definition
i	Index for Work level (Decision-making authority)	j	Index for decision-making centre (Number of project managers)
H_{ij}	The utilisation of personnel of decision making centre j at work level i	M	Number of decision levels
K_{ij}	The span of control for a decision-making centre with index j and ith work level	N_i	Number of decision position available at work level i
W_{ij}	Average waiting time(hours) a case is available to receive attention from the project manager	P_{ij}	The amount of time a project manager has no case requiring his/her attention
λ_{ij}	The subordinates arrive to consult the superior (project manager) at this rate	A_{ij}	The time required (in hours) for work scheduled in a day
N_O	Number of operation positions which perform terminal activities (number of the lowest cadre of staff)	μ_{ij}	The subordinates are attended to by a superior at decision-making centre j and work level i, at this rate
ϕ_h	Set of functions $(A_{ij}, \mu_{ij}, N_O, \lambda_{ij})$	L_{ij}	The average number of cases available for a project manager to attend to in one day
H	Personnel utilisation function for entire organisation structure which contains a set of functions (K_{ij}, N_i, M, ϕ_h)		

1.6.2 Organisation Design Problem: Project Management Office

For personnel utilisation based organisation design problem, Charles-Owaba (2002) stated the problem as follows: Given the values of N_o, λ_{ij}, μ_{ij} and A, judiciously select a feasible set of a span of control $\{K_{ij}\}$, a set of management / supervision positions $\{N_i\}$ and the number of management levels (M) such that the function, H $(K_{ij}, N_{i,} M, A, \lambda_{ij}, \mu_{ij}, N_o)$ is of the maximum possible value.

1.6.3 Model Assumptions

As earlier stated, a PMO is responsible for knowledge management, resource management, maintaining project standards and facilitation of training. The following assumptions from Charles-Owaba (2002) were adopted for use with two organisational design variables peculiar to PMO as identified by Hobbs and Aubry (2008). These are the number of project managers (NPM) and the level of decision making authority (DMA).

a) A specific number of immediate subordinates is assigned to a project manager in charge of a decision-making centre.
b) The time a case leaves its location and travels to the superior's desk is negligible
c) Superior is experienced enough to handle a decision centre. Otherwise, there will be a large heap of cases at every moment.
d) Each case from subordinates is attended to one at a time, this means first come, first served approach is used.
e) The workload assigned to a project manager at the decision-making centre is proportional to the span of control of the project manager
f) Every employee has, at least one job to perform in the organisation.
g) The arrival of cases and subsequent release by the boss is assumed to be stochastic events.
h) The business function is assumed to have a person-person, person-machine interaction, stochastic, dynamic decision and operation work system.
i) Standard workload (suitable for a position) is assigned to every staff.
j) There is a difference between terminal, supervisory and pure decision activities in the organisation.

1.6.4 Personnel Utilisation Function for the PMO

The non-linear constrained optimisation problem for the personnel utilisation (H) for PMO is expressed in equation 1.

Maximise

$$H(K_{ij}, N_{i,} M, A, \lambda_{ij}, \mu_{ij}, N_o) = \sum_{i=1}^{M} \sum_{j=1}^{N_i} H_{ij} / \sum_{i=1}^{M} N_i \tag{1}$$

subject to:

$$\sum_{j=1}^{N_i} H_{ij} = N_{i-1;} \quad N_o \text{ is known} \tag{2}$$

$$N_m = 1 \tag{3}$$

$$K_{ij}, N_i, M > 0$$

From equation 1, H_{ij} is expressed as:

$$H_{ij} = 1 - \frac{1}{A_{ij}(K_{ij}+1)} \left[\frac{\left[\frac{\sum_{n=2}^{K_{ij}} (n-1) C_n^{K_{ij}} n! \rho_{ij}^n}{1 + \sum_{n=1}^{K_{ij}} C_n^{K_{ij}} n! \rho_{ij}^n} + 1 - \left(1 + \sum_{n=1}^{K_{ij}} C_n^{K_{ij}} n! \rho_{ij}^n \right)^{-1} \right]^2}{\mu_{ij} \left(1 - \left(1 + \sum_{n=1}^{K_{ij}} C_n^{K_{ij}} n! \rho_{ij}^n \right)^{-1} \right)} \right] - \frac{\left(1 + \sum_{n=1}^{K_{ij}} C_n^{K_{ij}} n! \rho_{ij}^n \right)^{-1}}{K_{ij}+1} \tag{4}$$

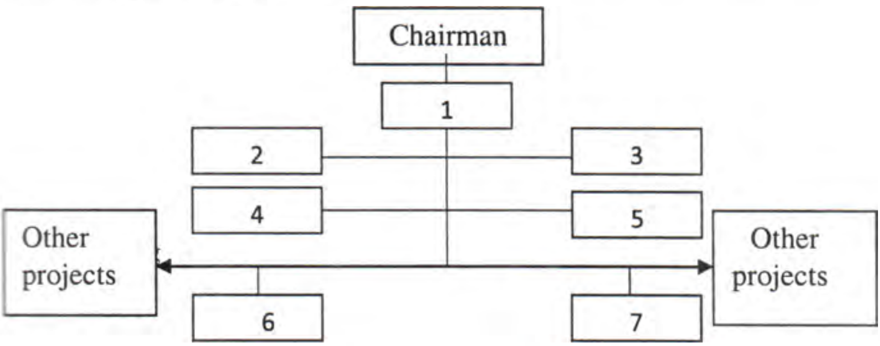
$$\lambda_{ij} = \frac{\text{total number of cases at position (i,j)}}{\text{total time (hours)for study at the position}} \tag{5}$$

$$\mu_{ij} = \frac{\text{total completed cases at position (i,j)}}{\text{time (hours)spent to treat all completed cases}} \tag{6}$$

$$\rho_{ij} = \frac{\lambda_{ij}}{\mu_{ij}} \;\; ; \;\; \lambda_{ij} < \mu_{ij} \tag{7}$$

1.6.5 Applicability

To use the model represented from equations 1 to 7, a PMO (a sample structure presented in Fig.1) organisational goals will be converted to the volume of work and personnel requirements. This involves the determination of terminal activities, skill identification, determine the amount of available work per skill, determination of the number of operations positions, determine the number of project managers and number of decision making authority. Also, the values of A_{ij}, λ_{ij},μ_{ij} K_{ij} and N_O have to be determined. A chronological review of organisation structure design algorithm to obtain an optimal design and compare to an existing design is contained in Charles-Owaba (2002, p. 223-225). It is expected that the number of projects (NP), number of project managers (NPM) and level of decision-making authority (DMA) that will reduce redundancy will be obtained.



1. Director, 2- Marketing Department, 3- Human Resources, 4-Finance and Administration, 5 – Legal, 6- Project A, 7- Project B

Fig.1 Project Organisation Structure for a sample Project management office

1.6.6 Summary

In this chapter, projects, project management, and components of project organisation structure were discussed. In the selection of a project organisation structure, some of the elements to consider include, the number of projects, number of project managers, level of decision-making authority, physical locations, operation positions, communication lines, and span of control. Therefore, due to inherent characteristics of projects, organisations have embraced project management office as a formal organisational structure to eliminate trial and error in project administration and to ensure efficient resource management. From the organisational design framework proposed by Professor Charles-Owaba through operations research paradigm, the modeling structure for a project management office was presented.

References

Anbari, F. T., Bredillet C.N., & Turner, J. R. (2008). Exploring research in project management: the nine schools of project management. Retrieved on October 2, 2020. Available at https://www.academia.edu/3294985/Exploring_research_in_project_management_Nine_schools_of_project_management_research_Part_2

Association for Project Management (2006). *APM Body of knowledge (APMBOK)* (5th ed.) Somerset: Butler and Tanner

Atkinson, R. (1999). Project Management; Cost, Time and Quality, Two Best Guesses and a Phenomenon, Its Time to Accept Other Success Criteria. *International Journal of Project Management, 17*(6), 337-342.

Babaeianpour, M & Zohrevandi, S. (2014) Using project management office (PMO) to improve Project Management Abilities, *International Journal of Business and Economics* *6* (1), 153-165.

Bard, J., Globerson, S., & Shtub A. (1994). Project Management Engineering Technology and Implementation. Prentice Hall, Inc., 1995, 634 pp., ISBN 0-13-556458-1.

Bredillet, C. N. (2007). Exploring Research in Project Management: Nine Schools of Project Management Research (Part 2). *Project Management Journal*, *38*(3), 3–5. https://doi.org/10.1002/pmj.20001

Charles-Owaba, O.E. (2002). *Organisational Design: A Quantitative Approach.* Ibadan: Opotoru

Books.
Dai, C.X. & Wells, W.G. (2004). An exploration of project management office features and their relationship to project performance. *International Journal of Project Management, 22*(7), 523-532.

Eames, C. (1969) *What Is Your Definition of "Design," Monsieur Eames?A Vitra Anecdote*

Retrieved October 3, 2020. https://www.vitra.com/en-us/magazine/details/what-is-your-definition-of-design-monsieur-eames
Food and Agriculture Organisation (FAO) of the United Nations: Management of Agricultural Research: A training manual. Module 3: Organizational principles and design. Retrieved October 3, 2020 at http://www.fao.org/3/w7503e/w7503e00.htm
Greenwood, R., & Miller, D. (2010). Tackling design, a new: Getting back to the heart of organizational theory. *The Academy of Management Perspectives, 24*(4), 78-88.
Hax, A. C., & Majluf, N.S. (1981) Organisation Design: A Survey and an Approach. *Operations Research*, 29(3), 417-447. Retrieved October 2, 2020, from http://www.jstor.org/stable/170106
Hobbs, B. & Aubry, M. (2008). An empirically grounded search for a typology of project management offices. *Project Management Journal*, 39, 69-82.
Hobday, M. (2000). The project-based organisation: An ideal form for managing complex products and systems? *Research Policy*, 29, 871-893
Hurt, M. & and Thomas, J.L. (2009) Building Value Through Sustainable Project Management Offices. *Project Management Journal, 40*(1), 55-72. https://doi.org/ 10.1002/pmj.20095
Kerzner, H. 2003. *Project management – A systems approach to planning, scheduling, and controlling*. 8th ed. New York: John Wiley & Sons
Larson, E.W., & Gray, C.F., (2008). *Project Management: The Managerial Process* (5th ed.).

McGraw-Hill/ Irwin.
Lundin, R. & Söderholm, A. (1995). A theory of the temporary organization. *Scandinavian Journal of Management*, *11*(4), 437-455.
Miterev, M., Mancini, M., & Turner, J.R. (2017). Towards a design for the project-based
Organization. *International Journal of Project Management*, *35*(3), 479-491. https://doi.org/10.1016/j.ijproman.2016.12.007

Moleli, L.J. (2012). The Impact of Project Management on Road Construction and Maintenance at Emfuleni Local Municipality. Retrieved October 2, 2020, from https://repository.nwu.ac.za/handle/10394/10317
Monteiro, A., Santos, V., & Varajão, J. (2016). Project Management Office Models – A
Review. *Procedia Computer Science*, *100*, 1085-1094. DOI: 10.1016/j.procs.2016.09.254
Odedairo, B.O., & Olenloa, O.E. (2021). Scheduling of Post-Flood Recovery Project with Flexible
Project Structure. *Journal of Engineering, Project, and Production Management*, *11*(2),
118-126. https://doi.org/10.2478/jeppm-2021-0012
Oliveira, R.R & Martins, H.C (2018). Strategy, People and Operations as influencing agents of the Project Management Office performance: an analysis through Structural Equation
Modeling, *Gest. Prod.* *25*(2), 410-429. http://dx.doi.org/10.1590/0104-530X2294-16
Pemsel, S. & Wiewiora, A. (2013). Project management office a knowledge broker in project-based organisations. *International Journal of Project Management*. *31*(1), 31-42
Premium Times Newspaper (2012) The Tragedy of Abandoned Projects by Nasir El-Rufai
Retrieved September 15, 2020, https://www.premiumtimesng.com/opinion/98468-the-tragedy-of-abandoned-projects-by-nasir-el-rufai.html

Project Management Institute (2004). *A Guide to The Project Management Body of Knowledge*
(PMBOK®) (3rd ed.) Newtown Square, PA
Project Management Institute (2017). *A Guide to The Project Management Body of Knowledge*
(PMBOK®) (6th ed.) Newtown Square, PA
Reiss, G. (2007). *Project Management Demystified* (3rd ed.). Routledge
Stanford, N. (2007). *Guide to Organisation Design: Creating high-performing and adaptable enterprises*. London: Profile Books.
Thiry, M. (2007). From PMO to PBO: the PMO as a vehicle for organizational change. Paper presented at PMI Global Congress North America, Atlanta, GA. Newtown Square, PA: Project Management Institute.
Turner, J. R., & Müller, R. (2003). On the Nature of the Project as a Temporary Organization.
International Journal of Project Management, 21(1), 1-8.
Van de Ven, A.H., Ganco, M. & Hinings, C.R. (2013). Returning to the Frontier of Contingency
Theory of Organizational and Institutional Designs. *Academy of Management Annals*, *7*(1), 393–440. https://doi.org/10.5465/19416520.2013.774981
Ward, J. & Daniel, E. M (2013). The role of project management offices (PMOs) in IS project
success and management satisfaction. *Journal of Enterprise Information Management*, *26*(3),316 – 336. http://dx.doi.org/10.1108/17410391311325252

CHAPTER 2

Options for the Nigeria Electricity Tariff Review: Cost Or Service Reflective Tariff?

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Abstract: The improvement in the Nigerian electricity value chain has not been visible after seven years of partial privatization of the sector as the government continues to subsidize tariffs to avert the total collapse of the sector. The electricity distribution companies tagged the weak link in the value chain, have been challenged with inherited dilapidated infrastructure and poor revenue generation. The Nigeria Electricity Supply Industry is currently considering service reflective tariff options after her inability to implement a cost-reflective tariff in the sector since privatization in 2013. The electricity value chain is presently challenged with poor cash flow due to customer payment apathy, perceived corruption in the system, unavailability of a cost-reflective tariff which resulted in poor remittance to the value chain by the distribution companies. This paper reviews the power sector evolution and the reforms in the sector, the performance of Nigeria Electricity Regulatory Commission regulations, the concepts of the cost, and service reflective tariff. The paper recommends a cost-reflective tariff option with strict regulatory performance monitoring of all the value chain participants in the sector.

Keywords - electricity value chain; privatization; service reflective tariff, cost-reflective tariff, electricity distribution, Nigeria power sector

1.0 INTRODUCTION

The level of infrastructural development of a country will determine her rate of attainment of sustainable development and economic growth (Elum & Mjimba, 2020). A good understanding of infrastructural service performance, especially electricity, is critical for planning and policymaking to achieve vibrant economic development. Nigeria is a developing nation with a population of 203 million over the 923,768km^2 area it covers (CIA, 2019). The International Energy Agency and the World Bank reported in 2017 that 58% of Nigeria's population is connected to electricity through the national grid. In 2019, the United States Agency for International Development (USAID) estimated the installed electricity generation capacity in Nigeria to be 12,522MW with daily generation hovering above 4,000MW. Oyedepo (2012) opined that the instability of electricity supply from the national grid resulted in 80% of consumers being underserved with only a few hours of supply daily. Thus, consumers have resulted in self-generation of electricity from renewable and non-renewable sources to be able to meet their energy needs. There are many issues with electricity supply which make the distribution from the national grid epileptic and cover only about 40% of the country's population (Aliyu *et al.*, 2013). According to Seymour, (2012) and Titus *et al.,* (2013), service outages could arise from transmission lines failure, traffic accidents, switching problems at injection substations, heavy start-up loads, background electrical noise, faulty distribution components, and lack of scheduled preventive maintenance. However, a very critical issue that determines the sustainability of the power sector, especially a deregulated power sector, is the tariff (Oladokun & Asemota, 2015). Recovery of cost in the value chain and avoidance of cross-subsidies by customers are two critical issues for consideration when setting right price in transition economies (Reneses *et al.,* 2011).Meanwhile, there are no policy consensus on the tariff regime that is most suitable for Nigeria viz a viz cost and service reflectivity of the regime (Nwangwu, 2019). The current tariff being charged electricity users in Nigeria is neither service nor cost-reflective and this is hurting the entire value chain. The section 2 of this paper reviews the history of electricity in Nigeria, the power sector reform and the electricity distribution company. The Nigeria electricity value chain is discussed in section 3 while section 4 details the electricity tariff building blocks in Nigeria. The section 5 explains the difference between the cost and service reflective tariff in Nigeria context while the authors' recommendation and conclusion can be found in the last section.

2.0 HISTORY OF ELECTRICITY IN NIGERIA

Nigeria started generating electricity in the Lagos colony with two small generators in 1886. A 60kW generator was introduced to power Lagos in 1896, after fifteen years of electricity introduction in England (Niger Power Review, 1985; Sambo, 2010; Onochie *et. al.* 2015). The foremost utility company that started operations in 1929 was the Nigeria Electricity Supply Company (NESCO), with a hydroelectric power station located in Kurra, near Jos. In 1964, the Nigerian Government Electricity Undertaking (NGEU) was established as part of the Public Works Department, to oversee both liabilities and assets of electricity distribution in Lagos. An act of Parliament was enacted in 1951 to create the Electricity Corporation of Nigeria (ECN). ECN was responsible for the integration of both privately-owned and government-owned power generating systems (Awosope, 2014). In February 1956, the Ijora power station was launched to increase accessibility and supply quality to Ikorodu, Shagamu, Ijebu-ode, and more cities in the Ibadan-Ijebu bloc leading to remarkable improvement in the economic activities in southwest states.

In 1962, another act of parliament was enacted to establish the Niger Dams Authority (NDA), and the first 132KV line was constructed to link Ijora generating plant to Ibadan generating plant. NDA was responsible for the development of hydroelectricity generation through the building and preservation of dams on the Niger River and beyond, improving navigation, supporting fish brine, and irrigation activities (Manafa, 1995). The renowned Kainji dam was constructed between 1962 and 1968. The Niger Power Review (1989) stated that the combined contribution of defunct NDA and ECN led to the commencement of the operations of the national grid in 1966. The grid power transmission system linked Lagos with Kainji. The connection between Kaduna and Kainji was increased up to Kano and Zaria. In the same vein, the construction grid network of the Benin-Onitsha-Afam and Oshogbo-Benin-Ughelli were done in the Nigerian southern region. The NDA was the generating company while ECN was the distribution company selling electricity to customers.

The National Electric Power Authority (NEPA) was established from the merger of NDA and ECN on the 1st of April 1972. The merger commenced with the appointment of the first manager for NEPA in January 1973. ECN was primarily in charge of sales and distribution and the NDA established to construct and operate transmission lines and power generating stations. The major reason for the merger is vesting authority for power production and distribution throughout Nigeria in one company which would also be accountable for the financial obligations. It will also lead to the useful utilization of resources available, financial, human, and other resources available in the industry across Nigeria. Okoro &Madueme (2004) stated in their study that despite annual network expansion since the inception of NEPA, the electricity supply is not regular, and the current electricity connection access rate at 45% (USAID, 2019). Meanwhile, the federal government, between 1978 and 1983, established two committees to develop templates for restructuring NEPA into an efficient and autonomous entity in readiness for its unbundling and privatization. In 2005, NEPA was renamed as Power Holding Company of Nigeria (PHCN) and takes responsibility for the entire power sector in readiness for the reforms (Sambo, 2008).

2.1 **Nigeria Power Sector Reform**

Nigeria's power sector is responsible for the supply of quality and reliable electricity for residential, commercial, and industrial activities. In 2002, the Federal Ministry of Economy affirmed that the Power sector is a vibrant and important part of the economic value chain playing a very strategic role in the remaining sectors of the economy. Oyedepo *et al.,* (2012) opined that inadequate power supply will impede commercial and industrial activities, the establishment of infrastructural facilities, and other social amenities. To this end, continuous improvement in power generation and distribution should be the utmost priority for all the participants in the power sector to achieve the desired growth. To have continuous growth in the sector, there has been an evolution to search for the way forward in resolving the enormous issues facing the sector over the last decades.

The Nigeria government embarked on massive power infrastructures rehabilitation from 1999 to 2004 in response to the pathetic state of the electricity supply (Lawal, 2008). This phase of the reform is known as the National Integrated Power Project (NIPP). Power plants were established at different parts of the country to improve power generating capacity through NIPP projects across the nation (REMP, 2005). In furtherance of the power infrastructure expansion program, licenses for power generation were granted to various Independent Power Producers (IPPs). The IPPs sell their generated electricity to private utilities and the public through the distribution companies (Adedayo & Yong 2010). In 2005, the Federal Government of Nigeria enacted the Power Sector Reform Bill into law with the key objective of deregulation of Nigeria Electricity Supply Industry (NESI) within two years of implementation. A major notable achievement of the reforms is the successful unbundling of PHCN into 18 succession companies – 11 DISCOs - distribution companies, 6 GENCOs - generation companies, and TCN – Transmission Company of Nigeria. The unbundling of PHCN is in readiness for privatization which was delayed due to change in government, policy inconsistency, administrative bureaucracy, and opposition by the workers' union (Onochie *et al.*, 2015).

Other achievements include the setting up of institutional framework and regulatory bodies such as the Nigeria Electricity Regulatory Commission (NERC), the Nigeria Bulk Electricity Trading Company (NBET), and the implementation of a Multi-Year Tariff Order – MYTO regime designed to achieve a cost-reflective tariff. The NERC was inaugurated on November 1st, 2005, as a regulatory body overseeing activities in the power sector including tariff regimes (Okafor, 2017). Other regulatory bodies created are the Nigeria Bulk Electricity Trading Plc (NBET) which oversees buying and selling of electric power and provision of ancillary services for the successor generation companies and the independent power producers. The Nigeria Electricity Liability Management Company (NELMCO) was established to take over the remaining PHCN assets and liabilities while the Rural Electrification Agency (REA) was created to ensure the expansion of electricity to the unserved area, oversees the development, and uphold transparency in the sector (Idemudia and Nordstrom, 2016).

The Federal Government sold 80% and retain 20% of the GENCOs. The GENCOs are Afam, Egbin, Kainji, Sapele, Shiroro, and Ughelli. There are some Independent Power Producers (IPPs) which are connected to the grid under the auspices of the Niger Delta Power Holding Company (NDPHC), while other IPPs are still under construction. The Nigerian Electricity Supply Industry (NESI) currently has 23 grid-connected power generation stations in operation with a total installed capacity of 12,522 MW (USAID, 2019) and an available capacity of 6,056 MW as of 10th of May 2019. The peak energy is 109,372.01 MWH and peak generation to date is 4602.4 MW (Okafor, 2017; Sambo, 2018). The thermal-based plant is prevalent with an installed capacity of 10,142 MW (81% of the total) and an available capacity of 4,996 MW (83% of the total). The total installed capacity of the three Hydropower generation stations is 1,938MW with an available capacity of 1,060MW. According to IEA, the Gas Thermal Plant with 64%, Hydro with 23%, and Steam Thermal Plant with 13% made up the total installed electricity generation in Nigeria. Figure 1 shows the Nigeria Power Sector Structure with the main participants.

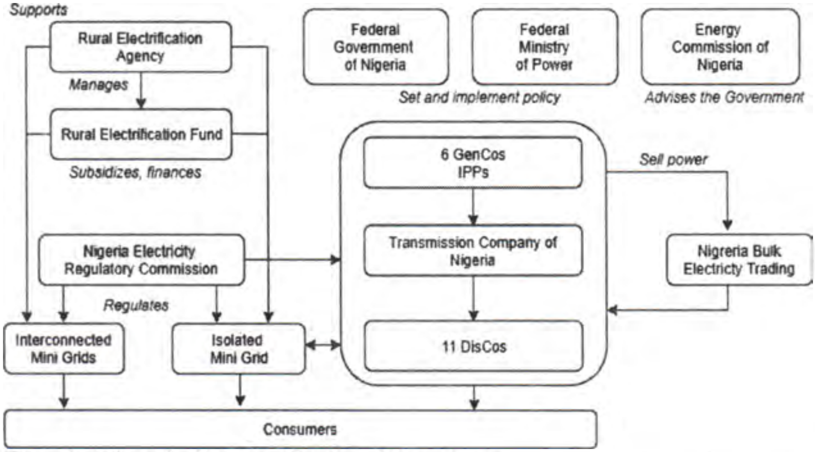

Fig. 1: Nigeria Power Sector Structure
Source: Energy Sector Management Assistance Program - ESMAP (2017)

The Federal Government still fully owned the Transmission Company of Nigeria (TCN) out of 18 successor companies unbundled from PHCN. The transmission asset was managed on a 4-year contract, on behalf of the government by Manitoba Hydro International (MHI Canada) whose responsibility is to revamp the network and wheel power from generating plants to distribution companies' infrastructure without system failure. MHI contract ended in August 2016 without achieving its objective and the government did not renew the contract. TCN is now being managed by the Federal Government and Nigerians. TCN has three operational departments: System Operations (SO), Transmission Service Provider (TSP), and Market Operations (MO). The System Operations is responsible for electricity flow from generation to distribution systems, control of electricity on the grid, dispatch, system operations planning, and grid reliability. Transmission Service Provider is responsible for transmission infrastructure development, operations, and maintenance. The Market Operations overseethe administration of the NESI market rules, the wholesale electricity market, and promoting efficiency (Onochie *et al.*, 2015).

TCN grid network of 20,000km transmission lines has anoverall (theoretical) wheeling capacity of about 7,500MW. The transmission system footprint does not cover every area of Nigeria (Sambo, 2010). A new generation and transmission peak of 5,375MW was achieved on Thursday 7th February 2019 at 2100hrs (TCN, 2019). There are acute infrastructure and operational challenges on the grid network. The network infrastructure is radial without redundancies consequently leading to an unreliable and technically weak grid with frequent failure due to major disturbances. The transmission losses on the network are approximately 7.4% which is higher than the 2 – 6% benchmark for emerging countries.

2.2 Electricity Distribution in Nigeria

A major outcome of the reform in the electricity sector was the unbundling of PHCN into eleven distribution companies – DISCOs, one transmission company – TCN, and six generation companies – GENCOs. The Federal Government sold 60% of the eleven electricity distribution companies (DISCOs) to the private investors and retains 40% ownership. The eleven DISCOs are EKEDC - Eko Electricity Distribution Company, Ikeja Electric (IE) in Lagos State, IBEDC - Ibadan Electricity Distribution Company covering the Southwest States, BEDC - Benin Electricity Distribution Company with franchise across the mid-western states, the eastern states were covered by Enugu Electricity Distribution Company - EEDC, KEDC - Kaduna Electricity Distribution Company, KEDCO - Kano Electricity Distribution Company, YEDC - Yola Electricity Distribution Company, JEDC - Jos Electricity Distribution Company covering the northern states, AEDC - Abuja Electricity Distribution Company for the federal capital territories and its environ and PHEDC - Port-Harcourt Electricity Distribution Company for the southern states. The available electricity on the grid is allocated to all the distribution companies as seen in Table 1 that shows the percentage Load Allocation for each DISCO. TheNigeria Electricity Distribution Network Map in Figure 2 shows the coverage area of each distribution company.

Table 1: Load Allocation for DISCOs. Source TCN (Oct. 2013)

s/n	1	2	3	4	5	6	7	8	9	10	11
DISCOs	*Abuja*	*Benin*	*Eko*	*Enugu*	*Ibadan*	*Ikeja*	*Jos*	*Kaduna*	*Kano*	*Port Harcourt*	*Yola*
% Load Allocation	*11.5*	*9*	*11*	*9*	*13*	*15*	*5.5*	*8*	*8*	*6.5*	*11.5*

Fig. 2:Nigeria Electricity Distribution Network Map
Source:https://www.nbet.com.ng/

3.0 NIGERIA ELECTRICITY VALUE CHAIN

Electricity is generated from different fuel sources like coal, hydro, natural gas, solar, wind biomass, and other renewable and unconventional sources. Natural gas is responsible for 80% of electricity generation in Nigeria (UNDP 2016), therefore the value chain would be incomplete without the gas suppliers. The electricity value chain comprises gas suppliers (producers and transporters), generation (independent power producers - IPPs), transmission and distribution companies, and the end-user – customers. The cost of gas (in the US dollar) is a key determinant in the pricing unit of electricity. The generating company signs a gas supply agreement with the natural gas supplier while NBET reviews the contract for risk allocation. The electricity flow commences from transporting gas to the generation companies to fire their turbines. The generation companies (IPPs) sign a power purchase agreement (PPA) with NBET while the latter issues bank guarantees for bulk electricity purchased from IPPs. The electricity produced is wheeled by TCN -transmission company of Nigeria to the eleven DISCOs - distribution companies through high voltage 330kv and 132kv cable network spanning several kilometers. TCN sends data to NBET for IPPs invoice verification and invoices to DISCOs. The DISCOs distribute electricity to the customers from their injection substations through low voltage 33kv and 11kv lines to various distribution transformers. Monthly bills (invoices) are issue to customers for settlement or purchase energy for their meters (Pre-paid) before consumption. Figure 3 shows the Nigerian electricity supply industry (NESI) value chain with participants' roles.

The industry average collection efficiency is currently 60% with residential customers responsible for the highest default in bills payment. The market operator issues invoices to all distribution companies for energy received from the grid monthly. The invoices are for market operators and NBET bills. The market operator's invoice is for the transmission tariff paid to TCN. The NBET bill is for the power purchase agreement (PPA) and capacity-energy charge for the month paid to the generation companies. DISCOs also pay regulatory charges to NERC while retaining only 26% of collections from the customers. GENCOs pay for gas supply and transportation in US dollars to the gas producers and transporters while the producers settle royalties and hydrocarbon taxes. All payments in the value chain are made in Naira except for gas supply and transportation. Figure 4 shows the electricity and cash flow in the value chain.

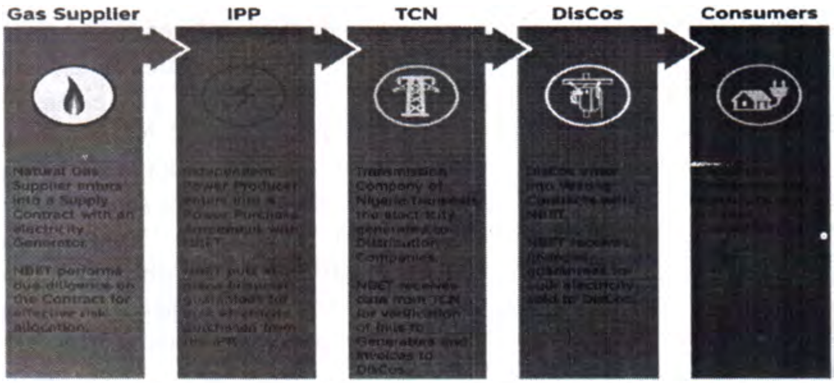

Fig. 3: Nigeria Electricity Supply Industry (NESI) Value Chain
Source: Nigeria Bulk Electricity Trading Company

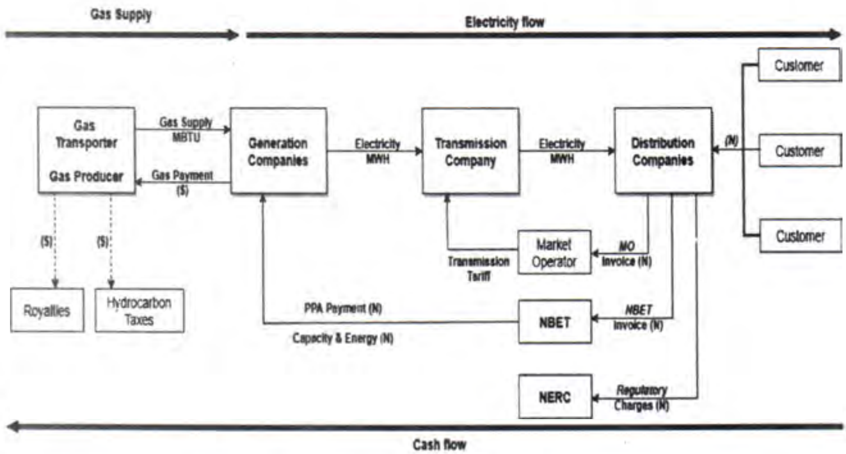

Fig. 4: Electricity and Cashflow in Value Chain

4.0 NIGERIA ELECTRICITY TARIFF BUILDING BLOCKS

Nigeria's government did not allow both minor and major tariff review since 2016. The current electricity tariff is due for a change because the last minor review was done in February 2016. There have been changes in macroeconomic indexes such as gas price, exchange rate, and inflation but tariff remains because most customers are against it due to poor supply and services. This has great implications on the market as revenue shortfall is being rammed up with a total of N1.1trillion tariff shortfall in 2019 and 2020 (EMRC, 2020). The situation is further worsened because of poor revenue collection from the residential and government customers is causing the distribution companies to accumulate huge debts.

The Act which sets the background for the Nigerian power industry is called the Electric Power Sector Reform Act (EPSRA) 2005.Section 32 (d) of this Act highlights the mainresponsibilities of the NERC. One of the NERC's responsibilities is toguarantee that the prices charged by licensees are fair to customers whilst allowing the licensees to finance their activities and obtainingrational profits. In agreementwith Section 76 (2) of the Act, the NERC set a frameworktoset electricity prices which arecalled the Multi-Year Tariff Order (MYTO). The MYTO aims to reward stakeholders that perform above certain thresholds, whilst also reducing the aggregate technical commercial and collection losses, hence leading to the recovery of costs and an overall performance standards improvement. The NERC uses the MYTO to fix the bulk and retail prices for electricity in the NESI by using anintegratedmethod to ascertain the revenue requirement for the power sector.

The objective of the MYTO is to fix tariffs that are cost-effective thereby causing the NESI to be self-sufficient. It delivers a tariff path for a period of 15-years for the NESI, with two minor reviews every year and a major review every 5 years. These reviews are conducted when it has been determined that there are fluctuations or changes in the macroeconomic variables used in tariff computation (for exampleexchange rates, inflation, interest rates, and generation capacity). All the variables will be appraised by the market participants during the reviews. The intents of the MYTO are:

- Recovery of costs and viability of the NESI to guarantee a realistic rate of returns on investment by the participants
- Provision of Key Performance Incentives that are modest and achievable
- Certainty and Steadiness of the pricing methodologythat boosts an effective capital injection into the industry
- Risk Allocation is efficiently done among the participants

In setting the tariffs for the NESI, the MYTOemploys the building blocks approach.This methodallows a combined advantage of the incentive-based regulations and price capping. The MYTO is premised on combining all costs in a dependable accounting methodology. The MYTO is built on three building blocks below to allow the returns on capital in achieving the following: -

(a) A fair rate of returns on capital invested
(b) Recovery of capital over the depreciation period of assets
(c) Well-managed overheads and operating costs.

Some macroeconomics indices that were considered in arriving at the tariff are exchange rate, inflation, invested capital, return on capital, generating capacity, load forecasts, aggregated technical, commercial & collection (ATC&C) losses, fuel costs, operating and maintenance costs, other technical data, customer population, etc. The minor tariff reviews have been scheduled for June and December of every year by NERC while a major review of the industry's pricing structure comes up every five years.

5.0 COST REFLECTIVE TARIFF VERSUS SERVICE REFLECTIVE TARIFF

Cost Reflective Tariff (CRT) regime is when the tariff charge for electricity have put into consideration all the inputs and parameters in the value chain before arriving at the pricing in a way that aligns electricity tariff with the cost of providing network services to customers (Passey., Haghdadi, Bruce, & MacGill, 2017). On the other hand, Service Reflective tariff (SRT) is based on availability hours of supply to incentivize the distribution companies toward improving their service by investing in network rehabilitation and upgrade. The CRT is the same for all customers while SRT is not the same across the board. Customers have been categorized using the electricity network feeders and distribution transformers. This makes it easy to track the availability hours of supply and thus determine the tariff. In the SRT regime, tariff increases according to the number of hours of supply. Nigeria as a transition electricity market has plans to achieve CRT gradually and in phases.

However, the NERC failed to adjust the macroeconomic indices to achieve cost reflectivity in the Nigeria Electricity Supply Industry since 2016. The Power Sector Recovery Plan makes provision for a steadychange to cost-reflective tariffs with protections for the lesserincome earners in the country. NERC proposed atransitional review in consumer tariffs on January 1, 2020, and a gradual transition to full cost-reflective tariffs shall be attained by July 2020. The review of basic assumptions in the MYTO is highlighted in the 2016 -2018 Minor Review of MYTO 2015 and Minimum Remittance Order for the Year 2019. This review covers changes to these parameters: loss target, Nigerian Inflation Rate, US$ Exchange Rate, Daily Generation Capacity, Transmission & Administrative Costs, Tariff and Market Shortfalls, etc. Thus, it aimed to provide some certainty about revenue shortfall that might have arisen due to tariff misalignment between the MYTO tariff and Cost Reflective Tariff. Table 4 below provides a summary of the actual and projected indices for 2015 to 2021.

Table 4: Macro-Economic Indices of MYTO and Non-Cost-Reflective Tariffs

MYTO Indices	MYTO 2015 Assumptions	The Reality	% Variance
Nigerian Inflation	8.80%	12.20%	30%
U.S. Inflation	0.20%	1.54%	650%
Debt Interest Rate	9.70%	20%	107%
Naira Vs USD$ Exchange Rate (₦)	198.97	361	54%
Generation (MW)	5,465	4,369	-20.0%

Source: NERC Website

Due to the prevalence of the COVID-19 pandemic across Nigeria, the NERC suspended the implementation of the cost-reflective regime in July 2020, thereby invariably creating a further tariff shortfall in the electricity market. Under this regime, customer tariff classes were categorized into residential (R1, R2, R3, R4), commercial (C1, C2, C3, C4), industrial (D1, D2, D3), special (A1, A2, A3), and Street Lighting (S1). Conversely, on September 1, 2020, the Nigerian Electricity Regulatory Commission published the MYTO 2020, which introduced the Service Reflective Tariff (SRT) regime across the country. This became necessary due to the high number of complaints received by the Commission at the public hearings held across the country, in the first quarter of 2020, during the Commission's consideration of the DISCOs' application for an extraordinary tariff review.

The Service Reflective Tariff (SRT) regime categorizes electricity customers into five (5) Service Bands based on the daily availability hours of supply. The service bands are: -

- Band A - a minimum of 20 hours supply daily
- Band B - minimum of 16 hours supply daily but less than 20 hours daily
- Band C - minimum of 12 hours supply daily but less than 16 hours daily
- Band D - minimum of 8 hours supply daily but less than 16 hours daily

- Band E - minimum of 4 hours supply daily but less than 8 hours daily

The new tariff regime further collapses the tariff classes into three (3) classes namely lifeline (LFN), non-maximum demand (NMD), and maximum demand customers (MD1 and MD2). The rate methodology is directly tied to the hours of electricity supply by associated feeders. The Commission aimed to incentivize the DisCos to invest in their networks to earn more by charging higher tariffs when availability hours improves. By implication, DisCos can meet their revenue requirements when they invest in their network rehabilitation and upgrade to achieve an increase in supply. The difference between the old tariff regime and the new SRT is shown in Table 5.

Table 5: Differences between the old tariff regime and the Service Reflective Tariff

INDICES	OLD TARIFF	SERVICE REFLECTIVE TARIFF
Rate Design	Rates/tariff designed at Disco level without regard to hours of supply in the different locations covered	Rates/tariff designed at feeder level recognizing the hours of supply on each feeder
Feeder Clustering	Not Applicable	Basis of rate design is clustering of feeders by Hours of Supply into 5 clusters
Number of Tariff Classes	Customer base classified by type into 14 classes (Residential, Commercial, Industrial, Special)	Customer base classified by type into 3 classes (Lifeline, Maximum Demand and Non-Maximum Demand)

6.0 RECOMMENDATION AND CONCLUSION

The power sector reforms are guided by government policies and regulations to ensure the success of the program. Unfortunately, there are extensive regulatory and policy changes as the government keeps given directives that are not in favour of the participants in the electricity sector. The commitment signed by both the government and investors at privatization is not adhered to and the government cannot hold investors for not fulfilling their obligations since they are equally guilty. This policy inconsistency is a great disservice to the sector as it discourages local and foreign investors. A good example is the non-implementation of the Multi-Year Tariff Order as required while the government continues to subsidize the unit cost of electricity.

This review has shown that inappropriate pricing of electricity in Nigeria is a major challenge to the progress that the reforms in the power sector are supposed to have gained in the past. The tariff shortfall created by the lack of cost-reflective tariff led to a dearth of required investment in the sector because of its liquidity problems. This is evidenced in the level of the dilapidated network infrastructure as DISCOs' investment in network rehabilitation is very low compared to requirements. New GENCOs and IPPs are not coming in despite the huge energy gap that is available for new investors. It is also very difficult to get loans from the financial institution due to the poor and risky nature of the participants' balance sheets. This liquidity crisis in the sector is expected to be relieved with the implementation of a cost-reflective tariff. This will encourage investors and private developers to invest in the sector. Prepaid metering is a good strategy as customers will have to pay for supply before consumption thus eliminating debt accumulation. A true cost-reflective tariff will be shocking to consumers but the further delay in implementing this will be more aching when it is eventually done. The new service reflective tariff introduced on September 1, 2020, was halted barely one month after introduction because the workers' unions gave notification of a nationwide strike to ground the economy. Government and workers' unions will negotiate to bring down the SRT pricing and pay for the shortfall.

Conclusively, we recommend regular annual tariff review to make up for changes in macroeconomic indexes until a cost-reflective tariff is reached. This will restore confidence in the industry and encourage both foreign and local investors to invest in the power sector. Customers will be willing to pay a cost-reflective tariff if there is a remarkable increase in supply. The service reflective tariff is a fallacy because the cost of

1kwh of electricity is the same whether customers get the supply for 20hours or just 1 hour. It is like robbing Peter to pay Paul as a customer living in a location with better supply will be paying far higher tariff than customers where supply is not sufficient, which is not the customer's making. Finally, the recent agreement signed by Nigeria and German governments for Siemen's electrification roadmap should be taken business-like. This program is funded by the government for upgrades and development of generation, transmission, and distribution capacities with the target of 25000MW. The government should ensure that projects are not abandoned but completed to standards and specifications.

REFERENCES

Adedayo, Z. & Yong, L. (2010). "Impact of Domestic Natural Gas Pricing on Electricity Tariffs in Nigeria" IEEE Trans. Power system.

Aliyu, A., Ramli, A., Saleh, M., (2013). Nigeria electricity crisis: Power generation capacity expansion and environmental ramifications. *Energy,* 61(8), pp. 354-367

Awosope C.A. (2014). Nigeria Electricity Industry: Issues, Challenges, and Solutions. Covenant University 38th Public Lecture Series, Vol.3, No. 2. October 2014.

Central Intelligence Agency US (2019). The World Factbook — Central Intelligence Agency, *www.cia.gov*. Retrieved 2019-02-23

Elum, Z. A., & Mjimba, V. (2020). Potential and challenges of renewable energy development in promoting a green economy in Nigeria. *Africa Review, 12* (2), 172-191.

Energy Market and Rates Consultants (2020). Nigeria Electricity market insights (NEMI). An EMRC Report – January 2020. http://www.energy-mrc.com

Energy Sector Management Assistance Program - ESMAP (2017). Mini-Grids in Nigeria: A Case Study Of A Promising Market. Written by Castalia Strategic Advisor, Conference Edition, Washington DC, Available at https://www.esmap.org/

Idemudia, I. G. and Nordstrom, D. B. (2016). Nigerian Power Sector: Opportunities and Challenges for Investment in 2016. Number 1930, 1 – 15, Latham & Watkins, Lagos, Nigeria.

Lawal, L. 2008. "Nigeria: A Case Study in Power Shortages" Energy Tribune, April 10, 2008.

Manafa N. (1995), Electricity Development in Nigeria, Rasheen Publisher, Lagos, 1995, pp.37-51.

Niger Power Review (1985). Development of the Electricity Industry in Nigeria (1960-1985), pp. 1-6.

Niger Power Review (1989). Development of the Electricity Industry in Nigeria (1960-1989), pp. 10-15.

Nwangwu, G. (2019). Quest for cost-reflective electricity tariffs in Nigeria: Managing the conflict between politics and economics. *Nnamdi Azikiwe University Journal of International Law and Jurisprudence, 10* (1), 158-165.

Okafor, F. N. (2017). Improving Electric Power Sector Performance: The Role of Nigeria Electricity Regulatory Commission. Nigerian Academy of Engineering Public Lecture held on March 29, 2017, at the University of Lagos, Akoka, Lagos, Nigeria, 1-14.

Okoro O.I. and Madueme T.C. (2004). "Solar Energy Investments in a Developing Economy", Renewable Energy, vol. 29, 2004, pp. 1599-1610.

Oladokun, V. O., & Asemota, O. C. (2015). Unit Cost of Electricity in Nigeria: A Cost Model for Captive Diesel Powered Generating System'. *Renewable & Sustainable Energy Reviews, 52*, 35-40.

Onochie, U.P., Egware, H.O., Eyakwanor, T.O. (2015). The Nigeria Electric Power Sector (Opportunities and Challenges) *Journal of Multidisciplinary Engineering Science and Technology (JMEST)* ISSN: 3159-0040 Vol. 2 Issue 4.

Oyedepo, S.O. (2012). Energy and sustainable development in Nigeria: The way forward. *Energy Sustainability and Society*, 2(15): 1-17

Passey., R., Haghdadi, N., Bruce, A., & MacGill, I. (2017). Designing more cost-reflective electricity network tariffs with demand charges. *Energy Policy, 109*, 642-649.

Reneses Javier, GómezTomás,RivierJuan,.AngaritaJorge L. (2011). "Electricity tariff design for transition economies: Application to the Libyan power system" *Energy Economics*, volume 33, issue 1, pages 33-43.

Sambo A.S. (2008). Matching Electricity Supply with Demand in Nigeria. *International Association for Energy Economics*. Fourth Quarter, pp 32 – 36

Seymour, J. (2012). The Seven Types of Power Problems, s.l.: Schneider Electric – Data Center Science Center.

Transmission Company of Nigeria (2019): Transmission Company of Nigeria. www.tcnorg.com

Titus Koledoye Olugbenga., Abdul-Ganiyu A. Jumah., Phillips D. A., (2013). The current and future challenges of the electricity market in Nigeria in the face of the deregulation process. *African Journal of Engineering Research.* Vol. 1(3), pp. 33-39

UNDP Nigeria 2016 Annual Report (2017). United Nations Development Programme Nigeria media.ng@undp.org www.ng.undp.org

USAID (2019): NIGERIA – Power Africa Fact Sheet. www.usaid.gov.

CHAPTER 3

Development Of An Artificial Neural Network-Fuzzy-Markov Model For Industrial Accidents Forecasting

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Abstract

Industrial accidents possess the potential of causing physical, psychological and even fatal consequences when they occur. In that regard, Industrial accidents forecasting aid stakeholders in properly managing and improving workplace safety by anticipating accident occurrences to prevent or minimise their consequences. Due to the high variation, random and fluctuating characteristics of industrial accident occurrences, machine learning and Markov based models methods have become increasingly popular as a tool for understanding their occurrence patterns and detecting their vibrational directions. However, little investigation has been made towards combining the positive characteristics of these methods for industrial accidents forecasting. This study is concerned with the development of a neuro-fuzzy-Markov model for the prediction and forecasting of industrial accident occurrences.

The methodology employed essentially involves the implementation of the Artificial Neural Network (ANN) model through the development of structured control methods to enhance improved forecast candidate generation potential. Further, an analysis of the model's residual was undertaken to obtain an ANN forecast correction factor by using a combination of fuzzy and Markov techniques. Based on this,

investigations were then carried out to determine the direction of vibration of the ANN predictor model. Subsequently, results were generated from the prediction mechanism. The model was validated by comparing its one window ahead (OWA) forecast potential with those of the ANN model using secondary industrial accident data based on the mean absolute percentage error (MAPE) and the Root Mean Square Error (RMSE). Also, an evaluation was done by comparing the forecast performances of the model with those of two traditional (Autoregressive moving average [ARIMA] and exponential smoothing [EXPSM]) models and two non-traditional (Mao and Sun grey-Markov (MSGM) and Grey-Fuzzy-Markov Pattern Recognition GFMAPR) models.

The forecast performance results obtained on the model's application showed that it possessed the capability to correct and improve ANN forecasts. The MAPE and RMSE results obtained for the ANN-fuzzy-Markov model were 15.39 and 26.39, while those produced by the ANN were 20.13 and 30.57 respectively. The model produced more superior forecast when compared with ARIMA and EXPSM, and compared well with the MSGM and GFMAPR.

The obtained results indicate that the model possesses the capability of carrying the predictions of industrial fire accident to an acceptable degree of accuracy.

1.0 Introduction

Accident occurrences are an important component of industrial activities. Every occupational activity is inherent with potential accidents which if manifested can lead to accidents. Industrial accidents are undesired occurrences that can occur in forms such as burns, cuts, lacerations, radiation and amputations and even fatalities. Industrial accident occurrences can negatively impact the physical and psycho-social health conditions for workers and their families on the one hand, and potentially affect the fortunes and continuity of businesses on the other. As a result, understanding the dynamics of their occurrences with a view to anticipating and effectively managing them becomes imperative.

Forecasting accidents ahead of their occurrences is a popular practice adopted by organisations as part of their management processes (Xiaoping & Liu, 2009; Mock, Nugent, Kobusingye, & Smith, 2017). Accident forecasting is a guess at the safety state of a system (Xiaoping & Liu, 2009). In most cases, this guess is made by the mathematical or statistical characterisation of a prediction mechanism based on available information and observations (Shmueli, 2011). Generally, forecasting involves the deployment of single or multiple input dependent models (Bontempi, 2008; Manaloto & Balahadia, 2017; Makridakis, Spiliotis, & Assimakopoulos, 2018; Mapuwei, Bodhlyera, & Mwambi, 2020) to produce outputs based on the mathematical or algorithmic rules governing the deployed model.

Single input forecasting models are used particularly in situations where the accident occurrence causal variables are sparse, unavailable, or difficult to extract as is the case with accident occurrences (Aidoo & Eshun, 2012; Ratnayaka, 2017), or when a simple model in terms of input data is desired (Aksoy & Dahamsheh, 2009). In this regard, traditional time series (TS) models such as Auto-Regressive and Moving Average (ARIMA), exponential smoothing and regression models find relevance and are still prevalently deployed (Ghedira, Kammoun, & Saad, 2018; Svs, 2018; Urrutia *et al.*, 2018; Malysa, 2020).

The non-traditional forms of TS models such as Artificial Neural Networks (ANN), Markov models and Fuzzy Time Series Models (FTSM) based models have become more popular in the last decade as a result of their ability to handle imprecise, ambiguous and incomplete data (Zhang, Qu, Wang, & Zhao, 2020). ANNs are computing systems that learn without formal statistical training, and possess the ability to detect complex nonlinear relationships between dependent and independent variables (Tu, 1996; Xiaoping & Liu, 2009), Fuzzy logic is used for the detection, description and representation of uncertainties (Pabuçcu, 2017) while the Markov methods possess the characteristic of detecting fluctuations and the vibrational direction of TS occurrences (Wang, Mehrabi, & Kannatey-Asibu, 2002). In their pure forms, these models have been found to perform satisfactorily from their successful application in various industrial areas including weather forecasting (Voyant, Muselli, Paoli, & Nivet, 2011), health emergency preparedness (Mapuwei *et al.*, 2020), crude oil production (Boaisha & Amaitik, 2010), stock price forecasting (Javedani Sadaei & Lee, 2014) and tool wear monitoring rolling bearings (Liu, Youmin, wu, Wang, & Xie, 2017).

Furthermore, the hybrid forms of these models have also been frequently applied. For example, Ali, Yohanna, Ijasini, and Garkida (2018) applied a Neuro-Fuzzy (NF) model in electricity load forecasting and the results of the study indicated a forecast accuracy greater than 98 %. Ganesan, Annamalai, and Deivanayagampillai (2019) used the fuzzy cognitive maps Markov chain model in the prediction of stock market behaviour. Das, Naik, and Behera (2020) developed a NF and fuzzy reduction model and successfully applied it to solving problems of data classification in data mining. In addition, a fuzzy neural network-Markov model was developed by (Shi, Hu, Yu, & Hu, 2016). The results obtained from the studies mentioned show that the hybrid forms of the non-traditional, non-linear models can be implemented in TS forecasting to produce outputs of high accuracies.

Some studies have been carried out concerning the use of single and hybrid forms of the ANN, Markov and FTSM models for industrial accident prediction and prevention. Lan and Zhou (2014) applied a variant of the grey-Markov model in carrying prediction and out a single step ahead forecast of annual coal mining deaths in China. A forecast of the number of occupational accidents, death and permanent incapacitation was made by (Ceylan, 2014) using models developed by ANN models. Results obtained showed that the aim for which the models were developed was achieved. Also, Edem, Oke, and Adebiyi (2018) developed a high variation tolerant grey-fuzzy-Markov model for a one-window ahead (OWA) forecast of industrial accidents. Sarkar, Vinay, Raj, Maiti, and Mitra (2019) observe that although some efforts have been made concerning carrying out studies in this area, the literature is sparse with the domain still slowly developing. As such, more research is required in this area for improved understanding.

Two major problems of utilizing the ANN for TS analysis is that of the choice of ANN architecture (R. Adhikari & Agrawal, 2013; Sánchez-Sánchez, García-González, & Coronell, 2020) and overtraining minimization (Faraway & Chatfield, 1998). Both of these problems have reduced the popularity of ANN for TS prediction. Two common attempts at overcoming this problem involve the use of model comparison criteria and cross-validation experiments (Ratnadip Adhikari, 2015). The use of the Markov technique as a tool for detecting TS vibrational directions and correcting model prediction anomalies is popular and has been successfully applied in various industrial areas (Yarmohammadi & Safaei, 2012; Liu *et al.*, 2017; Wilinski, 2019). However, little effort has been made at applying this technique in ANN TS prediction to correct and redirect forecasts that have been produced from inadequate architectures.

This study is aimed at the development of an ANN-Fuzzy-Markov model for OWA forecasting of industrial accidents. The objectives include the building of the model and its subsequent evaluation with other existing models currently utilised for the same purpose. The study seeks to demonstrate the effectiveness of the Markov technique in producing accurate ANN TS forecast without consideration given to the processes of optimal network architecture development. It is hoped that the model developed will serve as an approach for accident forecasting as well as present stakeholders with an effective accident management tool.

The rest of the work is presented as follows: Section 2 contains a brief presentation of the theoretical concepts of the model, a detailed description of the methodological steps undertaken in the development of the model is presented in section 3. Section 4 contains information regarding the application of the developed model and the discussion of the results obtained from its analysis and evaluation. The conclusions made from the study are presented in section 5.

2.0 Theoretical Background for the Model Development

The ANN-fuzzy-Markov industrial accidents (AFMIA) forecasting model is essentially founded on four concepts namely, ANN prediction procedure, fuzzy classification scheme, Markov transitions and the fuzzy-Markov probabilities determination. The ANN prediction procedure describes the method of setting up the ANN structure for industrial accidents TS prediction. The fuzzy classification scheme is concerned with capturing the imprecision detected from the prediction anomalies of the ANN while the Markov transitions are concerned with the re-direction of the prediction anomalies. The concept of the fuzzy-Markov probabilities determination is usually required in analysing situations where systems characterized by Markov properties also exhibit imprecise properties. These four concepts are subsequently discussed in this section.

2.1 General concept of Artificial Neural Network

ANN forecasting is a deep learning method employed for TS analysis. Unlike linear TS models, ANNs readily learn different types of relationships between variables in the absence of do not require complex mapping function assumption functions (Brownlee, 2018). Although different variants of ANN models such as the feed-forward network (FNN) or Multi-Layer Perceptron (MLP) network, as well as the back-propagation (recurrent Neural networks [RNN]) such as Convolutional Neural Networks (CNN) and the Long-Short Term Memory (LSTM) network, exist, the general architecture for all ANN models is essentially the same.

A typical ANN model is primarily made up of layers of nodes or neurons. The simplest ANN model must possess at least three neuron layers namely, not more than one input layer (responsible for receiving and processing input information), at least one hidden layer (concerned with the further processing of information received from the input layer) and not more than not output layer (which conveys the results of the information processed by the previously mentioned layers) [see Figure 1]. The key to the workings of the ANN is that within a layer, information processed, weighted and distributed to the next layer is made possible by the firing of biological system emulated signals arising from mathematically derived activation functions (MacLeod, 2013). Thus at the end of the process, the output layer makes a decision or produces an inference based on the values computed in the hidden layers.

The major difference between the FNN and the RNN variants is that in the FNN, information once weighted, cannot be modified as information flow is unidirectional while for the RNN, there is bi-directional information flow as the results received by the output layer can be communicated back to the hidden layer for weight readjustment towards improved learning.

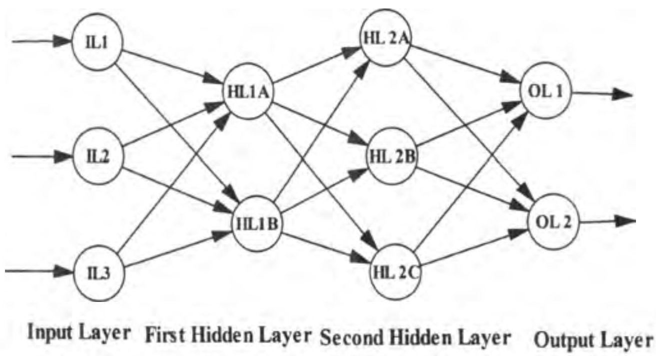


Figure 1: Illustration of a typical ANN architecture

2.2 Neural network model structure for forecasting The procedure for the deployment of ANN for forecasting involves firstly the preparation of a set of historical data X $\{X: x_i(i: 1,2,3,\dots, x_E)\}$ into the input vector form M and output vector form Y (Equations 1 and 2). M is a trajectory matrix made up of L lagged row vectors $m_i(i: 1,2,3,\dots, L)$ each of width N made up of a sequence of occurrences following each other. N $(1 \leq N \leq x_{E-1})$ is referred to as the forecast window length. Y is a column vector made up L rows for which each row value $y_i(i: 1,2,3,\dots, L)$ is mapped to m_i for learning and prediction.

It is worth noting that x_E does not constitute the entire historical data, but the portion of data set aside for building the model. M and Y are subsequently fed into the built network and a supervised learning process involving setting the process to the desired number of iterations (epochs) and learning rates (Kriesel, 2010) is executed to obtain forecast. Due to the time and computational complexities involved in the manual development and implementation of the process, the use of soft computational solutions such as Keras TensorFlow (in R and python programming) have become quite popular (Brownlee, 2018; Lewis, 2018)

(1) $$M = \left(X_{ij}\right)_{i=1,j=1}^{L,N} = \begin{pmatrix} x_1 & x_2 & x_3 \cdots & x_{N-1} & x_N \\ x_2 & x_3 & x_4 \cdots & x_N & x_{N+1} \\ x_3 & x_4 & x_5 \cdots & x_{N+1} & x_{N+2} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \end{pmatrix} \begin{matrix} m_1 \\ m_2 \\ . \\ . \\ . \\ m_{\cdot -1} \end{matrix}$$

(2) $$\begin{matrix} & y_1 & y_2 & y_3 \cdots & y_{L-1} & y_L & & L \\ Y = & (x_{N+1} & x_{N+2} & x_{N+3} \cdots & x_{E-1} & x_E\,)^T & & \end{matrix}$$

2.3 Fuzzy set classification

A fuzzy set $\mathcal{F}$ is defined by a set (Equation 3). $\mu_{\mathcal{M}}(x)$ is called a membership function of the set and represents a discrete or continuous function that specifies the extent to which the element s, a member of crisp set M, belongs to $\mathcal{M}$. s is associated with a fuzzy value that exists between 0 and 1 describing the extent in which it belongs to or satisfies some property attributed to M. Fuzzy values can be described using triangular, quadratic or exponential numbers (Bojadziev & Bojadziev, 2007).

$$\mathcal{F} = \{(s, \mu_{\mathcal{M}}(s) | s \in \mathcal{F}, \mu_{\mathcal{F}}(s) \in [0,1]\,)\} \quad (3)$$

2.4 Markov chain probabilities

Let S be a discrete sample space $S = \{s_i : i = 1,2,3, \dots, N\}$. A Markov chain can be defined as a random variable sequence X_t $(t: 1,2,3, \dots, T)$ that takes values in X such that the probability of an event $P_{s_i \acute{s}_i}$ occurring is dependent on the probability the event $\acute{s}_i$ occurs at time $t+1$ conditioned on the probability that event s_i occurred at time t (Dobrow, 2016). With consideration given to a Markov chain of finite-state (Equation 4), the probability of event $\acute{s}_i$ occurring for n number of step transitions is described in equations 5 and 6.

$$
P_{s_i\acute{s}_i} = \begin{array}{c} States(s_i) \\ 1 \\ 2 \\ 3 \\ . \\ . \\ . \\ N-1 \\ N \end{array} \begin{pmatrix} 1 & 2 & 3 \ldots & N-1 & N \\ P_{11} & P_{12} & P_{13} \cdots & P_{1N-1} & P_{1N} \\ P_{21} & P_{22} & P_{23} \cdots & P_{2N-1} & P_{2N} \\ P_{31} & P_{32} & P_{33} \cdots & P_{3N-1} & P_{3N} \\ . & . & . \;\cdots & . & . \\ . & . & . \;\cdots & . & . \\ . & . & . \;\cdots & . & . \\ P_{n-11} & P_{n-12} & P_{n-13} \cdots & P_{n-1N-1} & P_{n-1N} \\ P_{n-11} & P_{n-12} & P_{n-13} \cdots & P_{n-1N-1} & P_{n-1N} \end{pmatrix} \quad (4)
$$

$$P^t_{s_i\acute{s}_i} = P(X_{t+1}) = \acute{s}_i | P(X_t) = s_i \quad \{s_i, \acute{s}_i \in S, t \geq 1\} \quad (5)$$

2.5 Fuzzy Markov probabilities

Fuzzy Markov probabilities (FMB) are the probabilities of events that exhibit Markov properties. However, the precision of the state properties cannot be accurately estimated. FMB of events is determined from the combination of the concepts earlier presented in sections 2.3 and 2.4. Here, the FMB determination procedure of (Pardo & de la Fuente, 2010) is presented.

Suppose a set of fuzzy states $\mathcal{F}_k\{k = 1,2,3, \ldots, z\}$ is defined such that each $\mathcal{F}_i$ represents an event in the initial Markov chain (Equation 4), then the probability of a single step transition from a fuzzy initial state $\mathcal{F}_v$ to a fuzzy final state $\mathcal{F}_w$ is expressed in equation 6.

$$\tilde{P} = P(\mathcal{F}_w | \mathcal{F}_v) = P(\tilde{X}_1 = w | \tilde{X}_0 = v) = \sum_{i=1}^{N} \bar{P} \left(\frac{P_{s_i} \mu_{\mathcal{F}_v(s_i)}}{P(\mathcal{F}_v)} \right) \quad (6)$$

Where, $\mu_{\mathcal{F}_v(i)}$: Fuzzy membership value for initial Markov event i, P_{s_i}: Initial state probabilities; $P(\mathcal{F}_v)$: Fuzzy initial state probabilities; $\bar{P}$: The single-step transition probability to the final fuzzy state $\mathcal{F}_w$ given the initial state event.

$P(\mathcal{F}_v)$ and $\bar{P}$ are further described in equations 7 and 8.

$$P(\mathcal{F}_v) = \sum_{i=1}^{N} P\{X_0 = \acute{s}_i\}\mu_{\mathcal{F}_v}(\acute{s}_i) \quad (7)$$

$$\bar{P} = P(\tilde{X}_1 = w | X_0 = s_i) = \sum_{i=1}^{N} P_{s_i \acute{s}_i}\mu_{\mathcal{F}_w}(\acute{s}_i) \quad (8)$$

Equation 6 can be conveniently solved to obtain $\tilde{P}$ by adopting the following stepwise procedure (Pardo & de la Fuente, 2010)

Step 1: Create the initial Markov chain (crisp set) transition matrix $P = P_{s_i \acute{s}_i}$ of the events (Equation 4)
Step 2: Create the matrix of the initial Markov chain states versus their corresponding transition fuzzy state components Q as well as that of the initial Markov chain states versus their corresponding initial fuzzy state components H
Step 3: Obtain $\bar{P} = PQ$ via matrix multiplication
Step 4: From H, determine $P_{s_i}\mu_{\mathcal{F}_v(s_i)}$ for $\forall i$, $P(\mathcal{F}_v)$ for $\forall k$, then obtain $(H^{*})^T$ containing the values of $\frac{P_{s_i}\mu_{\mathcal{F}_v(s_i)}}{P(\mathcal{F}_v)}$.
Step 5:The fuzzy transition probability matrix $\tilde{P}$ for the event is finally obtained using equation 9.

$$\tilde{P} = (H^{*})^T \bar{P} \quad (9)$$

3.0 Methodology

In this section, the AFMIA forecasting model is presented. Section 3.1 gives an overview model development process. The notations and definitions employed are presented in Section 3.2. Section 3.3 contains a detailed description of the methodological steps deployed in developing AFMIA.

3.1 Overview of the model development process

The development of the AFMIA involves the collection and preparation of industrial accidents, then deploying the prepared data in the development of the ANN prediction model. The model is used to generate various predictions and forecast which are subsequently screened based on certain performance criteria. Predictions that satisfy the screening conditions are deployed in carrying out a direction of vibration analysis to correct the ANN forecast producing a modified value in the process. If the desired ANN forecast population level and corresponding corrections are met, then a procedure for determining a single value forecast is implemented if not met, then the model proceeds to regenerate more forecast candidates. Figure 2 presents a summary of the key activities involved in the AFMIA development process while Table 1 lists the symbols and notations employed in the work.

3.2 Description of the AFMIA development

In this section, each phase of the forecast model development is described in detail in the following subsections.

3.2.1 Development and implementation of ANN prediction model

Given a set of industrial accident historical data D ($D = \{D_t : t = 1,2,3, \ldots, K\}$), the OWA forecast process aims to forecast D_{K+1}. The first step taken towards achieving this step was to convert D into the input and output vector forms described in equations 1 and 2 with the input vector window width N set. To guide the decision on the choice of N, a partial auto-correlation analysis was carried out on D to determine the extent of the lagged relationship that exists between the data points N steps apart. Subsequently, the CNN neural network model was deployed. The CNN was built using Keras python 3.7 model with TensorFlow backend. Table 2 shows the parameters that were defined in building CNN and their corresponding values. The model was subsequently implemented by training D at different epoch values ε to obtain the vector of predictions $D^{\varepsilon}\,\{D_t^{\varepsilon} : t = N+1, N+2, N+3, \ldots, K-1, K\}$ and corresponding forecast D_{K+1}^{ε}.

Table 1: Symbols and notations

C_K: ANN Forecast residual	CNN: Convolutional Neural Networks
D_t^{ε}: ANN prediction made at time t	N: Swing window width
C_t: Cumulative residual at time t	CE: cumulative error
$\bar{F}_c$: Fuzzy correction span vector	TS: Time series
μ: Fuzzy membership	OWA: One window ahead
D: Vector of Industrial accident historical data	
D^{ε}: Vector of AFMIA predictions	Forecast residual direction of vibration range (VBR)
MAPE: Mean absolute percentage error	AS1, AS2: Accidents datasets 1 and 2.
β : Residual swing magnitude	MMFCR : Method of the most frequent cumulative residual
σ: Residual quality	RELU: Rectified Linear Activation Function
$\hat{\beta}, \hat{\sigma}$: Residual swing control parameters	AdaM: Adaptive moment estimator optimiser
$\phi_{t,t+1}$: Residual span value between t and $t+1$	
S_i: Residual state i	
$\rho^{+}\{r_K^{\varepsilon}\}$: Residual r_K^{ε} of positive polarity	
T^R T^I: regular and irregular step transitions	
$\rho(r_j^{*\varepsilon})$: Polarity of ANN residual of point j	
P: crisp Markov transition matrix	

3.2.2 Screening of ANN predictions

One of the major problems that impede effective ANN time series prediction is the existence of a plethora of local optima in the model search space. This feature creates a high probability of predictions being produced from unsuitable local optima during the learning process.

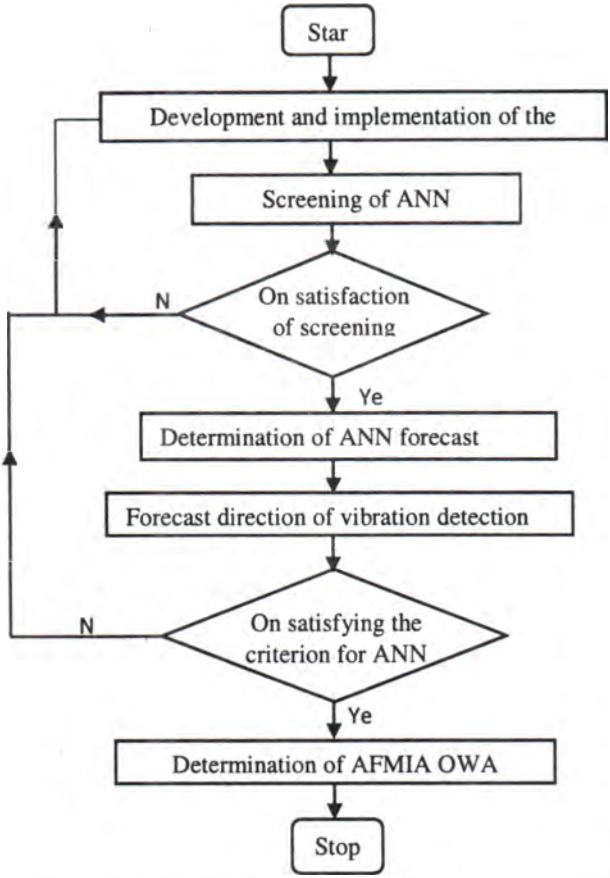


Figure 2: Flowchart of the AFMIA forecasting model

Table 2: CNN architecture parameters and corresponding values as used in the study

CNN architecture Parameter	Convolution dimension	Kernel size	Activation function	Input shape (batch size, samples, height, timestep, features)
	1	64	RELU	(1, dynamic ,4,1)
CNN architecture Parameter	**Pool size**	**Layers (dense/output)**	**Optimiser**	**Loss function**
	2	(5/1)	AdaM	MSE

To surmount this, D^{ε} was determined to exist in the range of acceptable predictions by evaluating some properties of their residuals r^{ε} and ensuring that they exist within a range which we define in this study as acceptable. The properties investigated were the residual swing magnitude β and residual quality σ.

β was obtained from the *MAPE* of D^{ε} and tries to capture the general swing magnitude prevalent in the residuals. σ, which estimates the were independent and identical distribution characteristic of the residuals was estimated using equations 10 and 11. The equation seeks to estimate the extent of dispersion of positive and negative peaks and troughs within the residuals.

The control property value $\hat{\beta}$ was set based on the maximum *MAPE* prediction fitness values produced by the grey-Markov $\{GM(1,1)\}$ and the double-declining exponential smoothing models on the preliminary application of the industrial accident data. $\hat{\sigma}$ was set to the value of 0.5. In both cases, the control property works by making D^{ε} and D^{ε}_{K+1} accepted prediction vector $D^{*\varepsilon}$ and forecast $D^{*\varepsilon}_{K+1}$ respectively when $\beta(D^{\varepsilon})$ and $\sigma(D^{\varepsilon})$ do not exceed their respective control values and rejecting D^{ε} otherwise.

$$\sigma(D^{\varepsilon}) = \frac{\sum_{j=1}^{K-2} s_j}{2*(K-2)}\{\rho(r^{*\varepsilon}_{j-1}) \neq \rho(r^{*\varepsilon}_{j}), j = 1,2, \dots K-2\} \quad (10)$$

$$r^{*}_{j} = \begin{cases} r^{\varepsilon}_{t+1} & \{t = K\} \\ r^{\varepsilon}_{t}(\rho\{r^{\varepsilon}_{t}\} \neq \rho\{r^{\varepsilon}_{t+1}\}) & \{otherwise\} \end{cases} \quad (11)$$

$$r_t^{\varepsilon} = \frac{100(D_t - D_t^{\varepsilon})}{D_t} \quad (12)$$

$$t: N+1 \ldots, K-1, K$$

3.3 Forecast correction

This is the most important stage of the neuro fuzzy-Markov model development. We assume that the D^{ε} is not accurate due to issues relating to local and plateau optima as well as model under-learning and over-learning. As such, the fuzzy Markov model was applied in the analysis of the ANN output towards obtaining improved outcomes.

The process which essentially involves the analysis to obtain the cumulative and span values of residuals, the fuzzy classification of r^{ε}, determination of a correction factor and subsequent modification of $D_{K+1}^{*\varepsilon}$ is discussed in this section.

3.3.1 Cumulative residual error and span residual error analysis

Based on the inferences provided by r^{ε} on the behaviour of the ANN model's attempt to accurately predict the historical data, we theorised that if a forecast residual r_{K+1}^{ε} was determined, then the forecast accuracy of the neural network model could be improved. To this effect, the concept of cumulative error (*CE*) tracking was introduced. *CE* tracking seeks to determine the sum of errors produced by the ANN at point t, dependent on the magnitude and polar direction of r_t^{ε}. Thus within the residual error space, the *CE* at t (C_t) is defined by equations 13. Also, to obtain C_t, the swing spans of r_t^{ε} ($d_{t,t+1}$) were determined (equation 14)

$$C_t = \begin{cases} C_{t-1} - |r_t^{\varepsilon}| & \{(\rho\{r_t^{\varepsilon}\} = \rho\{r_{t+1}^{\varepsilon}\}) \wedge (|r_t^{\varepsilon}| > |r_{t+1}^{\varepsilon}|)\} \\ C_{t-1} + |r_t^{\varepsilon}| & \{(\rho\{r_t^{\varepsilon}\} = \rho\{r_{t+1}^{\varepsilon}\}) \wedge (|r_t^{\varepsilon}| \le |r_{t+1}^{\varepsilon}|)\} \\ |r_t^{\varepsilon}| & \{(\rho\{r_t^{\varepsilon}\} \ne \rho\{r_{t+1}^{\varepsilon}\})\} \end{cases} \quad (13)$$

$$\phi_{t,t+1} = \begin{cases} |r_{t+1}^{\varepsilon} - r_t^{\varepsilon}| & \{\rho\{r_t^{\varepsilon}\} = \rho\{r_{t+1}^{\varepsilon}\}\} \\ C_{t-1} + |r_t^{\varepsilon}| & \{otherwise\} \end{cases} \quad (14)$$

3.3.2 Fuzzy classification of span residual errors

The residual error spans ($\phi_{t,t+1}$), were subsequently classified on basis of their span magnitudes (*SM*). Three lingustic crisp *SM* classes namely, Low $\{L:(0,0.33\theta)\}$, Medium $\{M:(0.33\theta,0.67\theta)\}$ and Large $\{H:(0.67\theta,\theta)\}$ were defined. The fuzzy membership of $\phi_{t,t+1}$ in the defined classes were determined using triangular membership functions (equations 15-17).

$$\mu_L = \mu_{\phi_{t,t+1}}\{L\} = \begin{cases} 1 & \{\phi_{t,t+1} \le 0.5\bar{L}\} \\ \frac{2\phi_{t,t+1}-\bar{M}}{\bar{L}-\bar{M}} & \{0.5\bar{L} < \phi_{t,t+1} \le 0.5\bar{M}\} \\ 0 & \{otherwise\} \end{cases} \quad (15)$$

$$\mu_M = \mu_{\phi_{t,t+1}}\{M\} = \begin{cases} \frac{\bar{L}-2\phi_{t,t+1}}{\bar{L}-\bar{M}} & \{0.5\bar{L} < \phi_{t,t+1} \le 0.5\bar{M}\} \\ \frac{\bar{H}-2\phi_{t,t+1}}{\bar{H}-\bar{M}} & \{0.5\bar{M} < \phi_{t,t+1} \le 0.5\bar{H}\} \\ 0 & \{otherwise\} \end{cases} \quad (16)$$

$$\mu_H = \mu_{\phi_{t,t+1}}\{H\} = \begin{cases} \frac{2\phi_{t,t+1}-\bar{M}}{\bar{H}-\bar{M}} & \{0.5\bar{M} < \phi_{t,t+1} \le 0.5\bar{H}\} \\ 1 & \{\phi_{t,t+1} \ge 0.5\bar{H}\} \\ 0 & \{otherwise\} \end{cases} \quad (17)$$

Where $\bar{L}, \bar{M}$ and $\bar{H}$ are the mid point values of L, M, H respectively.

$$f\{SM\}_{ij} = \begin{array}{c} \\ L \\ M \\ H \end{array} \begin{pmatrix} L & M & H \\ & f_{LM} & f_{LH} \\ f_{ML} & f_{MM} & f_{MH} \\ f_{HL} & f_{HM} & f_{HH} \end{pmatrix} \quad (18)$$

$$A_{SM}\{SM\}_{ij} = \begin{array}{c} \\ L \\ M \\ H \end{array} \begin{pmatrix} \mu_L & \mu_M & \mu_H \\ A_{LL} & A_{ML} & A_{HL} \\ A_{LM} & A_{MM} & A_{HM} \\ A_{LH} & A_{MH} & A_{HH} \end{pmatrix} \quad (19)$$

3.3.3 Determination of correction span for ANN forecast

The frequencies of $\mu_{\phi_{t,t+1}}\{SM\}$ as they occur in the different SM classes were determined, recorded and used to develop the crisp Markov transition matrix (P) as discussed in section XX (equations 18 and 20). Also, the fuzzy partition which shows the corresponding fuzzy states of the system $\left(Q = \mu_{SM}\{SM\}_{ij}\right)$ [equations 19 and 21] was also determined.

$$P\{SM\}_{ij} = \frac{f\{SM\}_{ij}}{\sum_{i=1}^{3} f\{SM\}_{ij}} \qquad \left\{\mu_{SM}\{SM\}_{ij} > 0\right\} \tag{20}$$

$$\mu_{SM}\{SM\}_{ij} = \max\left(A_{SM}\{SM\}_{ij}\right) \tag{21}$$

It is worth noting that $A_{SM}\{SM\}_{ij}$ is the set containing $\mu_{SM}\{SM\}_{ij}$ for all $\phi_{t,t+1}$ whose fuzzy membership falls within that set.

Based on P and Q and their derivatives, fuzzy-Markov transition probability matrix $\tilde{P}$ was then derived using equation 9. Let R be the vector containing the upper bounds of the SM classes, then the correction span vector was obtained as,

$$\tilde{F}_c = \sum_{j=1}^{3} \tilde{P}_{ij} R_j \left\{\mu_{\phi_{K-1,K}}\{SM\} > 0; R_j = \{0.33\theta, 0.67\theta, \theta\}\right\} \tag{22}$$

Finally, the ANN forecast correction span $(\phi_{K,K+1})$ was obtained as,

$$\phi_{K,K+1} = \max(\tilde{F}_c) \tag{23}$$

3.4 Forecast direction of vibration detection analysis

Observe from section 3.3 that the approach used in obtaining $\phi_{K,K+1}$ involved the use of values in their absolute forms. As such, the expected forecast cumulative residual is expected to be of the form described in equation (24). However, the direction of a TS event is usually exclusive to a single direction per instance of occurrence. This is what is referred to as the TS direction of vibration. This section aims to determine this direction thereby determining a single C_{K+1} value in the process.

$$C_{K+1} = 0.5(C_K \pm \phi_{K,K+1}) \tag{24}$$

The procedure essentially involves the creation of residual states, determination and classification of step transitions determined for r^{ε}, a procedure to obtain the forecast step transition and analysis to establish the forecast residual direction of vibration range (DVR). It is assumed here that r^{ε} satisfies the conditions for normally distributed residuals.

3.4.1 Creation of states for ANN prediction residuals

The second step involved the determination of the number of residual step transitions that occur from one ANN prediction point to another. In this regard, we initially apply the principle of grey-Markov forecasting of fluctuating time series (Zhan-li & Sun, 2011) which requires that if $\rho\{r_K^{\varepsilon}\}$ is of a particular polarity, then r^{ε} be reversed from the most polar residual form of $\rho\{r_K^{\varepsilon}\}$ to the least polar form. For example, if $\rho^{+}\{r_K^{\varepsilon}\}$, that is if r_K^{ε} is of positive polarity, then we reverse the set of residuals to obtain a new set $\hat{r}^{\varepsilon}$ arranged from the most positive r_t^{ε} to the least positive.

In the next step, we a series of residual states $S_i\{S_i = (r_{LB}, r_{UB}); i = 1,2,3, \dots W\}$ for $\hat{r}_K^{\varepsilon}$ using a fixed residual width w. In this work, the value of w was fixed using equation (25).

$$w = 0.5 * (MAPE^{*}\{D^{\varepsilon}\} - 1)$$

Where $MAPE^{*}\{D^{\varepsilon}\}$ is the integer form of $MAPE\{D^{\varepsilon}\}$.

As an example, suppose the vector V containing five residual values and $V = r^{\varepsilon} = \{-13.23, +4.71, +8.11, -10.24, +4.37\}$, then

$$r^{\varepsilon} = +8.11, +4.71, +4.37, -10.24, -13.23 \quad (25)$$

$$S = \{-14.00, -10.50, -7.00, -3.50, 0.00, 3.50, 7.00, 10.50, +14.00\} \quad (26)$$

$$S_i = \{i = 1: (-14.00, -10.50), i = 2: (-10.50, -7.00), \dots, i = 8: (10.50, 14.00)\}$$

A few observations can be made from S_i from equation 26.

i. The states are created from point 0.00 and progressively extended to the positive and negative polar coordinates using the mean of r^{ε} as w, but numbered in order of $\hat{r}^{\varepsilon}$.
ii. S_i may be filled (occupies r_t^{ε}) or empty.
iii. Within each polar coordinate, S_i generation should be terminated as soon as $\max(r_t^{\varepsilon})$ or $\min(r_t^{\varepsilon})$ has been accommodated by an already generated state except in cases of observation iv.
iv. An extra state is created to account for the imprecision in the residual location in situations where $\Delta S_a < \Delta S_b$.

$$\Delta S_a = \begin{cases} \left|\left(\left|min(S_i^{LB})\right| - |r_t^{\varepsilon}\{min(S_i)\}|\right)\right| \\ \left|\left(\left|max(S_i^{UB})\right| - |r_t^{\varepsilon}\{max(S_i)\}|\right)\right| \end{cases} \quad (27)$$

$$\Delta S_b = \begin{cases} \left|\left(\left|min(S_i^{UB})\right| - |r_t^{\varepsilon}\{min(S_i)\}|\right)\right| \\ \left|\left(\left|max(S_i^{LB})\right| - |r_t^{\varepsilon}\{max(S_i)\}|\right)\right| \end{cases} \quad (28)$$

3.4.2 Residual step transition determination and classification

This stage involved the determination of the step transitions of the residuals. The location of each r_t^ε in S_i and the state number $S_i\{r_t^\varepsilon\}$. The step transitions of r_t^ε from point t to $t+1$ were determined (equation 29)

$$T_{t,t+1} = S_i\{r_{t+1}^\varepsilon\} - S_i\{r_t^\varepsilon\} \qquad (29)$$

The set of step transitions T was then grouped into two classes namely regular transitions T^R and irregular transitions T^I. T^R are those step transitions that occur frequently while T^I are those that may be termed abnormal or outlier swings. Based on preliminary observations on twenty normally distributed residuals, the swing classes are defined as

$$T_{t,t+1} \in \begin{cases} T_j^R \; \{|T_{t,t+1}| \le 2\} \\ T_j^I \; \{otherwise\} \end{cases} \qquad (30)$$

Each transition class was further split into two classes in terms of the direction of the step transitions. As in the case of regular transitions, $T_j^R = \{T_j^{R+}, T_j^{R-}\}$ where T_j^{R+}, T_j^{R-} are the regular step transitions in the forward and backward direction respectively for the transition start position S_K. T_j^I was similarly defined.

3.4.3 Forecast residual transition step determination

Deploying the defined classes, the forecast transition step was then determined. Due to the imprecise nature of the system, forecast transitions can either in the forward or reverse direction. As such both directions had to be investigated towards obtaining the desired forecast direction. The forward and backward transition step candidates were first derived (equation 31). Their corresponding candidates for the desired forecast residual states S_k^+ and S_k^- repectively were located in S_i (equation 32). The respective forecast residual state boundary values $r_{LB}^\varepsilon\{S_k^q\}$ and $r_{UB}^\varepsilon\{S_k^q\}$ and for all transition directions q were then located.

$$T_{k,k+1} = \begin{cases} \bar{T}_j^{*Rq} & \{T_j^{Rq} \neq \{\emptyset\}; \forall q\} \\ T_j^{Rq} & \{otherwise; \forall q\} \end{cases} \qquad (31)$$

$$S_k^q = \begin{cases} S_K + T_{k,k+1} & \{T_{k,k+1} - Int(T_{k,k+1}) \leq 0; \forall q\} \\ S_K + T_{k,k+1} + 1 & \{otherwise; \forall q\} \end{cases} \quad (32)$$

3.4.4 Range of forecast residual direction and ANN forecast and prediction correction

This phase of the analysis concerns the determination of the range of forecast residual direction (V_{LB}, V_{UB}). This involved capturing potential scenarios that could result from the transition process. The aim is to guide the decision on the choice of the members of $r_{LB}^{\varepsilon}\{S_K^q\}$ and $r_{UB}^{\varepsilon}\{S_K^q\}$ that constitute (V_{LB}, V_{UB}). The scenarios and the recommended forecast residual direction values are presented in equations (32-35). Note that the computation of $C_{K+1}^a[C_{K+1}^a = 0.5(C_K + \phi_{K,K+1})]$ and $C_{K+1}^b[C_{K+1}^b = 0.5(C_K - \phi_{K,K+1})]$ using equation (24) was undertaken before proceeding.

If $|T_{K-1,K}| \in T_j^I$, then compute S_K^a,

$$S_K^a = S_k + min[T_{t,t+1}] \quad (33)$$

$$(V_{LB}, V_{UB}) = \begin{cases} [min(r_h^{\varepsilon}\{S_K^a\}), max(r_h^{\varepsilon}\{S_K\})] & \{\rho^-\{T_j^I\}\} \\ [max(r_h^{\varepsilon}\{S_K\}), min(r_h^{\varepsilon}\{S_K^a\})] & \{\rho^+\{T_j^I\}\} \end{cases}$$

Else, compute

$$R^{\varepsilon}\{S_K^q\} = r_{LB}^{\varepsilon}\{S_K^q\} \cup r_{UB}^{\varepsilon}\{S_K^q\} \quad (34)$$

If $\rho\{C_{K+1}^a\} = \rho\{C_{K+1}^b\}$, then

Obtain $R^{*\varepsilon}\{S_K^q\} \subseteq R^{\varepsilon}\{S_K^q\}$ such that, $[(\rho\{R_i^{*\varepsilon}\} = \rho\{C_{K+1}^q\}) \vee (R_i^{*\varepsilon} = 0),] \ \{\forall i\}$ where $R_i^{*\varepsilon}$ are elements of $R^{*\varepsilon}$

$$(V_{LB}, V_{UB}) = \begin{cases} [min(R_i^{*\varepsilon}\{S_K^q\}), max(R_i^{*\varepsilon}\{S_K^q\})] & \{\rho^-\{C_{K+1}^q\}\} \\ [max(R_i^{*\varepsilon}\{S_K^q\}), min(R_i^{*\varepsilon}\{S_K^q\})] & \{\rho^+\{C_{K+1}^a\}\} \end{cases} \quad (35)$$

Otherwise,

$$(V_{LB}, V_{UB}) = \{[min(R_i^{\varepsilon}\{S_K^q\}), max(R_i^{\varepsilon}\{S_K^q\})] \quad (36)$$

The scenario captured by equation 33 is that in which an irregular residual swing occurs at the period just preceding the forecast period $(T_{j=K}^I)$. In such a situation, the forecast DVR was fixed as that existing between the S_K and the maximum state length of existing step transitions in the reverse direction of $T_{j=K}^I$. If the first scenario is not observed, then we

check for the scenario in the forecast cumulative residual candidates are of a similar polarity. If this exists, C^q_{K+1} must be evaluated using the DVR with the same polar origin as C^q_{K+1} (equation 35). If all $R^\varepsilon\{S^q_K\}$values are of non-similar poles to C^q_{K+1}, then $R^\varepsilon_i\{S^q_K\}$ of magnitude closest to $C^q_{K+1}$are deployed to create the DVR. However, if non of the first two scenarios play out, then the DVR is fixed by the most negative and least negative values of the forecast residual state boundaries (equation 36).
Once the (V_{LB}, V_{UB}) has been determined, the C^q_{K+1} that meets the conditions of the DVR (C_{K+1}) is subsequently determined as the C^q_{K+1} having the least proximity value from the midpoint of the DVR (equation 37).

$$C_{K+1} = \begin{cases} C^a_{K+1} \; \{|C^a_{K+1} - \bar{V}| < |C^b_{K+1} - \bar{V}|\} \\ C^b_{K+1} \; \{|C^b_{K+1} - \bar{V}| < |C^a_{K+1} - \bar{V}|\} \\ 0.5(C^a_{K+1} C^b_{K+1}) \; \{Otherwise\} \end{cases} \quad (37)$$

C_{K+1} serves as the correction factor to the ANN forecast D^ε_{K+1}. Thus, the corrected ANN forecast $\widehat{D}^\varepsilon_{K+1}$was subsequently obtained (equation 38).

$$\widehat{D}^\varepsilon_{K+1} = \frac{D^\varepsilon_{K+1}}{(1-0.01C_{K+1})} \quad (38)$$

3.5 AFMIA forecast and prediction mechanism

The ANN aspect of the model requires that D^ε_{K+1} candidates be generated to ensure a statistically acceptable forecast. However, the iterative process involved in machine learning takes time and can affect model efficiency. In a bid to create a balance between the model's effectiveness and efficiency, each run of the AFMIA was designed to iterate and obtain 5 D^ε_{K+1} predictions within three epochs based on a specified start epoch (ε_s). Given that the AFMIA model is a OWA model, the ANN forecast generation and the fuzzy-Markov process was repeated for each $\widehat{D}^\varepsilon_{K+1}$ output generated.
Once the prediction and forecast process is completed and the set of $\widehat{D}^\varepsilon_{K+1}$ obtained $\widehat{D}$, the single value $\widehat{G}^\varepsilon_{K+1}$ was obtained by computing the mean

of $\widehat{D}$ (MMean) or the method of the most frequent cumulative residual C^{q}_{K+1} (MMFCR) identified and used to forecast $\widehat{D}^{q\varepsilon}_{K+1}$ (equations 39 - 41).

$$\widehat{G}^{\varepsilon}_{K+1} = \begin{cases} \frac{\sum \widehat{D}^{a}}{\# \widehat{D}^{a}} & \{\#\widehat{D}^{a} > \#\widehat{D}^{b}\} \\ \frac{\sum \widehat{D}^{b}}{\# \widehat{D}^{b}} & \{\#\widehat{D}^{b} > \#\widehat{D}^{a}\} \end{cases} \quad (39)$$

Where,

$$\widehat{D}^{a} = \left\{\widehat{D}^{\varepsilon}_{(K+1)i} \left\{C_{(K+1)i} = C^{a}_{(K+1)i}\right\}\right\} \quad (40)$$

$$\widehat{D}^{b} = \left\{\widehat{D}^{\varepsilon}_{(K+1)i} \left\{C_{(K+1)i} = C^{b}_{(K+1)i}\right\}\right\} \quad (41)$$

The ANN predictions $D^{\varepsilon}_{t} \{t: 1 \ldots, K\}$ were also corrected using a modified form of equation 38. The correction factors for the predictions were taken as the mean of their respective $S_i\{r^{\varepsilon}_{t}\}$ (equation 42)

$$\widehat{D}^{\varepsilon}_{t} = \frac{D^{\varepsilon}_{t}}{(1 - 0.01\bar{S}_i\{r^{\varepsilon}_{t}\})} \quad (42)$$

4. Model implementation, validation and evaluation

Given the computational complexity of the model, its process routines were implemented via a computer program developed using the Keras package with the Tensorflow backend of Python 3.7 environment. The model's prediction and forecasting capability was investigated by applying it to two secondary industrial accident data obtained from the literature (Bureau of Safety and Environmental Enforcement, 2018; Gov.UK, 2020). In both cases, the datasets were split into a training set and a testing set using a 70-30 ratio format.

The model's relative performance was investigated by comparing its outputs with those of two traditional models (exponential Smoothing [EXPSM] and ARIMA). The EXPSM and auto-ARIMA feature of the SPSS software was used for the traditional models' analysis. Also, AFMIA's performance was also compared with two non-traditional models Markov based models (Grey-Markov model (GMM) and the grey–fuzzy–Markov and pattern recognition model (GFMAPR). Computer programs were developed for the GMM and GFMAPR based on the theoretical principles provided by Zhan-li and Sun (2011) and (Edem *et al.*, 2018).

4.1 Prediction and forecast accuracy

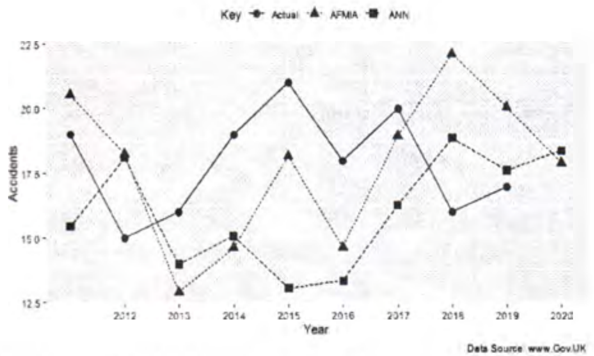
In a bid to ascertain the predictive capability of AFMIA, the industrial accident data (referred here as Accident data sets AS1 and AS2 respectively) were characterized to determine their suitability for TS prediction (Table 3). It was observed in both industrial accident data sets that. This observation helped to reaffirm the observation that although dependent on organisation's safety philosophy, industrial accidents occurrences are random, exhibiting fluctuating tendencies and non-seasonality characteristics. These characteristics fit the data profile for which the AFMIA was developed.

Table 3: Characteristics of fire accidents data to which the AFMIA was applied

Industrial Accidents Data	Characteristics of data		
	Variation	Fluctuation	Randomness
AS1	0.2462	89%	114.61%
AS2	0.2162	78%	76.81

4.2 Expected performance of the model

Given that the model was developed to obtain improved forecasts from the neural network predictor, the results obtained on the application of the model showed forecast superiority over the CNN-ANN base. It can be observed from Figures 3 and 4 that AFMIA exhibited good tracking and anticipation capability notwithstanding the level of variation observed within the two data sets. A summary of the MAPE and RMSE performances of the base and corrector models (Table 4) were observed to be 18.44 and 3.48 compared to 19.68 and 4.08 of the ANN. Similarly for AS2, 15.39 and 26.39 were the respective method of evaluation outcomes obtained from AFMIA application, while the ANN forecast evaluation results were 20.13 and 30.57. From the results and based on the data used, it is clear that the AFMIA is capable of correcting ANN thus improving the potential of improved occurrence monitoring.



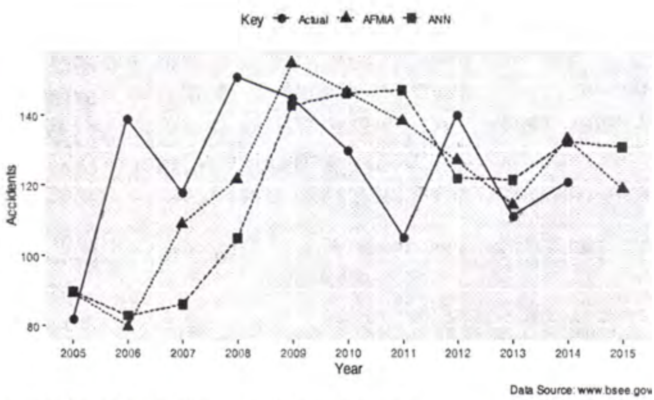


Figure 4: ANN and AFMIA OWA Forecasts for accident data AS2

Table 4: MAPE and RMSE of industrial accidents prediction by the ANN and AFMIA model

	AS1				AS2			
Industrial Accidents Data Type	In-sample Fit		Out-of-sample		In-sample Fit		Out-of-sample	
Evaluation Results	AFMIA	ANN	AFMIA	ANN	AFMIA	ANN	AFMIA	ANN
MAPE	19.50	15.35	18.439	19.679	8.052	7.171	16.828	21.012
RMSE	26.54	7.12	3.483	4.080	9.557	7.683	26.803	31.389

However, regarding the fitted or trained model results, Table 4 and Figures 5 and 6, show that although both models performed reasonably well, the ANN predictor results were more superior. This infers a greater degree of deep learning over the AFMIA. This tendency to overlearn has been one of the problems that have hampered the progress of ANN as a TS predictor and as such a more accurate fitting may lead to an inaccurate forecast of data that was not used in the model development. Further, the fitted data is only an end to a means in itself and is only recognized in situations of little or no information regarding future occurrence accidents. As such it is not considered relevant in this study as the OWA technique used in the validation process provides a more reliable approach at determining the validity of future occurrences.

4.3 AFMIA relative performances with the traditional and non-traditional models

The evaluation of the performance of the model with some of the existing models was also done. MAPE and RMSE results obtained from the application of the non-traditional model forms on AS1 were 49.94 and 10.20 for ARIMA and 20.20 and 3.92 for ESM. Given the degree of variation in AS1, the less accurate results produced by ARIMA is expected due to its inability to handle strong non-linearity situations. However, the ESM produced results that were comparable in accuracy to the AFMIA (Table 5). However, for AS2, both models produced less accurate forecasts in comparison to the AFMIA (Table 5).

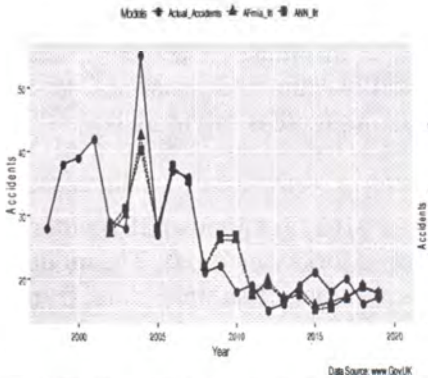


Figure 5: ANN fitted predictions for accident data AS1 and corresponding AFMIA correction

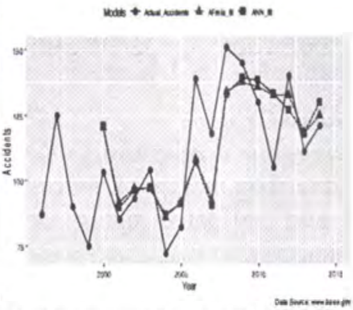


Figure 6: ANN fitted predictions for accident data AS2 and corresponding AFMIA correction

This result indicated that the non-traditional forecasting model types may be more accurate in industrial accident prediction. This view was strengthened by the results obtained from the non-traditional models MSGM and GFMAPR (Table 4).

Table 5: MAPE and RMSE of industrial accidents prediction by evaluated traditional and non-traditional forecasting models

	AS1				AS2			
Industrial Accidents Data Type	**Out-of-sample**				**Out-of-sample**			
Evaluation Results	**ARIMA**	**ESM**	**MSGM**	**GFMAPR**	**ARIMA**	**ESM**	**MSGM**	**GFMAPR**
MAPE	49.936	20.204	14.818	20.208	20.129	21.051	21.138	16.756
RMSE	10.20	3.917	2.943	4.216	31.794	30.800	32.789	27.633

It was observed that for AS1, the MSGM forecasts with MAPE of 14.82 and RMSE of 2.94 were more accurate than those of the AFMIA (MAPE of 18.44 and RMSE of 3.48) although slightly so. Similarly with respect to AS2, the performance evaluation results of the GFMAPR (MAPE = 16.76; RMSE = 27.63) generally matched those of the AFMIA (MAPE = 16.83; RMSE = 26.80). This could indicate the capability of the fuzzy and Markov component of the AFMIA, MSGM and GFMAPR to capture more accurately the imprecision that exists in industrial accident data. Generally, the AFMIA performed well as an industrial-accidents forecasting tool when compared with existing forecasting models.

5. CONCLUSIONS

This study developed a hybrid model (AFMIA) for industrial accident forecasting based on the use of neuro-fuzzy-Markov methods. The model was tested and validated using fitted and out-of-sample data from secondary sources. Also, the model's capability and accuracy were evaluated against existing traditional and non-traditional forecasting models.

Results obtained showed that the developed model produced more accurate forecasts than the ANN model as well as all the traditional models considered. However, AFMIA produced less accurate predictions in some cases when evaluated against the non-traditional models.

AFMIA relative prediction superiority ranges evaluated in terms of the MAPE were 6 – 25%, 9-170%, and 20 – 26% over the ANN, traditional models and non-traditional models respectively. The developed model's relative prediction inferiority range was 0 – 12. Thus based on the limit of the quantitative evaluation done, the model is can be used in carrying predictions without the need for complex ANN architectural development processes. In addition, the obtained results make the model effective and adequate for the prediction, anticipation and management of industrial accidents.

This work aims to present a perspective on the potential of combining machine learning techniques and related soft computing methods in the development of models with new and better capabilities through the development of the novel ANN-fuzzy-Markov industrial accident forecasting model. Further, the study increases the scope of industrial accidents forecasting as it opens up the window of the potential of combining machine learning techniques and Markov based techniques in industrial accidents investigation and management.

The field of machine learning in forecasting is still unfolding. There is still a lot of potential areas of research that can be carried out to usher in improvement. One such is related to the understanding of the multiple local optima problem that impedes satisfactory machine learning based forecasting. Another area worth investigating relates to the determination of the number and unit size of swing residuals that can produce the most precise neuro-fuzzy-Markov predictions.

It is hoped that this study will motivate more involvement from researchers and stakeholders towards improved safety management through the use of these forms of soft computing methods.

REFERENCES

Adhikari, R. (2015). A neural network based linear ensemble framework for time series forecasting. *Neurocomputing, 157*, 231-242. doi: https: //doi. org/10. 1016/j. neucom. 2015 .01.012

Adhikari, R., & Agrawal, R. (2013). An Introductory Study on Time Series Modeling and Forecasting. *ArXiv, abs/1302.6613*.

Aidoo, S. J., & Eshun, P. (2012). Time Series Model of Occupational Injuries Analysis in Ghanaian Mines-A Case Study. *Research Journal of Environmental and Earth Sciences, 4*, 162-165.

Aksoy, H., & Dahamsheh, A. (2009). Artificial neural network models for forecasting monthly precipitation in Jordan. *Stochastic Environmental Research and Risk Assessment, 23*, 917-931. doi:10.1007/s00477-008-0267-x

Ali, D., Yohanna, M., Ijasini, P. M., & Garkida, M. B. (2018). Application of fuzzy – Neuro to model weather parameter variability impacts on electrical load based on long-term forecasting. *Alexandria Engineering Journal, 57*(1), 223-233. doi:https://doi.org/10.1016/j.aej.2016.12.008

Boaisha, S., & Amaitik, S. (2010). *FORECASTING MODEL BASED ON FUZZY TIME SERIES APPROACH.*

Bojadziev, G., & Bojadziev, M. (2007). *Fuzzy Logic for Business, Finance, and Management* (2nd ed.). Singapore: World Scientific Publishing Co. Pte. Ltd.

Bontempi, G. (2008). Long term time series prediction with multi-input multi-output local learning. *Proceedings of the 2nd European Symposium on Time Series Prediction (TSP), ESTSP08.*

Brownlee, J. (2018). *Deep Learning for Time Series Forecasting* S. Martin (Ed.) *Predict the Future with MLPs, CNNs and LSTMs in Python* (pp. 557). Retrieved 10 September, 2020 from https://machinelearningmastery.com/deep-learning-for-time-series-forecasting/

Bureau of Safety and Environmental Enforcement. (2018). Fires Explosions. Available from Bureau of Safety and Environmental Enforcement Retrieved 24th September, 2020 from https://www.bsee.gov/stats-facts/offshore-incident-statistics/fires-explosions

Ceylan, H. (2014). An Artificial Neural Networks Approach to Estimate Occupational Accident: A National Perspective for Turkey. *Mathematical Problems in Engineering, 2014*, 756326. doi:10.1155/2014/756326

Das, H., Naik, B., & Behera, H. S. (2020). A Hybrid Neuro-Fuzzy and Feature Reduction Model for Classification. *Advances in Fuzzy Systems, 2020*, 4152049. doi:10.1155/2020/4152049

Dobrow, R. P. (2016). *Introduction to Stochastic processes with R* (2nd ed.). USA.: John Wiley & Sons, Inc.

Edem, I. E., Oke, S. A., & Adebiyi, K. A. (2018). A novel grey–fuzzy–Markov and pattern recognition model for industrial accident forecasting. *Journal of Industrial Engineering International, 14*(3), 455-489. doi:10.1007/s40092-017-0236-4

Faraway, J., & Chatfield, C. (1998). Time series forecasting with neural networks: a comparative study using the airline data. *Applied Statistics 47*, 231-250.

Ganesan, K., Annamalai, U., & Deivanayagampillai, N. (2019). An integrated new threshold FCMs Markov chain based forecasting model for analyzing the power of stock trading trend. *Financial Innovation, 5*(1), 35. doi:10.1186/s40854-019-0150-4

Ghedira, A., Kammoun, K., & Saad, C. (2018). Temporal Analysis of Road Accidents by ARIMA Model : Case of Tunisia. *International Journal of Innovation and Applied Studies, 24*, 1544-1553.

Gov.UK. (2020). Statistical data set Fire statistics data tables. Available from Gov.UK Retrieved 24th September, 2020 from https://www.gov.uk/government/statistical-data-sets/fire-statistics-data-tables

Javedani Sadaei, H., & Lee, M. H. (2014). Multilayer Stock Forecasting Model Using Fuzzy Time Series. *The Scientific World Journal, 2014*, 610594. doi:10.1155/2014/610594

Kriesel, D. (2010). *A brief introduction to neural networks* Retrieved 14 August, 2020 from http://www.dkriesel.com/en/science/neural_networks

Lan, J.-y., & Zhou, Y. (2014). Application of Gray Markov SCGM1,1c Model to Prediction of Accidents Deaths in Coal Mining. *International Scholarly Research Notices, 2014*. doi:10.1155/2014/632804

Lewis, N. D. (2018). *Deep Time Series Forecasting With Python Predict the Future with MLPs, CNNs and LSTMs in Python* (pp. 557). Retrieved 10 September, 2020 from https://machinelearningmastery.com/deep-learning-for-time-series-forecasting/

Liu, J., Youmin, H., wu, b., Wang, Y., & Xie, F. (2017). A Hybrid Generalized Hidden Markov Model-Based Condition Monitoring Approach for Rolling Bearings. *Sensors, 17*. doi:10.3390/s17051143

MacLeod, C. (2013). *An introduction to practical neural networks and genetic algorithms for engineers and scientists*. Jerhi Wahyu Fernanda, 157.

Makridakis, S., Spiliotis, E., & Assimakopoulos, V. (2018). Statistical and Machine Learning forecasting methods: Concerns and ways forward. *PLOS ONE, 13*(3), e0194889. doi:10.1371/journal.pone.0194889

Malysa, T. (2020). Use of Selected Adaptive Models to Forecast Accidents During the Repair, Maintenance, Installation of Machines and Equipment. *Multidisciplinary Aspects of Production Engineering, 3*(1), 141-149. doi:doi:10.2478/mape-2020-0012

Manaloto, R., & Balahadia, F. (2017). *Time series forecasting using multiplicative model: A predictive model for fire risk in the city of Manila.* Paper presented at the IEEE 15th Student Conference on Research and Development (SCOReD), Universiti Teknologi PETRONAS (UTP), Malaysia. 115-120.

Mapuwei, T. W., Bodhlyera, O., & Mwambi, H. (2020). Univariate Time Series Analysis of Short-Term Forecasting Horizons Using Artificial Neural Networks: The Case of Public Ambulance Emergency Preparedness. *Journal of Applied Mathematics, 2020*, 1-11. doi:10.1155/2020/2408698

Mock, C. N., Nugent, R., Kobusingye, O., & Smith, K. R. (2017). *Injury prevention and environmental health* (Vol. 7). Washington, USA: World bank Group.

Pabuçcu, H. (2017). Time series forecasting with neural network and fuzzy logic (pp. 195-204).

Pardo, M. J., & de la Fuente, D. (2010). Fuzzy Markovian decision processes: Application to queueing systems. *Computers & Mathematics with Applications, 60*(9), 2526-2535. doi:https://doi.org/10.1016/j.camwa.2010.08.004

Ratnayaka, R. M. (2017). *Factors Affecting Industrial Accidents: Empirical Evidence from Manufacturing Setting.* Paper presented at the Confronting Development Challenges through Promoting Innovative Management Thinking"

Proceedings of the 6th International Conference on Management and Economics. University of Ruhuna, Sri Lanka. , University of Ruhuna, Sri Lanka. 299-318.

Sánchez-Sánchez, P., García-González, J., & Coronell, L. (2020). Encountered Problems of Time Series with Neural Networks: Models and Architectures.

Sarkar, S., Vinay, S., Raj, R., Maiti, J., & Mitra, P. (2019). Application of optimized machine learning techniques for prediction of occupational accidents. *Computers & Operations Research, 106*, 210-224. doi:https://doi.org/10.1016/j.cor.2018.02.021

Shi, B., Hu, C. H., Yu, X. H., & Hu, X. X. (2016). New fuzzy neural network–Markov model and application in mid- to long-term runoff forecast. *Hydrological Sciences Journal, 61*(6), 1157-1169. doi:10.1080/02626667.2014.986486

Shmueli, G. (2011). To Explain or to Predict? *Statistical Science, 25*(3), 289–310. doi:10.1214/10-STS330

Svs, R. (2018). Prediction of fatal accidents in Indian factories based on ARIMA. *Production Engineering Archives, 18*, 24-30. doi:10.30657/pea.2018.18.04

Tu, J. V. (1996). Advantages and disadvantages of using artificial neural networks versus logistic regression for predicting medical outcomes. *Journal of Clinical Epidemiology, 49*(11), 1225-1231. doi:https://doi.org/10.1016/S0895-4356(96)00002-9

Urrutia, J., Villaverde, S., Algario, N., Malvar, R., Oliquino, A., & Gano, L. (2018). Forecasting the Number of Fire Accidents in the Philippines through Multiple Linear Regression. *Indian Journal of Science and Technology, 11*, 1-7. doi:10.17485/ijst/2018/v11i20/123341

Voyant, C., Muselli, M., Paoli, C., & Nivet, M.-L. (2011). Optimization of an artificial neural network dedicated to the multivariate forecasting of daily global radiation. *Energy, 36*(1), 348-359. doi:https://doi.org/10.1016/j.energy.2010.10.032

Wang, L., Mehrabi, M., & Kannatey-Asibu, E. (2002). Hidden Markov Model-based Tool Wear Monitoring in Turning. *Journal of Manufacturing Science and Engineering-transactions of The Asme - J MANUF SCI ENG, 124*. doi:10.1115/1.1475320

Wilinski, A. (2019). Time series modeling and forecasting based on a Markov chain with changing transition matrices. *Expert Systems* *with Applications, 133*, 163-172. doi:https://doi.org/10.1016/j.eswa.2019.04.067

Xiaoping, Z., & Liu, M. (2009). An overview of accident forecasting methodologies. *Journal of Loss Prevention in The Process Industries - J LOSS PREVENT PROC IND, 22*, 484-491. doi:10.1016/j.jlp.2009.03.005

Yarmohammadi, M., & Safaei, M. (2012). Markov Switching Models for Time Series Data with Dramatic Jumps.

Zhan-li, M. A. O., & Sun, J. (2011). Application of Grey-Markov Model in Forecasting Fire Accidents. *Procedia Engineering, 11*, 314-318. doi:10.1016/j.proeng.2011.04.663

Zhang, Y., Qu, H., Wang, W., & Zhao, J. (2020). A Novel Fuzzy Time Series Forecasting Model Based on Multiple Linear Regression and Time Series Clustering. *Mathematical Problems in Engineering, 2020*, 9546792. doi:10.1155/2020/9546792

CHAPTER 4

Ergonomics/Human Factors Training and Research in Nigeria: Early years and Current Efforts

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Abstract

This chapter gives an overview of one early career training and development as an ergonomics / human factors specialist, and provides an overview of research in Nigeria. Guides for the future of ergonomics as a course of study and area of specialism in Industrial Engineering are provided.

1. Introduction

The industrial revolution saw the rapid development of manufactured machines and production systems as well as the introduction of several consumer products that made living more interesting and bearable. For production and work systems, the main objective was to realise working prototypes of physical machinery. Once in service, the need to improve the efficiency of the systems soon arose, mainly for economic reasons. The work activities of the human operator, considered to be components of the production systems, were subject to analysis and strict control (Industrial engineering). However, while the analysis later demonstrated improved economic value, a considerably high number of work-related accidents and worker deaths also tended to be recorded. The initial effort to understand the causes of these incidents and minimise their occurrences contributed to the development of the ergonomics as an engineering discipline.

This chapter provides first, an overview of my early interactions with Professor O.E. Charles-Owaba and my training and development as an ergonomics/human factors specialist. Secondly, it provides an overview of ergonomics and human factors research in Nigeria, from three main perspectives:

i. The current research focus, i.e., domains of ergonomics application and issues being studied.
ii. Utility of the findings for solving human performance problems, within industrial and social work settings.
iii. Effective development of ergonomics practice and research.

2. Interactions with Professor Charles-Owaba, training and development

2.1 Initial career development

Having graduated with B.Sc. (Hons) degree in Mechanical engineering, I was convinced to pursue specialist ergonomics training after I was faced with a "fit the product to the person" type design problem, which defied my engineering design knowledge and understanding, and became clear after I stumbled and read the classic textbook "Human factors in engineering and design" by McCormick and Sanders (1982). The problem was design and construction of a consumer golf clubs cart. At this time, I was employed at Ogun State Polytechnic (Now Moshood Abiola Polytechnic), Abeokuta as a lecturer and took on the project as a private venture.

My quest to pursue further studies in the subject area led me to the department of Industrial and Production Engineering, University of Ibadan (UI), to enquire about registering for the M.Sc. Industrial Engineering course, as ergonomics was identified as a specialist component of the course. Professor O.E. Charles-Owaba was the Head of Department at the time (1987). He gave me more detailed insights about the ergonomics components of the M.Sc. course, including how I could best develop myself in the subject area. The clear and detailed explanation that he provided encouraged me to register for the course. One module of the course that I found most interesting was Systems Engineering, which presents ideas that are relevant to any work systems (engineering, social, medical, etc.). In simple terms, the system thinking supposes that every system (engineering, social, medical, economic, etc.) consists of two or more interconnecting elements that influence one another to determine the final state(s) of the system. Best control is gained through understanding of the inter-element influences. This thinking, I later discovered, is a key foundation to the development of the science of ergonomics.

On successful completion of the M.Sc. course, I joined the department at the University as a Lecturer II in 1990 and two years later, started on the Ph.D. programme with focus on human factor engineering research under the supervision of Professor Charles-Owaba. As part of my lecturing role, I led the supervision of ergonomics related undergraduate projects, including:

- Anthropometer design and construction
- Maintenance manpower requirement in a depressed economy
- Ergonomic investigation of an industrial task in relation to the time study
- Anthropometric relationship between industrial workers and workplace-Case study
- Visual abilities of people under different lighting conditions: A comparative study
- Analysis of work procedures in workshop settings, e.g. auto-repairs.

The elements of my Ph.D. research included design / construction of anthropometric instrumentation, development of anthropometric databases and ergonomics - based procedures for assessment / evaluation of equipment, products and workplace designs. In those days, there were very few ergonomics text books available in Nigeria bookshops and few persons with working knowledge of ergonomics on ground. Also, as the special options of the M.Sc. course were not yet on offer, I visited other faculties to register for and attend courses which my supervisor had identified as relevant to the line of research (e.g. Statistical Methods, Human Kinetics, etc). The consequence was that my research progressed quite slowly. Notwithstanding however, under the research study, and with my supervisor's support, I secured a university research grant and undertook an anthropometric survey of female hands in relation to design and use of some traditional farming and food processing tools. I was also able to interact with lecturers in the other faculties whose interests included ergonomics.

2.2. Further training and career development

The slow pace of the research, though personally frustrating, became a catalyst to look for opportunities abroad where the subject was more developed and I proceeded to the University of Nottingham to pursue the M.Sc. Human Factors in Manufacturing Systems programme, and a Ph.D. degree in ergonomics. These study programmes gave me a good grounding in the systems engineering analysis concept underlying the ergonomics discipline, more appreciation of risk assessment principles and developed my research ability to investigate and identify solutions to ergonomics - related engineering and social problems. I noted that though the course was offered in an engineering faculty, it was a unique postgraduate programme with little or no input from the other engineering departments in the faculty other than to deliver modules as designed. This structure encouraged us as students to de-emphasise thinking gained from our primary previous disciplines (e.g. engineering, psychology, etc) and adopt the unique ergonomics approach.

3. Overview of ergonomics research in Nigeria

3.1. Identification of literature for review

Studies were identified through web-based searches using the Google and Google Scholar engines, using the following key words: Ergonomics, Awareness, Practice, and Nigeria. Sixty studies were selected and were mainly published research articles / papers. The studies are listed in Appendix.

3.2.Findings

Majority of the studies (n=34) were published between 2013 and 2016, ten between 2000 and 2012, and sixteen of the studies were published between 2017 and 2020.

3.2.1. Affiliation of authors, stage settings and issues of the studies

The distribution, according to affiliation of the authors, is presented in Table 1, and the distribution, according to stage setting, is illustrated in Figure 1. The specific issues addressed are presented in Table 2

The authors of majority of the studies had engineering affiliations (n=24); nine studies had authors with management science affiliations, and fourteen studies with health science (Table 1).

Table 1 Distribution of the studies retrieved according to affiliation of the authors.

Researcher affiliation	*Frequency*
Engineering	24
Health Sc.	14
Management Sc.	9
Education	4
Computer Sc.	3
Forestry/Env Sc.	3
Library Sc.	3

Stage setting here refers to the focus (i.e. main issues addressed) of studies in relation to humans in work situations: object / thing, human conditions, and work method / task. In the main, the focus of the ergonomist is work method / task and optimising human performance in the process, which consequently requires that the object / thing and human condition are also addressed. Engineers tend to focus on objects / things, i.e., physical artefacts (e.g. hand tools, work machines, furniture, software programmes, etc.) and achieving a functional objective. Practitioners in most other career groups (health-care providers, psychologists, sociologists, educators, etc.) are generally concerned with the human conditions and how this can be changed to improve human performance.

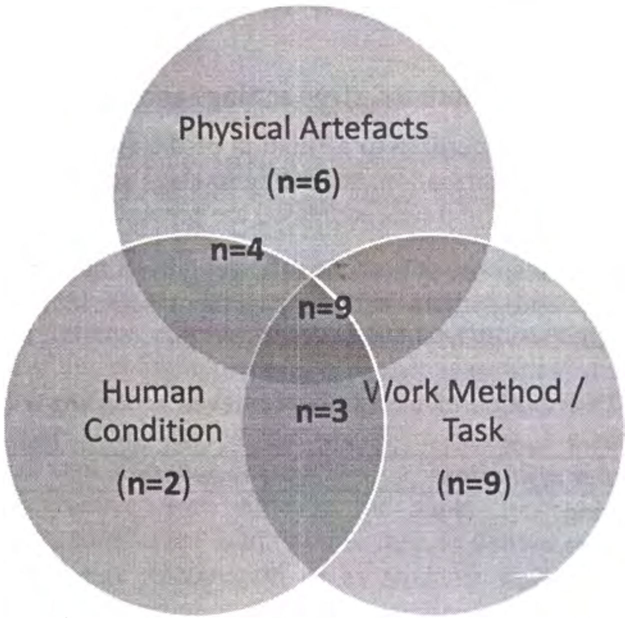

Figure 1: Distribution of the studies according to the main issues (focus)

Only nine of the studies include consideration for work method / task, which was mainly as a generic activity, or in terms of job designation (Figure 1). Asaolu and Itsekor (2014), for example, obtained information from library staff concerning ergonomics design of the computer workstations (item / object), which included recording of total time and time spent before taking a break from working on the computer (work method / task) and Musculoskeletal Disorders (MSD) type symptoms experience while working (Human conditions). Labeodan and Olaseha (2012) surveyed a group of secretarial staff at a university about their awareness / level of knowledge of computer ergonomics (human conditions), and use (work method / task) of computers (thing / object). Use of computer was evaluated in terms of hours spent daily and tasks performed.

Across the studies, prevalence and nature of musculoskeletal and disorders suffered by workers (and the workplace hazards) and awareness/level of implementation of interventions and policies were the most investigated issues, n=33 and n=32 respectively (Table 2). Workstation design, furniture design (including anthropometric data considerations), and working conditions / environment, were each addressed by an appreciable number of studies (n=23, n=18, n=10 respectively). None of the studies was specifically concerned with understanding the work task.

Table 2: Distribution of the studies according to physical artefacts, human condition, work method/task.

Issues investigated	*Frequency*
Physical artefacts (Thing/object)	
• Workstation design	23
• Work conditions	18
• Furniture design	10
• Machine/Equipment design	8
• Sustainable development	2
• Curriculum design	2
• Labour regulation/compliance	1
Human condition	
• Musculoskeletal disorders-MSD	33
• Awareness/implementation	32
• Training & competence	3
• Energy demands of work	2
• Visual acuity	1
• Job satisfaction	1
• Motivation	1

• Heat stress	1
Work method/task	
• Use of PPE	5
• Human computer work/human machine work	6
• Participatory intervention	3
• Situation awareness	1
• Manual handling-carrying, patient	1
• Job role-causal worker, designer	1
• Knowledge management	1

3.2.2. Methodologies applied

The distribution of the studies according to the methodology applied and main issues investigated is presented in Table 3.

Table 3 Distribution of the studies according to the applied methodology

Applied methodology	*Frequency*
Field survey (FS)	17
Cross-section (CS)	24
Literature review (LR)	5
Mixed-CS and FS	13
Mixed-CS and LR	1

Majority of the studies applied cross-sectional methodologies (n=24); seventeen studies applied field surveys, five studies were literature reviews and thirteen studies involved both field study and cross-section methodologies. Field studies generally enable the most reliable results compared to cross-sectional and reviews, particularly when quantitative measures of observed phenomena are obtained.

3.3.Discussion

3.3.1 Current focus of research

All the studies reviewed were published post 2000 and majority were post 2012. Secondly, prevalence and nature of MSD, awareness / level of implementation, workstation design, and/or working conditions / environment, was the focus of the majority of studies. Only few studies addressed organisational and cognitive issues such as Training & competence, Job satisfaction, Motivation, and situations. These observations suggested growing interest across Nigeria in ergonomics as a researchable subject (studies from the three main regions were found), and that much of the ergonomics related research is centred on the physical domain of application and characterising awareness. This also is not surprising as many work activities being undertaken are done at specific work stations and / or generally require physical effort. However, in spite of the general physical nature of many work activities undertaken in Nigeria industry sectors, organisational and cognitive issues need to be given greater prominence.

3.3.2 Utility of the findings for human performance problems

With respect to providing solutions to human performance problems, research findings need to have been generated from studies that included investigation of specific aspects of a task performance, and / or provide clear insights about performance by user trials. Less than a third of the studies reviewed (n=18) included consideration for work method / task in one form or the other; 12 of these studies applied cross-sectional methodologies, which only enable associations between variables to be established and not causal relationships. Furthermore, work method/task was often investigated in qualitative terms, e.g., workers' job roles or designated office, underlying management policy (compliance with labour standards/regulations, sustainability), and as a generic activity. The studies that included quantitative investigations were generally focused on one specific feature e.g. work posture, pattern of performance (time spent) and the impact of the task on the worker. Such studies provide only broad (non-specific) insights about tasks. In view of the fact that majority of the studies were about structural fit of workplaces or equipment to workers, and/or the human physical condition effects of work, the indications are that the findings have limited utility for solving human performance problems.

3.3.3. Towards a research and agenda

Majority of the studies approached the problem addressed as "a fitting the task to the man issue" (Grandjean, 1998) with bias towards the disciplines of the authors. This is seen in the fact that majority of the studies were undertaken by researchers with engineering, medical science, management sciences and education affiliations, and they mainly concerned themselves with issues related to the physical work equipment, machinery and environments, and the human condition. None of the studies was focused on work method / task.

In view of the summary given above, two factors that will need to be addressed for effective development of the ergonomics discipline, particularly when it sits in an engineering department, are:

- A functional / operational definition; and
- The uniqueness.

The definition and characteristics of ergonomics
Wojciech Jastrzębowski coined the word 'ergonomics' in 1857 in his book "An outline of Ergonomics, or the Science of Work" (Zunjic, 2017). He derived the term from the Greek words: *Ergon* (work) and *Nomos* (laws) to indicate it as a science. Since then, various operational definitions have been proffered to characterise ergonomics as a professional discipline (for example: Grandjean, 1998; Wilson, 2000; Karwowski, 2012; Dempsey et al., 2006; Zunjic, 2017). Dempsey et al. (2006) noted that the breadth of the field could be considered constrained because the "Ergo" of ergonomics means work. According to the authors, while many people may indeed limit "work" to mean activities associated with employment. The term "work" can however be interpreted broadly to include most types of activities that humans do, e.g. recreational sports

and social interactions. Wilson (2000) considered that ergonomics should be regarded as one of the first truly multi-, inter- and cross-disciplinary subjects that the world requires if we are to understand and improve the lives of people and societies going into the 21st century. Five common characteristics of most of the definitions proffered are:

- Focus on solving human performance problems
- Interactions between humans and the work environment
- Design related-provides information about humans and conceptual models of artefacts
- Systems-oriented
- Holistic approach

A clear and unambiguous definition of ergonomics is therefore needed to guide its practice and development in Nigeria, and to which all practitioners should ascribe.

The engineering content and uniqueness

As ergonomics is concerned with accomplishment of tasks and thereby is human centred, the discipline has drawn on knowledge from non-engineering (human centred disciplines) such as psychology and human biology, and developed its own set of rules and investigation procedures which do not follow usual engineering protocols. However, having originated from engineering (industrial and manufacturing engineering particularly), the discipline is often practiced by engineers and sits within engineering departments of universities. The fact that ergonomics is a design related discipline means the practitioners exercise a range of skills for effective practice, which are shared with engineering. It is the exercise of such skills, particularly logical reasoning and systems approach to problem solving, that qualify the discipline to continue under the engineering banner.

However, being multi-disciplinary in nature, ergonomics is uniquely different from engineering in how these skills are applied. The practitioners and researchers need to ensure that, while they seek to solve one problem, they are not inadvertently introducing new problems. For example a researcher who sets out to provide structurally fitting work furniture may introduce new health and safety related problems if consideration is not given to behaviour during work. This demonstration should be the basis of all research projects undertaken.

4. Conclusions

The current ergonomics research in Nigeria seems to be focused on structural fit of furniture, workstation, work environment and how the human condition is affected. Other issues, such as organisational (training & competence, job satisfaction, motivation) issues and cognitive issues (situation awareness, perception and interpretation of information) have received much less attention. Thus, much of the findings from the current research have limited utility for solving human performance problems. For ergonomics to grow with impacting effect in Nigeria, departments housing the discipline in universities and colleges need to consider making it an independent postgraduate training unit (M.Sc. and Ph.D.) with its own defined courses. Offering ergonomics as a sub-specialism of a mainstream discipline (industrial engineering, for example) at best helps to produce engineering graduates with knowledge of ergonomics (frontline practitioners), and not specialist ergonomist (strategic developers and thinkers). As a starting point, a clear and unambiguous definition of ergonomics is needed to guide the practice and development for Nigeria, and to which all practitioners and researcher should ascribe.

Training at tertiary level (Masters and above) should be such that the systems thinking is exercised as the norm; students need to be encouraged to de-emphasise thinking in the context of their primary previous ddisciplines (e.g. engineering, psychology) and adopt the unique multidisciplinary approach of the ergonomics discipline.

5. References

Asaolu, A.O. & Itsekor, V., (2014). Ergonomic computer workstation considerations for library staff. International Journal of Academic Library and Information Science, 2(3), pp.22-26.

Dempsey, P. G., Wogalter, M. S., & Hancock, P. A. (2006). Defining ergonomics/human factors. International encyclopedia of ergonomics and human factors, 2nd edn. London: Taylor and Francis, 32-5.

étienne Grandjean. (1988). Fitting the Task to the Man: A Textbook of Occupational Ergonomics. Taylor & Francis.

Karwowski, W. (2012). The discipline of human factors and ergonomics. Handbook of human factors and ergonomics, 4, 3-37.

Labeodan, T.A. & Olaseha, I.O., (2012). Knowledge of Computer Ergonomics among Secretarial Staff in a Nigerian University Community. International Journal of Health, Wellness & Society, 2(3).

McCormick, E. J., & Sanders, M. S. (1982). Human factors in engineering and design. McGraw-Hill Companies.

Wilson, J. R. (2000). Fundamentals of ergonomics in theory and practice. Applied ergonomics, 31(6), 557-567.

Zunjic, A. (2017). A new definition of ergonomics. IETI Transactions on Ergonomics and Safety, 1(1), 1-6.

APPENDIX

AbdulHafeez, I. and Smallwood, J., (2017). Adoption of Construction Ergonomic Interventions on Building Construction Sites in Nigeria. In International Conference on Applied Human Factors and Ergonomics (pp. 124-133).

Adedeji, G.A., Aiyeloja, A.A. & Nwosu, U.J., (2016). Ergonomic evaluation and labour inspection in cluster-sawmill in Port Harcourt, Nigeria. Pro Ligno, 12(2).

Adeodu, A.O., Daniyan, I.A. & Adaramola, O.O., (2014). Anthropometry as ergonomic consideration for hospital bed design in Nigeria. International Journal of Scientific & Engineering Research, 5(5), pp.1-8.

Adeyemi, A.O., (2009). Case study of ergonomics awareness among library staff of two universities in South-Western Nigeria. IFE PsychologIA: An International Journal, 17(1), pp.243-253.

Adje, M., Odebiyi, D.O., Okafor, U.A. & Kalu, M., (2018). Ergonomic principles in patient handling: Knowledge and practice of physiotherapists in Nigeria. Work, (Preprint), pp.1-8.

Adum, A.N., Ebeze, U.V., Ekwugha, U.P. & Okika, C.C., (2016). Opinion poll on Nigerian university students awareness of the health implications of inadequate ergonomic furniture in universities of south-east Nigeria. Communication Panorama: African and Global Perspectives Volume 2 Number 1.

Ahmad, H. I., Ahmad, D., Suleiman, D., & Aziz, S. (2015). Anthropometric Parameters of Tractor Operators in Kano State, Nigeria. Journal of Agricultural Engineering and Technology, 23(1), 83-95.

Ajayeoba, A.O., Oladosu, K.O., Adekoya, L.O. & Olajimi, A.O., (2016). Ergonomics evaluation and establishment of suitable classroom furniture design specifications for secondary school children in south-west Nigeria. Innovative System and Design Engineering, 7(3), pp.15-19.

Ajayi, O. & Thwala, W.D., (2015). Developing an integrated design model for construction ergonomics in Nigeria Construction Industry. African Journal of Applied Research (AJAR), 1(1).

Ajimotokan, H.A. (2009). The Effects Of Coupling Repetitive Motion Tasks With A Manually-Stressed Work Environment. Researcher, 1(2), 37-40.

Asaolu, A.O. & Itsekor, V., (2014). Ergonomic computer workstation considerations for library staff. International Journal of Academic Library and Information Science, 2(3), pp.22-26.

Ashiedu, F. & Amiebenomo, S.O., (2013). Investigation into the applications of ergonomic principles in the design of school furniture in Nigeria. Journal of Emerging Trends in Engineering and Applied Sciences, 4(1), pp.35-37.

Bello, S. R., & Okelola, F. (2009). Assessment of work environment in small scale rice mills: a case study of Ivo LGA, Ebonyi State. Pdf available on-line.

Chedi, J.M. & Mustapha, R., (2020). Biomechanics, visual and carrying discomfort: The role of ergonomics among technology education professionals on the use of laptop in no-desk settings. In Journal of Physics: Conference Series (Vol. 1456, No. 1, p. 012014). IOP Publishing.

Chedi, J.M. & Mustapha, R., (2020). Development of a new ergonomics-based technology education curriculum for Nigerian universities: needs analysis. In Journal of Physics: Conference Series (Vol. 1516, No. 1, p. 012044). IOP Publishing.

Dunmade, E.O., Adegoke, J.F. & Agboola, A.A. (2014). Assessment of ergonomic hazards and techno-stress among the workers of Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. Australian Journal of Business and Management Research Vol, 4(1), pp.27-34.

Eze, B.I., Okoye, O. & Aguwa, E.N., (2015). Awareness and utilization of welders' personal protective eye devices and associated factors: Findings and lessons from a Nigerian population. Workplace Health & Safety, 63(4), pp.170-178.

Ezugwu, U.A., Egba, E.N., Igweagu, P.C., Eneje, L.E., Orji, S. & Ugwu, U.C., (2020). Awareness of Awkward Posture and Repetitive Motion as Ergonomic Factors Associated With Musculoskeletal Disorders by Health Promotion Professionals. Global Journal of Health Science, 12(6).

Fajobi, M.O., Awoyemi, E.A. & Onawumi, A.S., (2016). Ergonomic Evaluation of Hospital Bed Design and Anthropometric Characterization of Adult Patients in Nigeria. International Journal of Scientific & Engineering Research, 7, 8, 640-651.

Fajobi M.O., Onawumi, A.S., Mfon, U.M.O. & Awoyemi E.A. (2019). Mismatch between Anthropometry Characteristics of Nigerian Occupational Bus Drivers and the In-Vehicle Measurement. Covenant Journal of Engineering Technology, 3(1), 20-37.

Gambo, A., (2017). Implication for office environment ergonomic intervention: a study of local government offices in Katsina state of Nigeria. M.Sc. Dissertation, Faculty of Mechanical Engineering (FKMP) Universiti Tun Hussein Onn Malaysia.

Gambo, A., (2020). Themes and perspectives in office ergonomics: implication for safety, health and workers' productivity in Katsina state local government offices in Nigeria. International Journal of Politics, Publics Policy and Social Works (IJPPSW), 2 (4), 01-16.

Gambo, A., Wee, S.T. & Mohamed, S., (2017). Creating Office Ergonomic Awareness among the Staff of Katsina State Local Government Offices in Nigeria: A Viable Strategy for Reducing the Prevalence of Work Related Musculo-Skeletal Disorders. International Journal of Research & Review, 31, 4, 1; 31-48.

Godwin, H.C. & Ndubueze, D.U., (2013). A survey on the prevalence of musculoskeletal disorders among building construction workers in Anambra state. Int J Adv Engg Tech/IV/IV/Oct-Dec, 11, p.15.

Ibrahim, A., Tasiu, M. & Abubakar, A.D., (2017). An assessment of adoption of ergonomic practices among selected craftsmen on building construction sites in Nigeria. In Joint CIB W099 & TG59 International Safety, Health, and People in Construction Conference (p. 210).

Ikonne, C.N. (2014). Influence of Workstation and Work Posture Ergonomics on Job Satisfaction of Librarians in the Federal and State University Libraries in Southern Nigeria. IOSR Journal of Humanities And Social Science (IOSR-JHSS), Volume 19, Issue 9, Ver. IV. PP 78-84.

Ikubanni, P.P., Akande, K.A. & Agboola, O.O., (2017). Application of anthropometric approach in lessening disorders and stress-related issues. Kathmandu University Journal of Science, Engineering and Technology, 13(1), pp.45-55.

Ismaila, S. O., Adogbeji, V. O., Kuye, S. I., Ola, I. A., & Banmeke, T. O. (2014). Estimation of heat dissipated during mounding operation in farming. Leonardo El J Pract Technol, 24, 73-82.

Ismaila, S.O. & Samuel, T.M., (2014). Human-centered engineering: the challenges of Nigerian engineer. Journal of Engineering, Design and Technology, 12(2): 195 - 208.

Ismaila, S. O., Kuye, S. I., Ola, I. A., & Banmeke, T. O., (2015). Ergonomic evaluation of manual hoe for ridging and mounding operations in farming. Annals of the Faculty of Engineering Hunedoara, 13(1), 199.

Ismaila, S.O., Akanbi, O.G., Oderinu, S.O., Anyanwu, B.U. & Alamu, K.O., (2015). Design of ergonomically compliant desks and chairs for primary pupils in Ibadan, Nigeria. J Eng Sci Technol, 10(1), pp.35-46.

Kolawole, A., Ikubanni, P., Adeleke, A., Agboola, O., & Alebiosu, A. (2019). Comparative analysis of anthropometric data of Hausas in northern and southern Nigeria. Journal of Applied Engineering Science, 17(2), 168-174.

Labeodan, T.A. & Olaseha, I.O., (2012). Knowledge of Computer Ergonomics among Secretarial Staff in a Nigerian University Community. International Journal of Health, Wellness & Society, 2(3).

Kolawole, A., Ikubanni, P., Adeleke, A., Agboola, O., & Alebiosu, A. (2019). Comparative analysis of anthropometric data of Hausas in northern and southern Nigeria. Journal of Applied Engineering Science, 17(2), 168-174.

Numan, A. I., Idris, M. O., Zirahei, J. V., Amaza, D. S., & Dalori, M. B. (2013). Prediction of stature from hand anthropometry: A comparative study in the three major ethnic groups in Nigeria. Journal of Advances in Medicine and Medical Research, 1062-1073.

Nwaogazie, I.L., Umeadi, K.K. & Bovwe, O. (2016). Ergonomics Workstation Assessment of Musculoskeletal Disorders in University of Port. International Journal of Tropical Disease & Health, 20(4): 1-14.

Nwaogazie, I.L., Omuruka, T.C. & Adaramola, S. S., (2016). Work-Related Musculoskeletal Disorders: A Case of Office-Based Civil Servants in Rivers State, Nigeria. International Journal of Tropical Disease & Health, 18(1): 1-13.

Obi, O. F., Ugwuishiwu, B. O., & Adeboye, B. S. (2015). A survey of anthropometry of rural agricultural workers in Enugu State, south-eastern Nigeria. Ergonomics, 58(6), 1032-1044.

Obi, O. F. (2015). The role of ergonomics in sustainable agricultural development in Nigeria. Ergonomics SA: Journal of the Ergonomics Society of South Africa, 27(1), 33-45.

Obi, O. F., (2016). Hand anthropometry survey of rural farm workers in south-eastern Nigeria. Ergonomics, 59(4), 603-611.

Odebiyi, D.O., Olawale, O.A. & Adeniji, Y.M., (2013). Impact of Computer Related Posture on the Occurrence of Musculoskeletal Discomfort among Secondary School Students in Lagos, Nigeria. Nigerian quarterly journal of hospital medicine, 23(4), pp.237-242.

Odunaiya, N. A., Owonuwa, D. D., & Oguntibeju, O. O. (2014). Ergonomic suitability of educational furniture and possible health implications in a university setting. Advances in medical education and practice, 5, 1.

Okafor, I.P., Odeyemi, K.A. & Dolapo, D.C., (2013). Knowledge of commercial bus drivers about road safety measures in Lagos, Nigeria. Annals of African medicine, 12(1), p.34.

Okafor, U.C., Awe, G.A., Oghumu, N.S., Adeniyi, A.C. & Sokunbi, G.O., (2018). Occupational Hazards: Awareness and Level of

Precautions Among Physiotherapists in Selected Health Institutions in Lagos, Nigeria. In Congress of the International Ergonomics Association (pp. 600-608).

Okoye, E.A., Ugbebor, J. & Adaramola, S., (2018). Assessing the Effectiveness of Ergonomics Practices in Selected Workplaces in Port Harcourt, Nigeria. In SPE Nigeria Annual International Conference and Exhibition. Society of Petroleum Engineers.

Olabode, S.O., Adesanya, A.R. & Bakare, A.A., (2017). Ergonomics Awareness and Employee Performance: An Exploratory Study. Economic and Environmental Studies, 17(44), pp.813-829.

Oladeinde, B.H., Ekejindu, I.M., Omoregie, R. & Aguh, O.D., (2015). Awareness and knowledge of ergonomics among Medical Laboratory Scientists in Nigeria. Annals of medical and health sciences research, 5(6), pp.423-427.

Olaitan, L., Oyerinde, O.O., Obiyemi, O. & Kayode, O.O., (2010). Prevalence of job stress among primary school teachers in South-west, Nigeria. African Journal of Microbiology Research, 4(5), pp.339-342.

Onawumi, A. S., K. A. Adebiyi, Fajobi FajobI, & Emmanuel Olusola OKE. (2016).Development of predictive models for some anthropometric dimensions of Nigerian occupational bus operators. European International Journal of Science and Technology 5, no. 5 (): 12-27.

Onawumi, A. S., & Oyawale, F. A. (2016).Ergonomic Survey of Commercial Motor-Cyclist in Nigeria. International Journal of Engineering and Science, 5(1), 53-58.

Sadiq, L. S. (2016). Assessing the Impact of Heat on Health and Productivity among Nigerian Farmers: A Review of Literature. Asia Pacific Environmental and Occupational Health Journal, 2(3).

Saidu, A.I., Utti, A.V., Jaiyesimi, A.O., Rufa'i, A.A., Maduagwu, M.S., Onuwe, A.H. & Jajere, M.A., (2011). Prevalence of musculoskeletal injuries among factory workers in Kano Metropolis, Nigeria.International journal of occupational safety and ergonomics, 17(1), pp.99-102.

Sambo, M.N., Idris, S.H. & Shamang, A., (2012). Determinants of occupational health hazards among roadside automobile mechanics in Zaria, North Western Nigeria. Borno Medical Journal, 9(1), pp.5-9.

Shiru, J.J., (2008). Ergonomic assessment of small scale mills in Niger state. In The Nigerian Academic Forum: A Multidisciplinary Journal (Vol. 14, No. 1-3, p. 142). National Association of the Academics.

Sumaila, F.G., Akinmoyede, R. & Gbirl, C.A.O., (2016). Knowledge of university lecturers about risk factors for neck pain in lecturing and prevention strategies. Occupational Health Southern Africa, 22(5), pp.13-16.

Tunmibi, S., Ijeoma, D. & Sanusi, B., (2012). The awareness and incidence of repetitive strain injuries in the computer graphic industries in Lagos state, Nigeria. In international conference on research, innovations and sustainable.

Uche, C.M. & Fanny, C.O., (2015). Educational Ergonomics in Higher Education Institutions in Nigeria. Makerere Journal of Higher Education, 7(2), pp.133-146.

Umoh, G.I. & Amah, E., (2013). Knowledge management and organizational resilience in Nigerian manufacturing organizations. Developing Country Studies, 3(9), pp.104-120.

Yekini, N.A., Adebari, F.A., Oloyede, A.O. & Sokunbi, M.A., (2015). Effects of Computer Ergonomics on Computer Engineering Sciences Students' Interest In Software Engineering, Computer Programming, And Overall Academic Performances. In Proceedings of the first Ibadan ACM International Conference on Computer Science Research and Innovations.

Yisa, M. G., (2002). IT—Information Technology and the Human Interface: Ergonomics of Tractors Assembled in Nigeria. Biosystems engineering, 81(2), 169-177.

CHAPTER 5

Some Developments In Scheduling Algorithms

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1.0 Introduction

It is widely acknowledged that time is a resource. Particularly in today's world, it is a critical metric of competitiveness. For designers of products and services the first to the market is key. When establishing production plans; the first to deliver is also key. The sequence of tasks is important in optimizing time metrics. Also, for effective deployment of resources, the start and finish times of the tasks in sequence aid in determining the schedules. In many respects, sequencing and scheduling are sometimes used interchangeably. While sequence represents the ordering of tasks, timetabling the sequence results in schedules. The use of time as a surrogate cost factor is due to the varied nature. Costs influencers are many but time is considered at the top of the leader board.

Work systems are replete with sequencing and scheduling examples. They are encountered in transport, computer, manufacturing, aviation, and banking systems among others. Even individual tasks and chores require that forethought be given to effective time management.

Deciding sequences and schedules to adopt can be confounding given the many combinations possible. The challenge of scheduling is how to sift through the many feasible schedules and make good choices in good time since time is a resource and metric of competitiveness.

Determining optimal sequences and hence schedules have preoccupied many researchers for decades. The challenge is in the manner in which real-life problems present. The problems may be encountered in varied settings such as :

a. Optimising single criterion
b. Optimising multiple criteria
c. Flow operations structures
d. Job shop operational structures
e. Single-channel inputs
f. Multi-channel inputs

These represent just a few of the settings, which sometimes could be a combination (hybrid).

With the COVID-19 pandemic and subsequent disruptions to supply chains, scheduling systems need re-examination to enable a reconfiguration for organisations to remain going concerns. This work is an attempt at reviewing the evolution of some scheduling solution approaches.

1.1 Exact and enumerative algorithms

Generally, solution methods for scheduling problems may be classified into two: Exact methods and approximation methods. In this section, the exact methods are discussed.
Exact methods are solution methods that can find an optimal solution to an optimization problem (of which scheduling problem is one). Exact methods have been found to always solve an optimization problem to optimality. The following solution methods may be classified under the exact methods:

1.1.1 Enumeration methods: Enumeration methods involve the complete listing of all the items in a collection. Also, it involves the listing of all of the elements of a given set. Enumeration methods are often used to solve combinatorial optimization problems such as scheduling of machines in production planning, aircraft rotation/crew

scheduling in airlines as well as transport routing/scheduling in logistics. Enumeration methods lead to lots of possible solutions with the difficulty of selecting and finding optimal solutions. The number of outputs of an enumeration method may be exponential in the size of the input.
Generally, enumeration methods may be classified into two: complete enumeration methods and incomplete enumeration methods.

1.1.1.1 Complete enumeration methods: Complete enumeration methods systematically consider all possible solutions. They are also called total or explicit enumeration methods. This method involves enumeration of all possible alternatives and a comparison of all of them to pick the best solution. Complete enumeration methods can be very expensive or even impossible for more complicated problems.

1.1.1.2 Incomplete enumeration methods: This can also be called an implicit or partial enumeration method. This method involves excluding parts of the solution space that are known to be sub-optimal.The method also involves the selection of alternatives by only considering parts of the solution space.This leads to a reduction in computation efforts because only the most promising solutions are often considered. Methods such as Branch & Bound (BB), and Dynamic Programming (DP) can be classified under implicit/incomplete enumeration methods.

1.1.2.2 Dynamic Programming method

Dynamic programming (DP) is a mathematical optimization method which breaks problems into smaller parts. It uses recursion to break and assemble them. The focus is mainly on simplification to enable traction. The method was developed by Bellman Richard around the 1950s. Although similar to divide and conquer in terms of the breakdown of the problem into smaller sub-problems; however in the DP method, the resulting sub-problems are not solved independently. The DP method remembers the results of the smaller sub-problems and then used the same for similar sub-problems. The dynamic programming approach is used to solve problems that can easily be divided into similar sub-problemsto re-usethe results obtained from these sub-problems.

In the dynamic programming method, referring to the output of the previous solution is cheaper (concerning CPU cycles) than re-computing it.The DPmethod avoids repeated work by remembering previous partial results.The DP approach trades space for time. This means that instead of calculating all the states thereby taking a lot of time but no space, space is taken up to store the results of all the sub-problems to save time later.

1.1.2.3 Branch and Bounds method

The branch and bound (BB) method is an enumeration technique in which schedules are discarded because they are worse off than established lower bounds. These could be single schedules or set of schedules. There are two important elements in the use of the branch and bound procedure. These are the search (branching) procedure and the bounding at nodes. The BB procedure, if well implemented, assures optimality (Oyetunji and Oluleye, 2008).

i. Search Procedures

There are two types of search procedures. These are depth-first and frontier search methods (French, 1982). The depth-first search procedure starts at the root node and explores the branches as far down as possible. They backtrack when better schedules are not feasible down the line. Essentially, it traverses the depths of the branch and uses a stack to determine the next vertex to begin a search, when improvements are infeasible (Fig. 1).

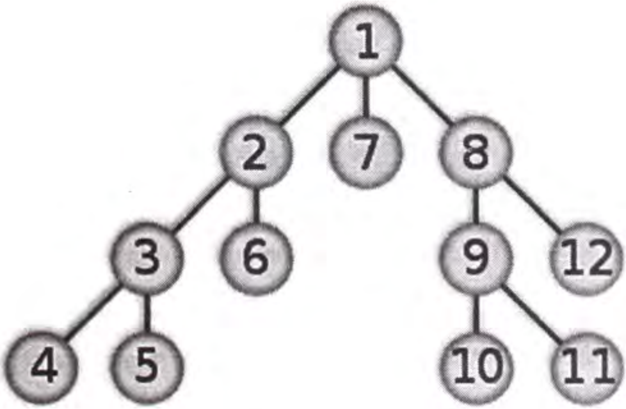


Fig. 1. Hypothetical search tree

On the other hand, the frontier search procedure is a novel approach applicable to wide classes of trade-offs between runtime and program size. Frontier search reduces the memory requirement by storing only the Open nodes while deleting closed nodes once they are expanded.

The depth-first procedure has the advantage of working with fewer variables at each node and thus requiring less storage while the frontier search procedure requires less calculations thereby obtaining solution quickly.

ii. Bounding

At every node, lower bounds must be computed for the objective function. The way the lower bound is obtained determines the efficiency of the branch and bound procedure. The lower bound gives an idea of what the value of the objective function is likely to be at the node. The typical way to develop a bound is to relax the original problem to an easily solvable problem. The relaxed problem solution bounds the original problem (Ólafsson, 2002). The lowestbound nodedetermines branches to be explored. When all the jobs have been assigned, the solution is the node with the lowest value.

1.1.3 Johnsons' 2-machines algorithm

Johnson's 2-machines algorithm is a method of scheduling jobs in two work stations or machines. Johnson's 2-machines algorithm seeks to find an optimal sequence of jobs to minimize makespan (the completion time of the last scheduled job). The rule also reduces the amount of idletime between two workstations. To apply Johnson's rule, the following conditions must be met:

i. Processing time ofeach job must be constant.
ii. Processing times of jobs must be mutually exclusive of the job sequence.
iii. All the jobs must be processed through the first work station before going through the second work station.
iv. All the jobs have the same priority.

Johnson's rule for the 2-machine problem can be described as follows:

Step 1: List all the jobs and their processing times on each machine.

Step 2: Select the job having the shortest processing time. If that processing time is on for the first machine, then schedule the job first. If that processing time is on the second machine then schedule the job last. Break the ties arbitrarily.

Step 3: Remove the scheduled job from the list of unscheduled jobs.

Step 4: Repeat steps 2 & 3until all the jobs have been scheduled.Johnson (1954)

Illustrating Johnson's 2-machine algorithm

Suppose we have a five-jobs two machines scheduling problem as shown in Table 1. Each of the five jobs needs to go through machine 1 and 2. We are required to find the optimum schedule of the jobs using Johnson's rule for a 2-machine problem.

Job Processing times (mins)		
Job	**Machine 1**	**Machine 2**
1	3.20	4.20
2	4.70	1.50
3	2.20	5.00
4	5.80	4.00
5	3.10	2.80

Solution

1. Since Job 2 has the smallest processing time (1.5 mins) and it is on machine 2, schedule job2 last.Remove Job 2 from the set of unscheduled jobs.

X	X	X	X	2

2. Job 3 has the next smallest processing time (2.20mins) and it is on machine 1, therefore schedule job 3 first.Remove Job 3 from the set of unscheduled jobs.

3	X	X	X	2

3. Job 5 has the next smallest processing time (2.80mins) and it is on machine 2, schedule job 5 last.Remove Job 5 from the set of unscheduled jobs.

3	X	X	5	2

4. Job 1 has the next smallest processing time (3.20 mins) and it is on machine 1, schedule job 1 first. Remove Job 1 from the set of unscheduled jobs.

3	1	X	5	2

5. Schedule the only remaining job (4) to the only available space.

3	1	4	5	2

So, the jobs must be processed in the order 3 → 1 → 4 → 5 → 2 and must be processed in the same order on the two machines.

1.1.4 Johnson's 3-machine algorithm

Johnson's 3-machine algorithm is similar to his 2-machine algorithm. Johnson extended his algorithm for the 2-machine problem to solve a variant of the 3-machine problem. Johnson (1954) considered a special structure case (i.e. problems in which the minimum processing time on the first or third machines is greater than or equal to the maximum processing time on the second machine).

Mathematically,

- The smallest processing time on machine 1 is greater than or equal to the largest processing time on machine 2, i.e.,

$$\text{Min } P_{i1} \geq \text{Max } P_{j2}, \forall i, j,$$

- The smallest processing time on machine 3 is greater than or equal to the largest processing time on machine 2, i.e.,

$$\text{Max } P_{j2} \leq \text{Min } P_{k3}, \forall j, k$$

At least one of the above two conditions must be met.

Where P_{tm}= processing time of t^{th} job on m^{th} machine.

When the above conditions hold, Johnson (1954) forms an artificial (machines a and b) 2-machine problem by letting

$P_{ia} = P_{i1} + P_{i2}$

$P_{ib} = P_{i2} + P_{i3}$

The artificial (2-machine) is solved by applying Johnson's 2-machinealgorithm.

1.2 Approximation algorithms

These are efficient algorithms that yield effective solutions to problems with provable guarantees on its closeness to the optimal one. The concept of complexity gives perspective on solution techniques concerning the computation requirements (Baker and Tritsch, 2013). The order-of-magnitude notation is used to measure the computational effort required by a solution method. For example, a scheduling problem of size ***m*** (*m*represents a quantum of information needed to specify the problem), the number of computations required by the algorithm is bounded by a function of ***m***. For example, if the function has an order of magnitude m^2, represented by $O(m^2)$, then the algorithm is polynomial. However, if the function is $O(2^m)$, the algorithm is nonpolynomial. For a function of the form,$O(2^m)$, it is called an exponential algorithm. Polynomial-time algorithms are more efficient than exponential-time algorithms given that the execution times grow rapidly with problem size.

Numerous scheduling problems in practice belong to a class of optimization problems called Non deterministic Polynomial time-complete (*NP-complete)* problems. For these classes of problems, no efficient solution has been established *(Weisstein, 2015).* A problem is NP if its solution can be estimatedand verified in polynomial time. Nondeterministic implies that no specific rule is adoptedfor the estimation. If two or more problems of the same class are NP and are polynomial-time reducible to each other, such problems are called NP-complete problems. Therefore, finding an efficient algorithm for a given NP-complete problem implies that an efficient algorithm can also be found for all other problems belonging to the same class since the problem can be restructured or modified to yield one another. However, many years of research in optimization has not yielded a single polynomial-time algorithm for problems in this class, and the surmise is that no such algorithm exists. This class of problem is thus called *NP-hard* (Non-deterministic Polynomial-time hardness) problems. Therefore, it is unlikely to obtain optimal solutions to NP-hard problems efficiently, i.e. by polynomial-time algorithms. An optimal solution can be found for an NP-hard problem either by complete enumeration or implicit enumeration techniques. In both cases, for real-life problems of practical interest, only small-sized problems can be solved due to the time complexity (exponential increased) involved. However, in real-life like industrial setting, production workshop, hospital, school among others where scheduling problems is a challenge, there is always the need to solve large problem-sized NP-hard problems. This practical importance necessitates relaxations to achieve tractability. A very fruitful approach has been to relax the notion of optimality and settle for an efficient and effective (or near-optimal) solution. It is desired that solutions be within a small multiplicative factor of the optimal value (approximation ratio). Approximation algorithms provide a provably good approximation ratioto the optimal. While there are numerous (good) approximation algorithms for several NP-Hard problems in the literature, scheduling problems of certain classes remain indistinguishablein the theory of NP-Completeness. They behave very differently when subjected to approximation algorithms (Brucker, 2007).

Furthermore, there exist numerous NP-hard scheduling problems thatrequire lesser time to execute the work in the workshop using approximation algorithms than to solve the problem optimally using the fastest available computing machine. Therefore, the reliance on approximation algorithms is often the rule in practice.Furthermore, the closeness of the generated solution (approximation ratio) of an approximation algorithm to the optimum is usually established analytically either in the worst-case or on the average (Akande, 2017).

Experimental analyses of heuristicsare usually through several runs (via simulation) against benchmarks.

Examples of approximation algorithms are dispatching rules, heuristics, and metaheuristics or evolution Algorithms.

Heuristics are constructive approximation algorithms that start with no jobs scheduled and gradually construct schedules by adding jobssystematically.Over the last four decades, sequencing and scheduling problems have been solved using heuristics in the form of dispatching or priority rules. The priority or position of a job in the schedule is determined by the job or machine parameter as well as the shop characteristics. Al- Harkan (2013) classified scheduling dispatching rules into local rules, global rules, static rules, dynamic rules among others. Several Dispatching rules have been developed, investigated, and implemented by researchers and practitioners. These include; The Shortest Processing Time (SPT) rule (Smith, 1956; Bansal and Kulkarni, 2015).Modified Due Date (MDD) rule (Baker and Bertrand, 1982; Naidu, 2002), HR9 and HR10 (Oyetunji and Oluleye, 2010), Heuristic AA (Akande, 2018) among others. Special structure problems have also been explored with the aim of using the features to converge to good solutions (Oluleye and Charles-Owaba (1999), Oluleye and Jolayemi, (2000)).

Furthermore, approximation algorithms that are initialized with a complete schedule with the exploration of systematic improvementsachieved by manipulating the current schedule are called metaheuristics or evolution algorithms. Some authors use heuristics and metaheuristics interchangeably.

1.3 Evolutionary Algorithms

Evolutionary Algorithms are based on computational intelligence. They are also called metaheuristics. Metaheuristics are designed to provide good solutions to optimization problems with limited computation capacity (Bianchi, *et al.*, 2009). Methods explorean existing schedule making improvements through manipulations of the optimization problem being solved (Blum and Roli, 2003). Much like heuristics, metaheuristics do not guarantee optimality though they yield better solutions over and above the initially selected schedule (seed).

Evolutionary Algorithms explore local search procedures. The desire is to find a better schedule in the neighborhood.. Two schedules are neighbours, if one can be obtained by modifying the other. The method is performed through iteration. Many neighborhood solutions are generated by modification of the current solution by iteration. The method of modifying the current solutions to form a new neighbor, the acceptance-rejection criterion as well as the termination of the iterations are the basis for the classification of metaheuristics. Examples of metaheuristics include Tabu Search (TS), Simulated Annealing (SA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Water Waves Optimization (WWO), League Championship Algorithm (LCA), and Variable Neighborhood Search (VNS) among others. (Interested readers can read more about different heuristics and metaheuristics approaches from the literature)

1.4 Some illustrative examples

Some selected algorithms are to be applied to some real-life/random problems

In this section, two scheduling problems; Single Machine Total Tardiness Problem (SMTTP) with zero release date and the Single Machine Total Flowtime Problem (SMTFP) with non-zero release date are considered. Some existing problems and the corresponding proposed heuristics found in the literature were explored.

1. Single Machine Total Flowtime Problem (SMTFP) with a non-zero release date

Problem Definition: Given a single machine scheduling problem with a set of n jobs with minimize of the total flowtime as a performance measure. It is assumed that the problem is deterministic and only one job can be processed at a time.For every job *Ji, parameters like the*release time, r_i the processing time p_i are known. Also,*the* start time denoted as $S_i$is given by:

$$S_i \geq \quad r_i \qquad (1)$$

Also, the completion time of each job (C_i) is defined as:

$$C_i = S_i + p_i \qquad (2)$$

The flow time of each job defined as the time the job spent in the shop is given as the difference between the completion time and the release date:

$$F_i = C_i - r_i \qquad (3)$$

Oyetunji (2009) defined the total flow time (F_{tot}) as

$$F_{tot} = \sum_{i=1}^{n} F_I = F_1 + F_2 + F_3 + \ldots + F_n \qquad (4)$$

For the problem of minimizing the sum of flowtime on a single machine with releasedatesOyetunji*et al*, (2012), proposed the KSA 1 heuristic. The steps are as follows:

KSA1 Algorithm Steps

STEP 1: Initialization

Job_Set_A = [$J_1 J_2 J_3 \; . \; . \; . \; J_n$], set of given jobs

Job_Set_B = [0], set of schedules job

Job_Set_C = [$J'_1 J'_2 J'_3 \; . \; . \; . \; J'_n$], set of unscheduled jobs,$J'_i = J_i$

n = number of jobs

STEP 2: Find index = $p_i + r_i$ for all jobs in Job_Set_A, i = 1, ..., n

STEP 3: List jobs in the Job_Set_A in increasing index order and put the jobs in Job_Set_C. To break ties, select first the job with the lowest r_i, else break tie arbitrarily.STEP 4: Add the first job in Job_Set_A, to Job_Set_B and

remove it from Job_Set_C.

STEP 5: Compute the Completion time, (C_i) of the job scheduled in step 4

STEP 6: Compute $\Delta W_j = |R_j - C_j|$ for all the remaining jobs in the Job_Set_D. Where $R_j$is the
release date of each of the remaining jobs in Job_Set_D and (C_j is the completion time of jobs scheduled prior to the next target position (i-1) in Job_Set_D, j= 2, 3, … n-1, I = 1, 2, 3, …, n.

STEP 7: Re-arrange the remaining jobs in Job_Set_D in the order of their increasing ΔW_jcomputed in Step 6 and schedule the job with the lowest ΔW_j in the next unscheduled position

STEP 8: Repeat step 6and 7 until all the jobs have been scheduled
STEP 9: Append Job_Set_D to Job_Set_B
STEP 10: Stop

Application

Consider a 4 x1 scheduling problem with the problem parameter in Table 1. Determine the total flowtime using the KSA 2 algorithm. Compare the results to the optimal value.

Table 1: A 4x1 Scheduling Problem

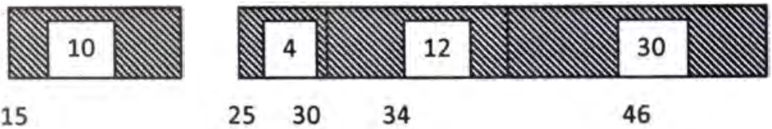
S/N	R	p
1	15	10
2	30	4
3	4	12
4	20	30

Solution.
Optimal value can be obtained by complete enumeration or implicit enumeration. In this case, we want to explore complete enumeration.

Number of Feasible Schedule = 4! = $4 \times 3 \times 2 = 24$

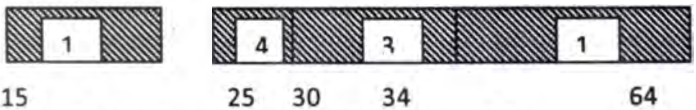
The 24 schedule will be analyzed using the Gantt chart.

[1 2 3 4]



The Sum of flow time = 10 + 4 + 42 + 56 = 112
(NOTE:$F_i = C_i - r_i$)

[1 2 43]

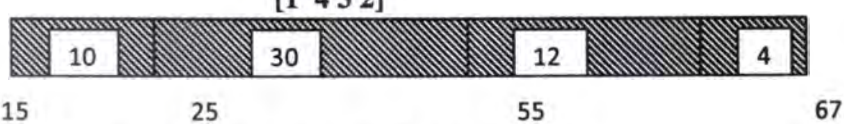


The Sum of flow time = 10 + 4 + 44 + 76 = 134

[1 4 2 3]

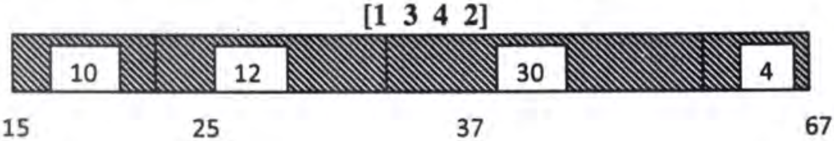
The Sum of flow time = 10 + 35 + 29 + 67 = 141

[1 4 3 2]



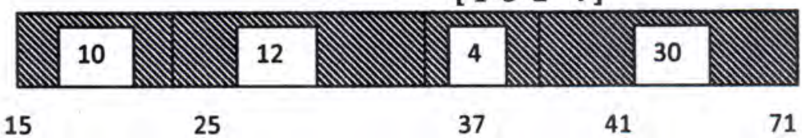
The Sum of flow time = 10 + 35 + 63 + 41 = 149

[1 3 4 2]



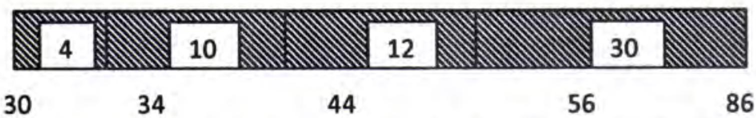
The Sum of flow time = 10 + 33 + 47 + 41 = 131

[1 3 2 4]



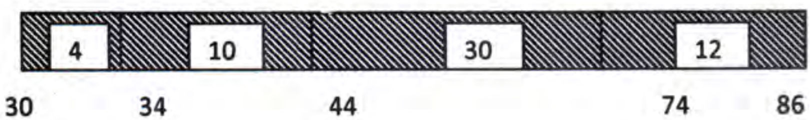
The Sum of flow time = 10 + 33 + 11 + 51 = 105

[2 1 3 4]



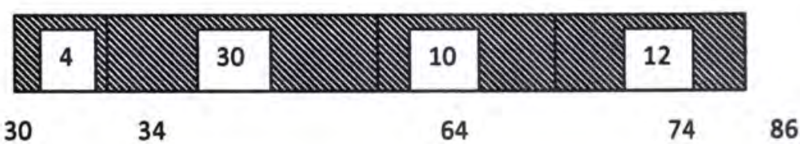
The Sum of flow time = 4 + 29 + 52 + 66 = 151

[2 1 4 3]



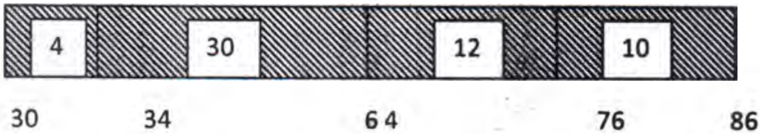
The Sum of flow time = 4 + 29 + 54 + 82 = 169

[2 4 1 3]



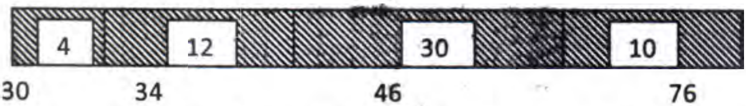
The Sum of flow time = 4 + 44 + 69 + 82 = 199

[2 4 3 1]



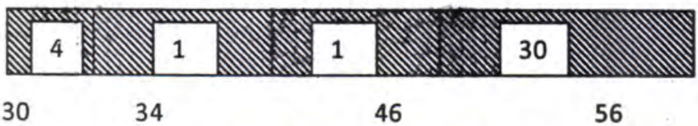
The Sum of flow time = 4 + 44 + 72 + 71 = 191

[2 3 4 1]



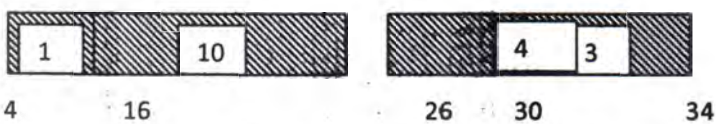
The Sum of flow time = 4 + 42 + 56 + 71 = 173

[2 3 1 4]



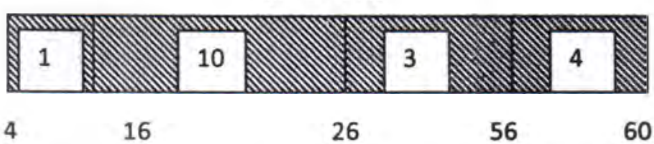
The Sum of flow time = 4 + 42 + 41 + 66 = 153

3 1 2 4]



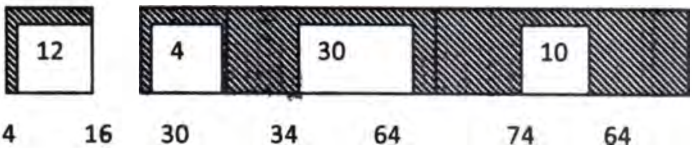
The Sum of flow time = 12 + 11 + 4 + 44 = 71

[3 1 4 2]



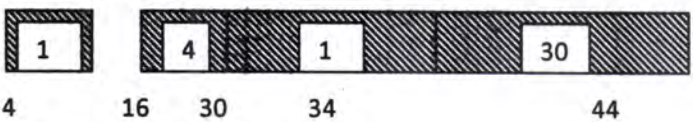
The Sum of flow time = 12 + 11 + 36 + 30 = 89

[3 2 4 1]



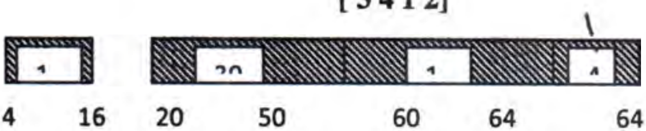
The Sum of flow time = 12 + 4 + 44 + 59 = 119

[3 2 1 4]



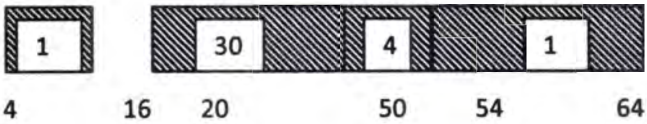
The Sum of flow time = 12 + 4 + 29 + 54 = 101

[3 4 1 2]



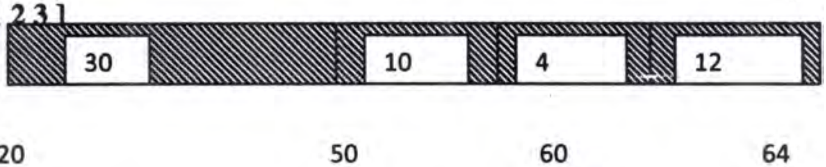
The Sum of flow time = 12 + 30 + 45 + 34 = 131

[3 4 2 1]



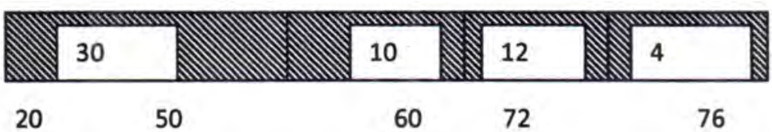
The Sum of flow time = 12 + 30 + 24 + 49 = 111

[4 1 2 3]



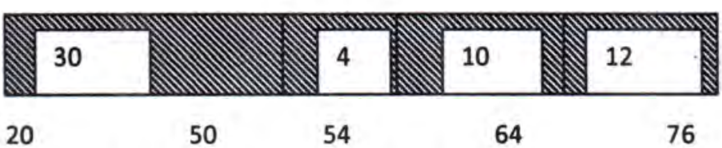
The Sum of flow time = 30 + 45 + 34 + 72 = 181

[4 1 3 2]



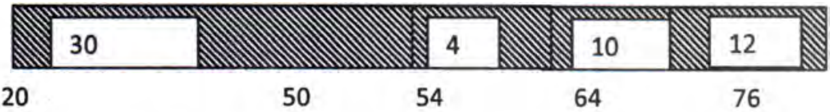
The Sum of flow time = 30 + 45 + 68 + 46 = 189

[4 2 1 3]



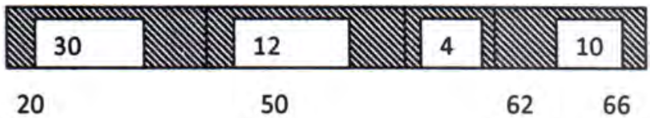
The Sum of flow time = 30 + 24 +49 + 72 = 175

[4 2 3 1]



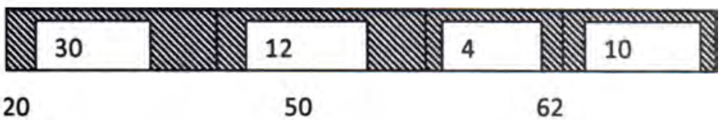
The Sum of flow time = 30 + 24+60 + 61 = 175

[4 3 2 1]



The Sum of flow time = 30 + 58 + 36 + 61 = 185

[4 3 1 2]



The Sum of flow time = 30 + 58 + 51 + 46= 185

From the complete enumeration, the optimal schedule is [3 1 2 4] with the optimal value (total flowtime) of 71

The Proposed Approximation Algorithm: K.S.A1 ALGORITHM

STEP 1: Initialization
Job_Set_A = [1 2 3 4], set of given jobs
Job_Set_B = [0], set of schedules job
Job_Set_C = [1 2 3 4], set of unscheduled jobs, $J'_i = J_i$
n = 4

STEP 2: Compute the index = $p_i + r_i$ for each of the jobs in Job_Set_A, i = 1, .., n

S/N	R	P	P+r
1	15	10	25
2	30	4	34
3	4	12	16
4	20	30	50

STEP 3: Job_Set_C = [3 2 1 4]

STEP 4: Job_Set_C = [2 1 4]

Job_Set_B = [3− − −]

STEP 5: Completion time of job 3, (C_i) = (4+12) = 16

STEP 6 : (Job_Set_C = [2 1 4] explore)

: For job 2, ΔW j = | 16–30| = 14

For Job 1 , ΔWi = | 16–15| = 1**-----------Minimum (Selected)**

i+3 = Job 4, ΔW j = | 16–20| = 4

Then;

Job_Set_C = [2 4]

Job_Set_B = [3 1 − −]

Completion time of job 1, (C_i)= (16 + 10) = 26

STEP 6: (Job_Set_C = [2 4] explore)

: For job 2, ΔW j = | 26–30| = 4 **-----------Minimum (Selected)**

For Job 4, ΔW j = | 26–20| = 6

Job_Set_C = [4]

Job_Set_B = [3 1 2 4]

KSA 1 gives = [3 1 2 4] the optimal schedule.

1. Single Machine Total Tardiness Problem (SMTTP) with zero release date

Problem Definition: Given a single processor scheduling problem, where a set of *n* jobs have to be sequenced on a processor to minimise the total tardiness. Taking into consideration the following assumption;

i. only one job can be processed at a time
ii. the problem is deterministic that is the processing time (p_i) and the due dates (d_i)
iii. the release dates (r_i) is zero

A job is said to be late or tardy if it is completed after its due date.

The tardiness of job*i* is given by: $T_i = \max(0, C_I - D_i)$
The total tardiness is $T_{tot} = \sum_{i=1}^{n} T_i$

The SMTTP has been established to be NP-hard. One of the most tested effective and efficient heuristics for the problem is the Modified Due Date (MDD) algorithm.

Consider the five-job problem of minimizing total tardiness. Use the MDD solution method and compare the result to the optimal. (Source: Baker and Trietch, 2013)

Job *i*	1	2	3	4	5
Pi	4	3	7	2	2
Di	5	6	8	8	17

SOLUTION

In this case, the number of feasible schedules is = 5! = 5 × 4 × 3 × 2 = 120

This will take a prohibitive computation time using the complete enumeration. Thus, Branch and Bound implicit enumeration Techniques will be employed to find the optimal.The branching tree is as in Figure 2

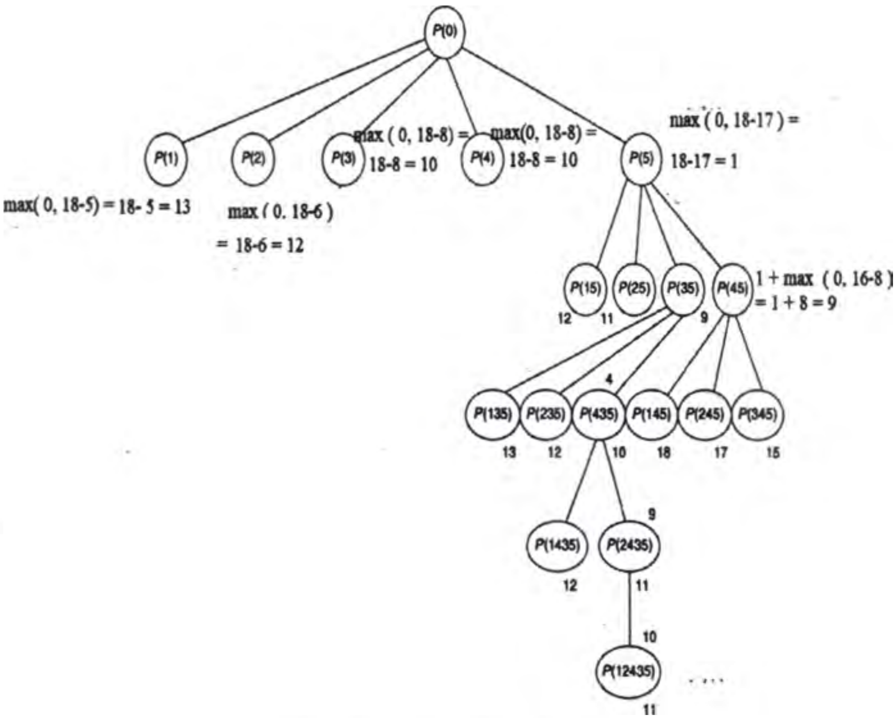


Fig. 2: The branching Tree

Analysis of the branching tree

At the step 1, the tree consists of $P(0)$, with no job schedule.

At the step 2, the problem p(0) was partitioned into n subproblems, p(1), p(2), . p(3), p(4), p(5), by assigning the last position in the sequence to each of the nodes in the first level of the branching tree. For the subproblems, put each associated job in the last position sequentially. That is, for p(1), put job 1 last, for p(2) put job 2 last, etc. The tardiness for each job at the last position is computed as follows:

For p [- - - - 1],: $T_i = \max(0, C_I - D_i) = \max(0, 18 - 5) = 13$

For p[- - - -2] : $T_i = \max(0, C_I - D_i) = \max(0, 18 - 6) = 13$

For p [- - - - 3],: $T_i = \max(0, C_I - D_i) = \max(0, 18 - 8) = 10$

For p[- - - - 4],: $T_i = \max(0, C_I - D_i) = \max(0, 18 - 8) = 10$

For p [- - - - 5],: $T_i = \max(0, C_I - D_i) = \max(0, 18 - 17) = 1$

NOTE (The completion time will be the summation of all the processing time since the last position of the job is assigned)

To eliminate some redundant branches, only the branch with the minimum tardiness value is explored further.At the next stage, the remaining jobs (1, 2, 3, 4) are assigned the position,$n - 1$. The tardiness of each of the sub-problem is computed as follows

For p[- - - 45],: $T_i = 1 + \max(0, C_I - D_i) = 1 + \max(0, 16 - 8) = 9$

For p[- - - 35],: $T_i = 1 + \max(0, C_I - D_i) = 1 + \max(0, 16 - 8) = 9$

For p[- - - 25],: $T_i = 1 + \max(0, C_I - D_i) = 1 + \max(0, 16 - 6) = 11$

For p[- - - 15],: $T_i = 1 + \max(0, C_I - D_i) = 1 + \max(0, 16 - 5) = 12$

Also, the p[- - - 45] and the p[- - - 35] are explored further. This process continues until all the explored branches were explored as illustrated in Fig. 1. The optimal solution from the Branch and Bound is **11** and the schedule is (12435).

The Modified Due Date (MDD) heuristics for the Problem

The Modified Due Date (MDD) Rule: MDD schedules the next job from unscheduled jobs set 'U' with the smallest priority index (Πi). The priority index is given by:

$$\Pi_i = \{\max\{t_i + p_i , d_i\}\}$$

where:

t_i is the starting time of the next unscheduled job $i(i\in U)$ which can either

be the completion time of the job in position i-1 or the release date of job i,

$p_i$is the processing time, and

d_i is the due date.

If two jobs j and k compete to be scheduled at time t, then, job j will precede

job k if $\Pi_j \leq \Pi_k$

However, the MDD rule does not consider two jobs at a time when there are more than

two unscheduled jobs. It considers all the available jobs, computes their priority indices

(Π_i) and chooses the job with the least priority index.

STEP 1: Initialization

Job_Set_A = [1 2 3 4], set of given jobs

Job_Set_B = [0], set of schedules job

Job_Set_C = [1 2 3 4], set of unscheduled jobs, $J'_i = J_i$

n = 5

For i = 1, t = 0, JobSET B = { }

Job *i*	1	2	3	4	5
Pi	4	3	7	2	2
Di	5	6	8	8	17

$t_i + p_i$	4	3	7	2	2
$\Pi_i = \{\max\{t_i + p_i, d_i\}\}$	5	6	8	8	17

The minimum $\Pi_i = 5$, Thus, JobSET B = {1}

For i = 2, t = 5, JobSET B = {1}

Job *i*	2	3	4	5
Pi	3	7	2	2
Di	6	8	8	17
$t_i + p_i$	8	12	7	7
$\Pi_i = \{\max\{t_i + p_i, d_i\}\}$	8	12	8	17

The minimum $\Pi_i = 8$, Thus, JobSET B = {1 2} or JobSET B = {1 4}

Though, the MDD does not specify how the tie should be broken. The common approach is to break the tie with the due date (by assigning jobs with lower date) as explored by Akande (2017).

Thus, job 2 is scheduled.

For i = 3, t = 8, JobSET B = {1 2}

Job *i*	3	4	5
Pi	7	2	2
Di	8	8	17
$t_i + p_i$	15	10	10
$\Pi_i = \{\max\{t_i + p_i, d_i\}\}$	15	10	17

The minimum Π_i = 15, Thus, JobSET B = {1 2 4}
For i = 4, t = 10, JobSET B = {1 2 4}

Job i	3	5
Pi	7	2
Di	8	17
$t_i + p_i$	17	12
$\Pi_i = \{\max\{t_i + p_i , d_i\}\}$	17	17

The minimum Π_i= 17, (break the tie by assigned the job with the lower due date) Thus, JobSET B = {1 2 4 3}
For i = 5, JobSETB = [1 2 4 35] MDD heuristic schedule is [1 2 4 35]

Job i	1	2	4	3	5
P_I	4	3	2	7	2
C_I	4	7	9	16	18
Di	5	6	8	8	17
$T_i = \max(0, C_I - D_i)$	0	1	1	8	1

$$T_{tot} = \sum_{i=1}^{n} \max(0, C_I - D_i) = 11$$

1.5 Future directions

After about seven decades of active researches on scheduling which have resulted in the development of many scheduling algorithms, the followings are some of the areas where future research efforts are of utmost importance.

i. **Quality of solutions (Effectiveness):** Owing to advancements in the information communication technology over the years, there have been tremendous improvements in the computing speed. Thus, it is of utmost importance for researchers to concentrate more efforts on the developments of algorithms that are capable of generating solutions that are extremely close to (if not) the optimal. It is believed that we can always leverage improvements in computing power/speed.

ii. **Execution time of solutions (Efficiency):** Even though there have been improvements in the computing speed/power over the years, there is a need for researchers to continue the search for faster/shorter methods of solving combinatorial/optimization problems. The world itself is not static, hence researchers should be encouraged to continue to explore the development of fast (efficient) algorithms that can produce results if possible at the speed of light.

iii. **Multi-criteria/Multi-objective problems:**Since most combinatorial/scheduling problems are mostly multi-criteria in nature, research efforts should be majorly focused on developments of algorithms that can be applied to multi-criteria problems. Today, a number of the algorithms purportedly developed for multi-criteria scheduling problems reduce the original problems into single criterion problems. There is the need to further develop algorithms that will explore multi-criteria problems in a multi-criteria manner and not pseudo-multi-criteria manner.

iv. **Real-life scheduling problems:** Although many researchers have explored multi-criteria scheduling problems, some of these have been limited to hypothetical problems, with only a few exploring real-life problems. Since real-life scheduling problems have their own unique characteristics, future research efforts should therefore be directed at solving real-life problems that are of practical importance to the society at large.

1.6 Conclusion

In this work, sequences and scheduling have been introduced with time being used as an underlying surrogate measure for cost factors.

Algorithms that enable the solution of scheduling problems have been classified andmethodologies espoused. Exact methods have been distinguished from approximation methods. This enables a tradeoff between accuracy and timeliness. Examples have been given to enable readers to have traction with implementing some selected solution methods. This should generate more interest in applying scheduling approaches to improve the performance of individual and organisational work systems.

References

1. Akande, S. (2018). New solution methods for single machine bicriteria scheduling problems: Minimizing the total flowtime and maximum tardiness with zero release dates.*International Journal of Engineering Research in Africa*, 38, 144-153.
2. Akande, S. (2017). Development of heuristics for single processor scheduling problems with tardiness-related performance measures. *Statistics*, 1.
3. Al-harkan, I. *Algorithms for Sequencing and Scheduling.* Available from: faculty.ksu.edu.sablog(http://http://faculty.ksu.edu.sa/ialharkan/IE428) retrieved 15 September, 2020.
4. Baker, K.R and Trietsch, D. (2013). Principles of sequencing and scheduling.Canada: John Wiley & Sons
5. Bansal, N. and Kulkarni, J. (2015). Minimizing flow-time on unrelated machines. *Proceedings of the Forty-Seventh Annual ACM on Symposium on Theory of Computing*. Portland. 92-102.
6. Bellman, R, (1957). Dynamic Programming. Princeton : University Press.
7. Bianchi, L., Marco, D., Luca, M.G., and Walter, J. G. (2009). A survey on metaheuristics for stochastic combinatorial optimization. *Natural Computing: an International Journal,* 8, 239–287.

8. Blum, C. and Roli, A. (2003). Metaheuristics in combinatorial optimization:
Overview and conceptual comparison. *ACM Computing Surveys,* 35, 268–308.
9. Brucker, P. (2007) . *Scheduling Algorithms*, 5th ed. Springer: Heidelberg
Publisher.
10. French, S. (1982). Sequencing and Scheduling. United Kingdom : Ellis Horwood Limited.
11. Johnson, S.M. (1954) . Optimal two- and three-stage production schedules with setup times included. *Naval Research Logistics*, 1 : 61-68.
12. Naidu J.T. (2003). A Note on a Well-Known Dispatching Rule to Minimise Total Tardiness. *International Journal of Management Science* 31, 137–140.
13. Oluleye, A E and Charles-Owaba, O E, (1999). Optimality Conditions for Some Special structure Scheduling Problems, *Proceedings of the International Conference on Production Research (ICPR-15), Ireland, UK* 333 - 336.
14. Oluleye, A E and Jolayemi J K, 2000, Performance Evaluation of Some Index Based Flowshop Heuristics. *Nigerian Journal of Engineering Management* 44 – 48.
15. Oyetunji, E. O., Oluleye, A. E. and Akande, S.A. (2012) . Approximation
algorithms for minimizing sum of flow time on single machine with release
dates. *International Journal of Modern Engineering Research,*2, 687-696.
16. Oyetunji, E.O., (2009) . Some common performance measures in scheduling
problems. *Research Journal of Applied Science, Engineering and Technology,*2, 6-9.
17. Oyetunji, E.O. and Oluleye, A.E. (2010). Hierarchical minimization of total

completion time and number of tardy jobs criteria. *Asian Journal of Information Technology*,74, 157-161
18. Oyetunji, E. O. and Oluleye, A.E. (2008) . Heuristics for minimizing total completion time and number of tardy jobs simultaneously on single machine with release time. *Research Journal of Applied Sciences*, 3, 147-152.
19. Ólafsson, S. (2002), IE 514 Lecture notes, Industrial Engineering Department, Iowa State University http://www.public.iastate.edu/%7Eolafsson/ie514_2001.html
20. Smith, W. E., (1956). Various Optimisers for single-stage production. *Naval Research Logistic Quarter*,31, 59-66.
21. Weisstein, E W. Complexity Theory. A Wolfram Web Resource. http://mathworld.wolfram.com/ComplexityTheory.html [Accessed: June, 21st 2015].

CHAPTER 6

An Integer Linear Programming Model of a University Soccer Timetabling Problem

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1. Introduction

Timetabling is an integral part of the human life. Schedules and timetables are made every day, although in an informal way. This ranges from deciding whether or not to go to the market, to deciding what time to go see that friend or go to the bank. Plans and schedules of activities are made every single day. Without timetabling, there would be low productivity and chaos in the arrangements of activities. Hence, it is important that there is an optimization method that provides some form of organization. The whole process of timetabling is aimed at finding suitable timeslots for defined tasks, all subject to certain constraints. Essentially, the allocation of resources to time is the sole purpose of timetabling. Timetabling can be applied in several sectors, such as schools, factories, sporting events and so on.

The application of timetabling in sporting events has grown to become perhaps the most popular use case amongst the various application areas mentioned. Many sporting events feature games or matches between teams. There is also a specified duration of the sporting event, along with other constraints like stadium and official availability. The teams also have to be taken into consideration, as they must not be put under duress by the tournament schedule.

Also, whether or not the teams will be put in groups have to be determined. There are several other essential factors that need to be studied and determined for a sporting event to be a success. This means that for any sporting event to be well organized, an optimization method to assign the teams to time slots subject to the many constraints has to be employed. The importance of timetabling in sports cannot be overemphasized as every single sport tournament employs timetabling methods to ensure seamless and smooth operations.

Resources will not be properly utilized if the schedule of a sporting event is not well planned. The quality of the schedule of sporting events impacts the fairness of competition, revenue generation from the event, and the satisfaction of the players, coaches and fans(Goldberg, 2003). Given the importance of the schedule of sporting events, it is very paramount to optimize the various resources of these events.

Timetabling in sports has been studied by several scholars over the years. Extensive studies have been done on various types of sporting events, particularly, National sports tournaments (Bartsch et al., 2006; Cocchi et al., 2018; Della Croce & Oliveri, 2006; Durán et al., 2007; Kostuk & Willoughby, 2012; Ribeiro & Urrutia, 2012). Studies on sport scheduling and soccer timetabling in particular have been focused more on professional and commercial sports. College basketball competition was scheduled for nine universities (Nemhauser & Trick, 1998) but information is sparse on scheduling of university soccer. Also, University course time tabling has been studied extensively(Chung & Kim, 2019; Gülcü & Akkan, 2020; Oladokun & Badmus, 2008; Thepphakorn & Pongcharoen, 2020) but there are no studies reported in the literature on university soccer timetabling to the best of our knowledge. This study aims at formulating a university soccer timetabling problem by identifying the variables, parameters and constraints of University soccer timetabling problem and defining and solving the University soccer timetabling problem.

2. **Literature review**

This section gives the general review of scheduling, the concept of timetabling and its application, overview of sport scheduling problem, soccer timetabling problem and its solution methods.

2.1 **General Review of scheduling**

Scheduling and timetabling is everyday activity of humans and it is a vital tool in decision making. Scheduling is a decision making process which has significant contribution to the operations of production and manufacturing systems, information processing environments, transportation, distribution and other service industries(Pinedo, 2008). It deals with the problem of allocating resources over time to perform a number of tasks (jobs) with the aim of maximizing profit or minimizing cost. Oluleye & Oyetunji, (1999) stated that the real problem of scheduling is determining schedules that best satisfies the set objectives.

Earlier work on scheduling was done by Henry Gantt who developed a chart which tracks the activity to be carried out and the time designated for each activity (Pinedo, 2008). This also provides tracking of activities to be done and the extent to which it has been executed. This has led to development of other tools used in scheduling such as loading, planning to mention a few. Development of computer based scheduling system has greatly helped in quick response to customer order, on-time delivery and also development of realistic schedules. Despite all that has been done, implementing effective scheduling system still remain a challenge to this present day.

Scheduling problems contain a set of tasks to be carried out with available set of resources with certain capacity to perform those tasks putting into consideration uncertainties with the sole aim of determining the timing of the tasks. Scheduling problem can be classified based on the scheduling environment, the characteristics of the job to be scheduled and objective function which could be single or multiple but real life situation always have multi objectives(Vieira *et. al.* , 2003).

Nagar et al., (1995) give detailed review on multiple and bi-criteria scheduling problem. The study also provides a broad classification of scheduling based on the nature of the problem, shop configuration, solution methods, performance measures, criteria and application. Oyetunji, (2011) considers solving multi-objective scheduling problem which has both minimisation and maximization type and a methodology is proposed to solve this mixed multi objective scheduling problem. A bicriteria algorithm was developed by Oladokun et al., (2011) for single machine scheduling problem with sequence dependent set-up time. Oyetunji & Oluleye, (2010) proposed two heuristics to solved bi-criteria scheduling problem for single processor. Also, a generalized algorithm for solving multi-criteria scheduling problem was proposed by Oyetunji & Oluleye, (2012).

Scheduling has found application in real-life problems such as healthcare, production and manufacturing processes and maintenance. Scheduling in health care is different from that in other industries because the physiological state of a patient is dynamic and this introduces an inherent uncertainty into patient flow. Brandenburg et al., (2015) argue that this clinical variability or uncertainty has not been consistently addressed in scheduling system for elective appointment and this result in an impromptu method of triage. Huang,(2003) considers the limitations of the current patient scheduling system, and a model which meets the clinic policies and ancillary services was developed and implemented. Gupta & Denton, (2008) study the opportunities and challenges of appointment scheduling in healthcare.

Job and machine scheduling has been well studied in the literature for various class of problem and different shop configuration. Horn, (1974) presents scheduling algorithms for jobs that require only one operation on a single machine or one of a set of identical machines. Glazebrook, (1987) considers sensitivity analysis for stochastic single machine scheduling problem. Position-based learning effect in stochastic scheduling for single machines was analysed by Zhang et al., (2013). Skutella et al., (2014) give the combination of classical unrelated machine scheduling model with stochastic processing times of jobs. Dynamic stochastic scheduling of preemptive jobs on parallel machine was considered by Megow & Vredeveld, (2014) with processing times that follows independent discrete probability distribution.

(Lawler et al., 1993) review optimisation and approximation algorithm and results complexity for parallel machine, single machine, open shop, job shop and flow shop scheduling problems. The authors also consider stochastic machine scheduling and resource constrained project scheduling. Stephen & Sewell, (1997) consider job shop scheduling problem with uncertain processing times. The study compares dynamic and static application of exact and heuristics methods for the problem. The study by Pfund et al., (2006) give the review of dispatching techniques and overview of deterministic scheduling approach in semiconductor manufacturing. Stochastic job shop scheduling problem was modelled as non-linear mathematical programming and a hybrid method was proposed in solving the problem.(Tavakkoli-Moghaddam et al., 2005). Other applications are maintenance scheduling(Charles-Owaba et al., 2015; Charles-Owaba et al., 2008a, 2008b; Oke, 2004; Oke & Charles-Owaba, 2006)and resource constrained project scheduling(Lawler et al., 1993; Odedairo & Oladokun, 2011).

Wren, (1996) gives a relationship between scheduling and timetabling by giving the following definitions. The author defines scheduling as "the allocation subject to constraints, of resources to objects being placed in space –time in such a way as to minimise the total cost of some set of resources used" while timetabling is defined as "the allocation subject to constraints, of given resources to objects being placed in space time in such a way to satisfy as nearly as possible a set of desirable objectives". This can be simply put that timetabling is the process where by a schedule is derived from sequence while schedules contains timetabling as well as the sequencing information that is the order of processing activities through given resources. This study focuses on timetabling.

2.2 Timetabling

A large variety of problem in real life fits into timetabling problem and this among other reasons made timetabling problem attracted a lot of attention in the research community(de Werra, 1985). Timetabling problem involves the allocation of resources in time and space such that utilization and stakeholders' requirements is optimised. Leite et al., (2019) defined timetabling problem as "scheduling of a set of events (lectures, exams, surgeries, sport events, trips) to a set of resources (teachers, nurses and medical doctors, referees, vehicles) over space (classrooms, examination rooms, operating rooms, sport fields), in a prefixed period of time" The goals of timetabling is to achieve feasible timetable by satisfying all hard constraints and minimising the soft constraints costs.

Timetabling problem is an NP-hard problem which cannot be solved optimally in polynomial time. Approximation method (heuristic based) are employed to obtain satisfactory solution within a good computation times. Classes of timetabling problem as given by Burke et al.,(2004) includes school timetabling, university course timetabling, examination timetabling, sports timetabling, transport timetabling, employee timetabling and roster problem. The authors applied graph theory to solve these classes of timetabling problem and illustrated the graph theory application to timetabling for class-teacher timetabling, university course timetabling, university examination timetabling, and sport timetabling.

2.3 Application of timetabling

Timetabling has a wide range of application in university course and examination timetabling, transportation, healthcare, sports, entertainment, workers' shift scheduling. Some of the applications are presented as follows:

2.3.1 Train Timetabling

Train timetabling problem considers models which are operations-centred and passenger-centred. Railway operations such as operation cost minimisation, maximisation of robustness of timetable to absorb disruption are the focus of operations-centred models. The passenger-centred models focuses on increasing the passengers' satisfaction such as maximisation of the number of direct links between rail stations and minimisation of passengers waiting time. Operations –centred models have been widely studied(Fischetti et al., 2009; Liebchen & Stiller, 2009) while there is sparse literature on passenger-centred models(Espinosa-Aranda et al., 2015; García-Ródenas et al., 2020; Wong et al., 2008)

Some studies on train scheduling problems are as follows: Wang et al., (2019) establish two models for high speed railway train timetabling problem using space-time network method. Zhang et al., (2019) reformulate cyclic train timetabling problem and applies two dual composition approaches to solve it. Qi et al.,(2019)propose a new method for train timetabling problem which considers special passenger demands of women-only passenger cars. Caprara et al., (2002) apply graph theory to model and formulate train timetabling problem which uses a directed multigraph with its nodes corresponding to arrival/departure at any defined rail station at any given time. García-Ródenas et al., (2020) propose a mathematical model for passenger-centred train timetabling with the consideration of elasticity of demand against the supply's features. Improved variant of bundle method which uses disaggregate method was proposed for solving train timetabling problem. The proposed approach gives a reduced computation time when compared to the standard bundle method(Ait-Ali et al., 2020).

2.3.2 University Course and Examination timetabling

Exact and approximation methods are used in solving the university course and examination time tabling problem. (de Werra, 1985) describes class-teacher timetabling problem and its variations which was formulated and solved as graph theoretical models. (Oladokun & Badmus, 2008) models the university course timetabling as integer linear programming which assigns, courses, rooms and lecturers to timeslots that are fixed, usually a week. The model also, satisfies some problem-specific constraints. The study by (Chung & Kim, 2019) consider university course timetabling and examination timetabling problems. The problem was formulated as integer programming and a solution approach called NOGOOD was used to solve the problem.

Also, Leite et al., (2019) use a simulated annealing approach for solving examination timetabling. The author proposes two simulated annealing algorithm; the standard simulated annealing and fast simulated annealing. The result shows that fast simulated annealing is better in terms of solution cost when compared to standard simulated annealing. Gülcü & Akkan,(2020) formulate robust university course timetable as bi-criteriá optimisation problem and Multi Objective Simulated Annealing was proposed for solving the single and multiple disruptions. Leng et al., (2020) apply a two-phase hybrid local search algorithm to solve post enrollment course timetabling problem. Cuckoo search algorithm was developed by Thepphakorn & Pongcharoen, (2020)for solving university course timetabling problem to minimise the total operating cost incurred by the university.

2.4 Sport scheduling problem

Sport scheduling problem is important because of its impact on the attendance, public interest as well as the profitability of sponsors, broadcasting and advertising organisations. Each of these stakeholders have their preferences which must be considered in ensuring good schedules. Sport scheduling problem helps in generating schedules that ensures requirements are met and fairness to all stakeholders. It can be difficult to generalize sports scheduling problem because the objectives and constraints of each league differs and these differences makes generation of schedule with respect to requirements and constraint difficult. Nurmi et al., (2010) argue that the development of an effective solution method for real-life scheduling problem is to understand relevant requirements and request of the league. This suggests that the knowledge about the requirements of each league is paramount in achieving a good schedule.

Sport scheduling has been widely studied for several sports and different tournament types(Cocchi et al., 2018; Froncek, 2010; Nemhauser & Trick, 1998; Nurmi et al., 2010; Urban & Russell, 2003). It has considered sports such as soccer(Alarcón et al., 2017; Bartsch et al., 2006; Recalde et al., 2013; Ribeiro & Urrutia, 2012), table tennis(Schonberger et al., 2004), basketball(Nemhauser & Trick, 1998; Wright, 2006; H. Zhang, 2002), handball(Larson & Johansson, 2014), ice hockey(Kyngäs & Nurmi, 2009; Nurmi et al., 2015), volleyball(Cocchi et al., 2018).

Sports timetabling and management of schedules has been attracting scholars across various disciplines and different optimization methods have been employed to solve sports scheduling problems. The optimization techniques employed for any sporting event depends on the complexity of the desired schedule and the constraints. The type of tournament is also another factor to consider in sports timetabling. A sports event is usually either a round robin tournament, a group tournament, an elimination tournament or a combination of any of the types. This has to be considered in selecting the type of optimization method to employ in solving it.

This study considers a tournament played by an even number of teams. A round robin tournament is defined by Ribeiro, (2012) as "one in which each team plays against every other a fixed number of times." Every team plays each other exactly once and twice in a single round robin (SRR) tournament and double round robin (DRR) tournament respectively and plays at most once in each round. Most tournaments and leagues across the world uses round robin sport schedules(Lewis & Thompson, 2011). Round robins are schedules that involve n teams and each team played each other m number of times in a fixed number of rounds. Single round robin and double round robin are the most common round robin types.

(Wright, 2009) reviews the application of operations research to sports for a period of 50 years. The study covers the analysis of tactics and strategy, scheduling and forecasting and other policy issues and the effect of sports on the society. Nurmi et al., (2010) give the major reason for the interest of academic in sports scheduling as the minimisation of distance travelled by teams during tournaments, the use of smart computers for computational tasks demand of sport scheduling, development of algorithms in tackling the intractable problem of sport scheduling and the organisation of sports in more professional manner requires a good schedules for the success of the league.

Also, Kyngäs et al., (2014) identify three major problem of sport scheduling as minimum number of breaks problem, travel tournament problem and constrained sport scheduling problem. The identified problem has been addressed in general and for specific sports. The study by Van Bulck et al., (2020) propose a three-field notation to describe a round robin sport scheduling in terms of tournament format, constraint in operation and the objective of sport timetabling. Froncek, (2010) presents several schedules for round robin tournament for alternate home and away games and some other features are consider in the construction of various schedules. (Larson & Johansson, 2014) give a methodology for scheduling general tournament that allows each division holds a round-robin tournament before a double round-robin tournament. The study gives tournament schedules that satisfy alternate venue requirement with consideration of necessary conditions for home-away patterns.

Nurmi et al., (2010) define the framework for scheduling professional sport leagues by introducing a set of artificial and real life instances and some of the best solutions of these examples were published. Lewis & Thompson, (2011) view sports timetabling problem as a graph coloring problem. Two algorithms for real-life sport scheduling was proposed based on the links between round robin sports scheduling and graph coloring. Briskorn & Drexl, (2009) consider the prominent requirements of round robin tournament in developing sport league schedule. These requirements are defined as integer programming model and solved by CPLEX.

Constraint programming was used by Carlsson et al., (2017) to schedule double round robin tournament with divisional single round robin tournament. Sport league scheduling problem was formulated as constraint satisfaction problem and was solved using repair-based linear time algorithm(Hamiez & Hao, 2004). Kyngäs & Nurmi, (2009) propose algorithm for constrained minimum break problem for scheduling Finnish major Ice Hockey league .The algorithm gives a feasible and acceptable schedule which was used for that season and the schedule was used for 2008-2009 season. Nurmi et al.,(2015) applied PEAST algorithm to scheduling of Finnish major ice Hockey league. The study shows that the algorithm generates a good quality schedules for 2013-2014 season.

The study develops suitable schedule for Atlantic Coast Conference basketball competition which involves 9 universities using a combination of integer programming and enumerative techniques. The solution approach gives a schedule which was accepted for play in 1997-1998 by Atlantic Coast Conference(Nemhauser & Trick, 1998). Wright, (2006) considers the scheduling fixtures for Basket Ball league in New

Zealand. This study gives detailed description of the problem and a general solution method was adopted. Zhang, (2002) develops a schedule for College Conference Basketball which was formulated as constraint satisfaction problem which was solved using 3-phase procedure of Nemhauser & Trick, (1998).

Mixed integer linear programming was developed by Cocchi et al., (2018) for regular season schedule for Italian Volleyball Leagues which has at least 12 teams. Non-professional indoor football league schedules was developed by Van Bulck et al., (2018) .The authors present integer programming formulations and Tabu Search based heuristics. Della Croce & Oliveri, (2006) adapt the solution procedure of Nemhauser & Trick, (1998) for scheduling of Italian football league which gives a feasible schedule that satisfies the cable television's requirements. Briskorn & Drexl, (2009) reiterate that integer programming approach in finding optimal schedule for sport scheduling outperforms the constraint programming in terms of run-time.

Wright, (2009) identifies the study of sports at amateur level and suggests that the focus of research should not only be on the professional level scheduling but it should consider amateur level which has a large proportion of the population as their audience. Schonberger et al., (2004) argue that timetabling of non-commercial sport leagues have received minor attention as compared to the commercial sport leagues. The authors propose a model for timetabling of non-commercial sport leagues that uses Memetic algorithm in solving the problem.

Non- professional sport scheduling is interesting because the games are not planned in rounds but each team considers time slots to play home games and timeslots they cannot play at all (Van Bulck et al., 2018).The study gives reviews on professional and non-professional sports scheduling problem. Table 1 gives the sport type, it states whether it is a professional or non-professional and the algorithm used in sport scheduling. Based on the article reviewed, the argument that professional sport scheduling has been given more attention more than the non-professional is further established.

Table 1: Professional and non- professional sport scheduling showing the sport type and solution method

Sport type	Author(s)	Professional	Non-professional	Solution method
Volleyball	Cocchi et al., 2018	√		Mixed integer linear programming
Soccer	Alarcón et al., 2017	√		Integer programming
Table tennis	Schonberger et al., 2004		√	Memetic algorithm
Ice hockey	Kyngäs & Nurmi, 2009	√		A blend of evolutionary and local search method
Handball	Larson & Johansson, 2014	√		
Ice Hockey	Nurmi et al., 2015	√		PEAST algorithm
Football	Van Bulck et al., 2018		√	Integer programming and Tabu search heuristics
Basket ball	Wright, 2006	√		
Football	Della Croce & Oliveri, 2006	√		
Basket ball	Nemhauser & Trick, 1998	√		Integer programming and enumeration techniques
Soccer	Rasmussen, 2008	√		Logic-based Benders decomposition
Football	Ribeiro, 2012	√		Integer programming
Football	Recalde et al., 2013	√		Integer programming
Soccer	Bartsch et al., 2006	√		Graph coloring
Soccer	Fiallos et al., 2010	√		Integer Programming solved by CPLEX

Soccer	Ribeiro & Urrutia, 2012	√		IP with 3-phase decomposition method
Soccer	Goossens & Spieksma, 2009	√		Integer programming
Football	Urban & Russell, 2003	√		Integer programming
Soccer	Durán et al., 2007	√		Integer Linear Programming
Soccer	Russell & Urban, 2006			Constraint programming
Football	Kyngäs et al., 2014	√		PEAST algorithm
Football	Roboredo et al., 2014	√		Improved decomposition method
Basketball	Zhang, 2002	√		3-phase approach using SAT solver
Volleyball	Bonomo et al., 2012	√		Integer programming and Tabu search heuristic
Baseball	Easton et al., 2001	√		Integer programming and constraint programming
Baseball	Easton et al., 2002	√		Hybrid method
Football	Kent & Keith, 2011; Kostuk & Willoughby, 2012	√		Decision based method

2.5 Soccer timetabling problem

Soccer is one of the most significant sports in terms of general acceptance and its activities involve several stakeholders whose contribution must be considered for efficient and feasible schedule. Alarcón et al., (2017) apply operations research to soccer scheduling at the international level. The study shows that the application of operations research to soccer scheduling gives economic savings and its impact is significant on the sports fans, the media and the public institutions.

Goossens & Spieksma, (2009) argue that there is no single model that can be applied to all soccer timetabling problems because each tournament/ league is unique by its structure and requirements. Kyngäs et al., (2014) schedule Australian Football league using a three-phase procedure proposed by Nemhauser & Trick, (1998). PEAST algorithm was applied to generate schedules for 2013 season. Roboredo et al., (2014) schedule Brazilian football league as classical mirrored double round robin tournament which considers place constraints and even number of teams. This study proposed a scheduling problem that minimises the number of breaks and the total number of the extended carry-over effects. It also uses the procedure of Nemhauser & Trick, (1998)

Study by Urban & Russell, (2003) addresses the problem of sport scheduling and balancing of sport competitions over multiples venues. The problem was defined and solved as integer goal programming. Also, Russell & Urban, (2006) use constraints programming for the same problem and the study shows that constraint programming gives optimal schedules for problem of about 16 teams and near optimal for teams up to 30.

2.6 Solution Methods for soccer timetabling problem

Karger et al., (1996) argue that the choice of solution methods for scheduling problem depends on the application of the problem, the decision maker and size of problem. Different exact and approximate methods such as integer programming, constraint programming, metaheuristics and hybrid methods have been applied to solving soccer timetabling problem.

2.6.1 Integer programming

Integer programming is a mathematical optimization method which maximises and minimises the objective function(s) while satisfying a set of constraints. Integer programming is used to model and solve sport scheduling problem. Nemhauser & Trick, (1998) apply integer programming to phases one and two and enumeration for phase three in scheduling of a major college basketball conference. Goossens & Spieksma, (2009) modelled the Belgium football league as a mixed integer programming and was solved as a two-phase approach. Heuristic approach and branch and bound method was used by Bartsch et al., (2006) in scheduling of Austrian and German football leagues.

Della Croce & Oliveri, (2006) apply a heuristic solution procedure to the Italian football league which solves a series of integer programming models and generates double round robin timetables which meets the league' s various requirements. A logic-based Benders decomposition was applied by Rasmussen, (2008)and found home-away pattern sets was found as well as the timetables from the sub problems. Recalde et al., (2013) formulate the Ecuadorian football league scheduling problem as an integer programming formulation which was solved for optimality and ca feasible sports schedule was created. The authors apply a heuristic approach based on three phases. Integer programming was applied by (Durán et al., (2007) to develop the schedule for the Chilean football league. Ribeiro & Urrutia,(2012) formulate the Brazilian football league scheduling as an integer programming and a three-phase solution approach was developed. (Fiallos et al., 2010) develop a mathematical integer programming model for the Honduran football league. It can be seen that heuristics is used in solving the integer programming models to generate round robin timetables that considers several constraints. This combination of methods can be referred to as hybrid method.

2.6.2 Constraint programming method

Constraint programming method is seen to be appropriate for tournament scheduling because acceptable schedules must satisfy many constraints. Constraint programming (CP) has been applied to schedule sports leagues particularly soccer. Russell & Urban, (2006) use constraints programming for soccer timetabling problem which considers multiple venues. Constraint programming has been applied to travelling tournament problem by Easton et al., (2002)

2.6.3 Heuristics

Heuristics are approximation methods that gives satisfactory solutions in good time. It is used for large and NP-hard problems and also for problems that are intractable by enumeration methods. Della Croce & Oliveri, (2006) apply a heuristic solution procedure to the Italian football league scheduling problem. Recalde et al., (2013) apply heuristics to solve the Ecuadorian football league scheduling problem which was formulated as integer programming.

2.6.4 Meta heuristics

It is a master strategy that guides and modifies other heuristics to produce solutions beyond those that are normally generated in a quest for local optimality.it provides a means for approximately solving the complex optimization problems and it is designed to search for global optimum. Three well known heuristics are Tabu search, scatter search and genetic algorithms. Ant based hyper-heuristics algorithm was applied by Chen et al., (2007) to determine double round robin tournament schedule which minimises the travel distance. Lim et al.,(2006) applied simulated annealing and hill climbing to travelling tournament problem while Anagnostopoulos et al., (2006) applied simulation annealing to the same problem.

2.6.5 Decision based method

Decision based methods have been used by scholars in solving timetabling problems. This approach helps the users in answering certain questions that determine what resources will be allocated to what timeslots in timetabling problems. Decision-based models have several advantages. some of these are simplicity, ease of comprehension, ease of application, and so on. It also has some drawbacks in that it is very sensitive to changes in parameters, very limited and have to be specifically designed for their application cases. This study employs the decision based method in solving the university timetabling problem. Decision based model was applied to scheduling of Canadian football league(Kent & Keith, 2011; Kostuk & Willoughby, 2012)

2.6.6 Graph-based method

Graph-based methods are based on graph-colouring heuristic approaches. Graph-colouring heuristics are often also called sequential heuristics. Generally, sequential heuristics have been found to be quite effective and yet simple methods for determining a feasible timetabling solution. However, its major limitation is that it cannot be able to produce a very high quality and accurate solution with respect to the satisfaction of the timetabling problem's soft constraints. Bartsch et al., (2006) applied graph coloring to solve soccer timetabling problem.

Integer programming has been applied extensively to solve soccer timetabling problem and some studies also combine several other methods in solving this problem and such approaches that combine a number of methods is referred to as hybrid method. Most of the methods have strengths and limitations but this study will consider decision based method in solving the university soccer timetabling because of its advantages.

3. Methodology

3.1 Variables, Parameters and Constraints of soccer timetabling problem

The general timetabling problem is concerned with assigning resources to a fixed time period while satisfying some set of constraints. Soccer timetabling is the process of assigning matches, fields, teams and officials to a fixed time period subject to a given number of constraints. The variable of soccer timetabling problem is a binary variable which gives match scheduled at a particular period on a particular field.

The parameters required for modelling soccer timetabling are the Number of officials, Number of matches, Number of soccer fields available, Number of soccer teams, Number of soccer team groups, Duration of soccer matches, and so on. The soccer timetabling constraints are divided into two categories – hard constraints and soft constraints. Hard constraints are requirements that must be fulfilled to have a feasible timetable while soft constraints are secondary constraints which are desirable for timetabling but not necessary to satisfy.

Hard constraint

1. A field must not be assigned for more than one match at a timeslot.
2. A team in a group cannot take more than one match at a time slot, z

3. Not more than h matches can be played in a day for the group stage.
4. The total number of matches is expressed as
5. There must be more than one-day break between consecutive games of a unique team in any match that is there must be a break between i^{th} match and the next $i^{th}+1$ match.
6. There must be at least a day's break between the last game of all football group games and the first game of the semi-finals.
7. There must be at least a day's break between the last semi-final game and the final match

Soft constraints

1. There should be days off between the last game of a football group and the first game of the next football group
2. There should be days off between the last game of all football group games and the first game of the semi-finals
3. There should be days off between the last semi-final game and the final match

3.2 Model formulation, defining and solving the University soccer timetabling problem

3. 2.1 Notations

The following notations used in the model formulation, defining and solving the problem are described below:

x = Match index (where x=1, 2,3,...,r) , $1 \leq x \leq n$ for group stage, $n < x \leq m$ for knock out stage, $m < x \leq q$ is for quarter final, $q < x \leq w$ for semifinal and r is the final match.

y = Field index (where y=1, 2,3,...,s)

z = Time slot index (where z=1,2, 3, ..., t)

h = Number of available time slots per day

H = Number of available time slots

A = Set of team groups($a_1, a_{2,} \dots, a_{v,}$)

v = Number of team groups

J = Number of teams in a group, a

F =Total number of teams in all groups

K =Number of matches (set of two unique teams) to be played in a group (K ϵ U)

U = Total number of matches to be played all through the competition (group stage and knockout stages)
CG_a =Set of matches to be taken by team group, a

CT = Set of timeslot available for match per day

d = number of days off between two consecutive games

Decision variable, $P_{xyz} = \begin{cases} 1, if\ match\ x\ is\ played\ on\ field\ y\ at\ timeslot\ z \\ 0,\ If\ otherwise \end{cases}$

3.2.2 Mathematical Model Formulation

The soccer timetabling problem which assigns matches, fields and officials to fixed timeslots considering a number of problem-specific constraints is modelled as integer linear programming.

Assumptions

The underlying assumptions for the University Soccer timetabling problem are highlighted below:

1. The soccer teams in each soccer group are predetermined
2. The set of two unique soccer teams in every soccer match in the group stage is predetermined
3. Every soccer group has a set of available timeslots during which only soccer games in such groups can be scheduled
4. Every team in a soccer group is available on all available timeslots assigned to the group

5. Set of Officials (referee, linesmen and third official) for each soccer game are predetermined
6. No set of officials can officiate two soccer matches at the same time
7. For every given timeslot, the soccer game will be played at a predetermined time and all teams are available at that time
8. Every soccer match must have a total allocated time which is equivalent to its time pocket and is contiguous
9. The actual time used for a soccer match must be greater than or equal to the total time allotted to that soccer match.
10. No field preferences are given to any soccer team
11. All fields are available on all available days in the time table duration
12. All games must be within the defined tournament schedule (timetable duration), and the number of available days must be specified
13.

Development of Constraints and Objective Functions

The hard constraints of the soccer timetabling problem are shown mathematically as follows:
A field must not be assigned for more than one match at a timeslot.

$$\sum_{x=1}^{r} P_{xyz} = 1 \text{ , } \forall \mathrm{y} = 1, 2, \ldots, \mathrm{s} \ \forall \mathrm{z} = 1, 2, \ldots, t \qquad (1)$$

A team in a group cannot take more than one match at a time slot, z

$$\sum_{x \epsilon CG_a} \sum_{y=1}^{s} P_{xyz} \leq 1 \quad \forall \mathrm{x} = 1,2, \ldots, \mathrm{r} \ \forall \mathrm{a} = 1,2, \ldots, \mathrm{v} \qquad (2)$$

Not more than *h* matches can be played in a day for the group stage.

$$\sum_{y} \sum_{z \, \epsilon \, CT_H} P_{xyz} \leq h \, for \, 1 \leq x \leq n \qquad (3)$$

The total number of matches is expressed as

$$\sum_{x=1}^{r} \sum_{y=1}^{s} \sum_{z=1}^{t} P_{xyz} = U \tag{4}$$

There must be more than one-day break between consecutive games of a unique team in any match that is there must be a break between i^{th} match and the next $i^{th}+1$ match. The last match x_i of two unique teams played at z_i and the next matchx_{i+1} of those same teams must be scheduled at time$z_{i+(h+1)}$, where h is the number of timeslot in a day.

$$z_{i+(h+1)} - z_i > h \tag{5}$$

There must be at least a day's break between the last game of all football group games and the first game of the semi-finals.

$$|x_w - x_n| \geq 1 \tag{6}$$

There must be at least a day's break between the last semi-final game and the final match

$$|x_r - x_w| \geq 1 \tag{7}$$

The soft constraints of the soccer timetabling problem are shown mathematically as follows:

There should be days off between the last game of a football group and the first game of the next football group

$$|x_n - x_1| \geq d \tag{8}$$

There should be days off between the last game of all football group games and the first game of the semi-finals

$$|x_w - x_n| \geq d \tag{9}$$

There should be days off between the last semi-final game and the final match

$$|x_r - x_w| \geq d \tag{10}$$

Objective Function

The combination of the soft constraints gives the objective function:

Let f1(t) represent equation (8). Let α1 be the weight assigned to this constraint. Hence, we aim to maximize: $\alpha 1 f1(t)$

Let f2(t) represent equation (9). Let α2 be the negative weight assigned to this constraint. Hence, we aim to maximize: $\alpha 2 f2(t)$

Let f3(t) represent equation (10). Let α3 be the negative weight assigned to this constraint. Hence, we aim to maximize: $\alpha 3 f3(t)$

Combining the above three soft constraints, gives the objective function of the model:

$$F(t) = \alpha 1 f1(t) + \alpha 2 f2(t) + \alpha 3 f3(t) \tag{11}$$

The University soccer timetabling model is given as

$$Maximize\ F(t) = \alpha 1 f1(t) + \alpha 2 f2(t) + \alpha 3 f3(t)$$

Subject to:

$$\sum_{x=1}^{r} P_{xyz} = 1$$

$$\sum_{x \epsilon CG_a} \sum_{y=1}^{s} P_{xyz} \leq 1$$

$$\sum_{y} \sum_{z \epsilon CT_H} P_{xyz} \leq h$$

$$\sum_{x=1}^{r} \sum_{y=1}^{s} \sum_{z=1}^{t} P_{xyz} = U$$

$$z_{i+(h+1)} - z_i > h$$

$$|x_w - x_n| \geq 1$$

$$|x_r - x_w| \geq 1$$

3.2.3 Method of Solving the Soccer Timetabling Problem

A decision-based algorithm is applied to solve the soccer timetabling problem. Figure 1 gives a flowchart representation of the algorithm. Given a pool of unassigned match indices and a specific time slot to assign matches to, the algorithm is given as follows:

STEP 0 Check if there exist unassigned match indices. If yes, proceed to step 1. If no, stop

algorithm.

STEP 1 Randomly select the maximum number of match indices that can fit into the current time slot.

STEP 2 For each unique soccer teams in the match indices selected, do:

2-A Check if the same soccer team appears in multiple match indices selected

2-B If the soccer team appears in more than one of the match indices selected, select only one such match index and discard the other selected match indices the team appears in

2-C Proceed to randomly select another n match indices from the unassigned pool to replace the n discarded index / indices above. This selection will be done such that the soccer teams in the selected index in step a. above are not present in any of the newly selected match index / indices.

STEP 3 For each match index in the selected match indices, do:

3-A Check if any of the soccer teams in the match index have had any immediate previous games

3-B If no, proceed to step 4. If yes, proceed to 3-C.

3-C Check if the difference between the current timeslot and the timeslot of the immediate previous game is greater than one.

3-D If yes, proceed to step 4. If no, discard the match index

3-E If this is the last match index amongst selected match indices, proceed to step 0.

STEP 4 Insert match index in this timeslot

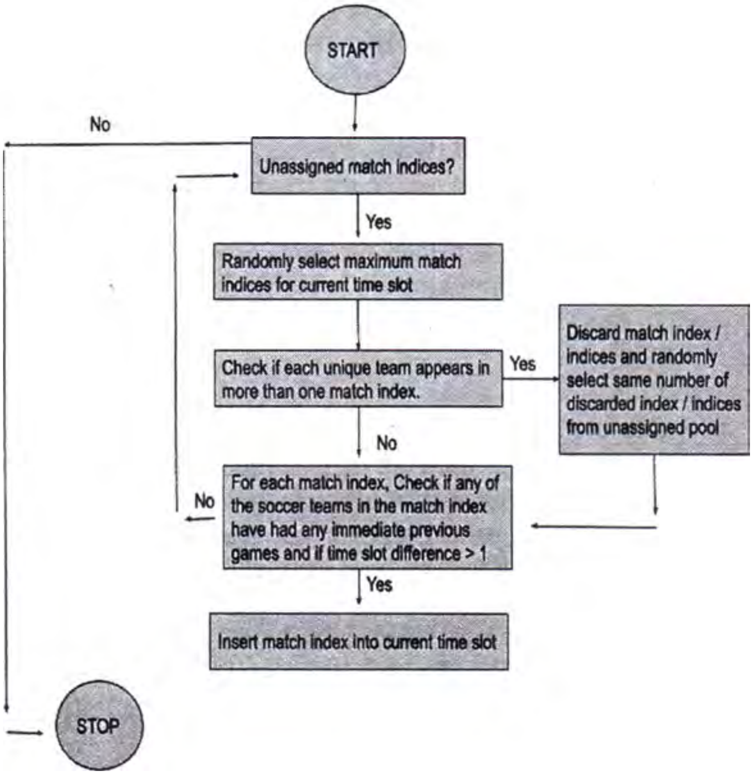

Fig. 1: Flowchart for decision-based algorithm

4. Model Application and Discussion of Results

This section gives the description of the case study, collection of data, defining and solving the University of Ibadan inter-faculty soccer timetabling problem, presentation and discussion of results.

4.1 Brief description of the case study

The interfaculty soccer competition in the University of Ibadan is an annual competition. This competition is held between faculties in the

University of Ibadan. The competition has two phases - a single-round robin group stage and a knockout stage. The competition usually consists of 12 teams split into two groups. Each team in a group plays every other team in the same group once. Two teams then qualify from each group based on a point-based system (win – 3 points, Draw – 1 point, Loss - 0 point). The two top two teams which qualify from each group (making four teams in total) then proceed to the semi-final stages. Two teams are knocked out in this stage and then the two teams which qualify then proceed to the final. The winning team at the final wins the competition. The duration of this tournament is usually five weeks.

4.2 Data Collection

The data and information about the university of Ibadan inter-faculty soccer competition was gotten from the organizing sports council. The organizing sport council provided the various rules of the competition, as well as information about facilities, officials, groups, teams, fields, and so on. The values of the parameters for the competition obtained are shown in Table 2. Also, the faculty teams that will play in the University of Ibadan inter-faculty competition and their respective groups are shown in Table 3. The predefined teams that will play in soccer matches in the competitions were obtained and match indices were assigned to them as shown in Table 4.

Table 2: List of Parameters and their respective values for the University of Ibadan Inter-faculty soccer timetabling problem

Name of Parameter	Value
Number of football fields	2
Timetable Duration	5 weeks (Available days – Mondays to Saturdays)

Number of available days	30
Number of football teams	12
Number of football groups	2
Number of football teams per group	6
Number of soccer matches to be played per group	15
Total Number of Soccer matches in the group stage	30
Number of soccer matches in knockout stages	3
Total Number of soccer matches in the inter-faculty competition	33

Table 3: Groupings of teams in the University of Ibadan Inter-faculty soccer competition

Group A	Group B
Science	Law
Social Science	Basic Medical Sciences
Pharmacy	Public Health
Agriculture and Forestry	Clinical Sciences
Technology	Education
Arts	Veterinary Medicine

Table 4: List of Soccer matches and their corresponding match indices in the University of Ibadan Inter-faculty soccer competition

Match	Corresponding Match Indices
Science vs Social Science	1
Science vs Pharmacy	2

Science vs Agriculture and Forestry	3
Science vs Technology	4
Science vs Arts	5
Social Science vs Pharmacy	6
Social Science vs Agriculture and Forestry	7
Social Science vs Technology	8
Social Science vs Arts	9
Pharmacy vs Agriculture and Forestry	10
Pharmacy vs Technology	11
Pharmacy vs Arts	12
Agriculture and Forestry vs Technology	13
Agriculture and Forestry vs Arts	14

Public Health vs Veterinary Medicine	27
Clinical Sciences vs Education	28
Clinical Sciences vs Veterinary Medicine	29
Education vs Veterinary Medicine	30
First semi-final game	31
Second Semi-final game	32
Final game	33

Other rules concerning the tournament were stated thus:

- Four teams will be eliminated from each group, leaving two teams from each group to qualify for the knockout phase
- Timeslot is defined as the continuous length of time during which the match takes place. For the university soccer timetabling, since matches can only be played early in the morning or in the evening before or after lectures respectively. 2 timeslots are available per day. The number of available timeslot per day is equal to 2 timeslots per day multiply by the number of football pitch available. Timetable must span a maximum of 5 weeks, and the only available timeslots are from Mondays to Saturdays. This means there are 30 available days, available timeslot in 5 weeks is 2 x 2 x 30 = 120

4.3 Defining and Solving the University of Ibadan Inter-Faculty Soccer Timetabling Problem

Problem parameters are estimated and weights are selected for the objective function and a decision based model is applied to solve the University timetabling problem for inter-faculty soccer competition.

Defining the University of Ibadan Inter-Faculty Soccer Timetabling Problem

The soccer timetabling problem is defined as the University of Ibadan inter-faculty soccer competition. The problem parameters are listed as follows:

Number of football fields (s) - 2

Timetable Duration - 5 weeks

Number of available timeslots in days -30

Number of available timeslots (H) – 120

Number of football teams (F) - 12

Number of football groups (v) -2

Number of football teams per group (J) - 6

Number of soccer matches to be played per group (K) - 15

Total Number of soccer matches in the inter-faculty competition (U) – 33

The mathematical model for University of Ibadan inter-faculty soccer timetabling is given as

$$Maximize\ F(t) = 3\,(f1(t)) + 1.5\,(f2(t)) + 2\,(f3(t)))$$

Subject to

$$\sum_{x=1}^{r} P_{xyz} = 1\, , \forall \mathrm{y} = 1, 2.\ \forall \mathrm{z} \ = 1, 2, \ldots, 120$$

$$\sum_{x \in CG_a} \sum_{y=1}^{s} P_{xyz} \leq 1 \quad \forall \mathrm{x} = 1,2, \ldots ,33\, \forall \mathrm{a} = 1,2.$$

$$\sum_{y} \sum_{\mathrm{z} \in CT_H} P_{xyz} \leq h \; for\; 1 \leq x \leq 30$$

$$\sum_{x=1}^{r} \sum_{y=1}^{2} \sum_{z=1}^{120} P_{xyz} = 33$$

$$z_{i+(h+1)} - z_i > 4$$

$$|x_w - x_n| \geq 1$$

$$|x_r - x_w| \geq 1$$

Solving the University of Ibadan Inter-Faculty Soccer Timetabling Problem

The decision algorithm was used to solve the University of Ibadan Inter-faculty soccer timetabling problem and the result is shown in Table 5. There is 4-timeslot per day which makes a total of 120 timeslots for the available days for the match which is 30 days. For constraint of space, the result only shows the timeslot for each match and the field at which the match will take place. The results in Table 5 is presented as follows; On Day 1, Match 2 takes place on field 1 at timeslot 1 while match 7 takes place on field 2 at timeslot 4.

Table 5: Timetable obtained for the University of Ibadan Inter-faculty soccer competition

Available days for match	Available Time Slots	Match Indices	Field indices
1	1, 4	2,7	1,2
2	6	15	1
3	11	1	2
4	14,15	11,14	1,2
5			
6	21,24	9,10	1,2
7	26	4	1

8	31	6	2
9	33,36	5,13	1,2
10			
11	42,43	3,8	1,2
12	45	12	1
13			
14			
15	58,59	17,28	1,2
16	61	30	1
17	68	16	2
18	69,72	26,29	1,2
19			
20	78, 79	24,25	1,2

21	81	19	1
22	87	21	2
23	89,92	20,28	1,2
24			
25	98,99	18,23	1,2
26	101	27	1
27			
28	110,111	31,32	1,2
29			
30	117	33	1

4.4 Discussion of Results

A feasible timetable obtained for the University of Ibadan inter-faculty competition with the use of the decision algorithm indicates that an optimal timetable was obtained. The timetable obtained satisfies all hard constraints and all soft constraints of the University soccer timetabling problem. 33 soccer matches were assigned to 33 timeslots out of the available total of 120 timeslots, Matches were played on 22 days out available 30 days. This means that there were eight seven timeslots during which no soccer match held. The field assignment shows that field 1 was used more than field 2. Out of the 33 games to be played in the University of Ibadan inter-faculty soccer competition, 18 are to be played on field 1. The remaining 15 soccer matches were assigned to field 2. The timetable obtained shows that the soccer matches begin on the first timeslot and the last soccer match, which signifies the end of the competition is assigned to the last available timeslot. The results show that the group stage matches is completed by day 26 and necessary breaks are observed in the timetable. Also, there would be a day rest before the semi-final games as well as a day rest before the final game. The results show that the decision algorithm gives a feasible timetable that satisfies all hard and soft constraints.

5 Conclusion and Recommendation

This study focuses on the development of the University soccer timetabling problem. The parameters, decision variables, hard constraints and soft constraints were identified for the university soccer timetabling problem. A mathematical model was developed for the university soccer timetabling problem. The model developed was applied to University of Ibadan inter-faculty soccer competition. The competition featured 12 teams split into 2 groups, with 6 teams in each group. The competition featured a single-round robin group stage from which two teams qualified into the knockout stage.

The timetable for this competition was obtained with the use of a decision algorithm. The algorithm was developed to adequately cater for the hierarchical weighted soft constraints. The algorithm was applied until an optimal solution was obtained. 33 soccer games were scheduled over 120 available timeslots within 30 available days without violating any hard or soft constraint. The result shows that the soccer timetabling problem is feasible as demonstrated in its application to the inter-faculty soccer competition in the University of Ibadan.

Based on the results of the study, it is recommended that the decision algorithm developed for this study be further studied to improve its computational efforts as it took several trials for an optimal timetable to be obtained.

References

Ait-Ali, A., Lindberg, P. O., Eliasson, J., Nilsson, J. E., & Peterson, A. (2020). A disaggregate bundle method for train timetabling problems. *Journal of Rail Transport Planning & Management*, 100200. https://doi.org/10.1016/j.jrtpm.2020.100200

Alarcón, F., Durán, G., Guajardo, M., Miranda, J., Muñoz, H., Ramírez, L., Ramírez, M., Sauré, D., Siebert, M., Souyris, S., Weintraub, A., Wolf-Yadlin, R., & Zamorano, G. (2017). Operations research transforms the scheduling of Chilean soccer leagues and South American world cup qualifiers. *Interfaces*, *47*(1), 52–69. https://doi.org/10.1287/inte.2016.0861

Anagnostopoulos, A., Michel, L., Hentenryck, P., & Vergados, Y. (2006). A simulated annealing approach to the travelling tournament problem. *Journal of Scheduling*, *9*(2), 177–193.

Bartsch, T., Drexl, A., & Kröger, S. (2006). Scheduling the professional soccer leagues of Austria and Germany. *Computers & Operations Research*, *33*, 1907–1937. https://doi.org/10.1016/j.cor.2004.09.037

Bonomo, F., Cardemil, A., Durán, G., Marenco, J., & Sabán, D. (2012). An Application of the Traveling Tournament Problem : The Argentine Volleyball League. *Interfaces*, *42*(3), 245–259.

Brandenburg, L., Gabow, P., Steele, G., Toussaint, J., & Tyson, B. J. (2015). Innovation and Best Practices in Health Care Scheduling. In *NAM perspectives*. http://iom.edu/~/media/Files/Perspectives-Files/2015/SchedulingBestPractices.pdf

Briskorn, D., & Drexl, A. (2009). IP models for round robin tournaments. *Computers and Operations Research*, *36*(3), 837–852.

https://doi.org/10.1016/j.cor.2007.11.002

Burke, E., de Werra, D., & Kingston, J. (2004). Application to Timetabling. In J. . Gross & J. Yellen (Eds.), *Handbook of Graph Theory*. CRC Press.

Caprara, A., Fischetti, M., & Toth, P. (2002). *Modeling and solving the train timetabling problem. 50*(5), 851–861.

Carlsson, M., Johansson, M., & Larson, J. (2017). Scheduling double round-robin tournaments with divisional play using constraint programming. *European Journal of Operational Research, 259*, 1180–1190. https://doi.org/10.1016/j.ejor.2016.11.033

Charles-Owaba, O. E., Oluleye, A. E., Oyawale, F. A., & Oke, S. . (2008a). An opportunity cost maintenance scheduling framework for a fleet of ships: a case study. *Journal of Industrial Engineering International*, *4*(6), 57–70. http://www.iaujournals.ir/article_511076_3ab78c2d353e3875ab7d651c21929662.pdf

Charles-Owaba, O. E., Oluleye, A. E., Oyawale, F. A., & Oke, S. A. (2008b). A facility maintenance scheduling model incorporating opportunity and inflationary costs. *International Journal of Industrial and Systems Engineering*, *3*(4), 423–446. https://doi.org/10.1504/IJISE.2008.017553

Charles-Owaba, O., Oladokun, V., & Okunade, O. (2015). Development of the Contiguous-cells Transportation Problem. *Engineering,Technology & Applied Science Research*, *5*(4), 825–831.

Chen, P., Kendall, G., & Berghe, G. Vanden. (2007). An Ant Based Hyper-heuristic for the Travelling Tournament Problem. *Proceedings of the 2007 IEEE Symposium on Computational Intelligence In Scheduling*, 19–26.

Chung, Y., & Kim, H. (2019). The University Examination And Course Timetabling Problem With Integer Programming III . Problem

Description. *Journal of The Korean Society of Computer and Information*, *24*(9), 9–20.

Cocchi, G., Galligari, A., Nicolino, F. P., Piccialli, V., Schoen, F., & Sciandronea, M. (2018). Scheduling the Italian National Volleyball Tournament. *Interfaces*, *48*(3), 271–284.

de Werra, D. (1985). An introduction to timetabling. *European Journal of Operational Research*, *19*(2), 151–162.

Della Croce, F., & Oliveri, D. (2006). Scheduling the Italian Football League: An ILP-based approach. *Computers and Operations Research*, *33*(7), 1963–1974. https://doi.org/10.1016/j.cor.2004.09.025

Durán, G., Guajardo, M., Miranda, J., Sauré, D., Souyris, S., Weintraub, A., & Wolf, R. (2007). Scheduling the Chilean Soccer League by Integer Programming. *Interfaces*, *37*(6), 539–552.

Easton, K., Nemhauser, G., & Trick, M. (2002). Solving the Travelling Tournament Problem : A Combined Integer Programming and Constraint Programming Approach. *International Conference on the Practice and Theory of Automated Timetabling*, 100–109.

Easton, K., Nemhauser, G., & Trick, M. (2001). The Traveling Tournament Problem Description and Benchmarks. *International Conference on Principles and Practice of Constraint Programming*, 580–584.

Espinosa-Aranda, J., Garcıa-Rodenas, R., Ramırez-Flores, M., Lopez-Garcıa, M., & Angulo, E. (2015). High-speed railway scheduling based on user preferences. *European Journal of Operational Research*, *246*, 772–786.

Fiallos, J., Pérez, J., Sabillón, F., & Licona, M. (2010). Scheduling Soccer League of Honduras using Integer Programming. *Proceedings of the 2010 Industrial Engineering Research Conference*.

Fischetti, M., Salvagnin, D., & Zanette, A. (2009). Fast Approaches to Improve the Robustness of a Railway Timetable. *Transportation Science*, *43*, 321–335.

Froncek, D. (2010). Scheduling a tournament. In J. A. Gallian (Ed.), *Mathematics and Sports*. The Mathematical Association of America.

García-Ródenas, R., López-García, M. L., López-Gómez, J. A., & Linares, L. J. (2020). Passenger Centric Train Timetabling Problem with elastic demand. *Transportation Research Procedia*, *47*, 465–472. https://doi.org/10.1016/j.trpro.2020.03.122

Glazebrook, K. D. (1987). Sensitivity Analysis for Stochastic Scheduling Problems. *Mathematics of Operations Research*, *12*(2), 205–223.

Goldberg, A. B. (2003). *Highly Constrained Sports Scheduling with Genetic Algorithms*. Amherst College.

Goossens, D., & Spieksma, F. (2009). Scheduling the Belgian Soccer League. *Interfaces*, *39*(2), 109–118. https://doi.org/10.1287/inte.1080.0402

Gülcü, A., & Akkan, C. (2020). Robust university course timetabling problem subject to single and multiple disruptions. *European Journal of Operational Research*, *283*(2), 630–646. https://doi.org/10.1016/j.ejor.2019.11.024

Gupta, D., & Denton, B. (2008). Appointment scheduling in health care: Challenges and opportunities. *IIE Transactions (Institute of Industrial Engineers)*, *40*(9), 800–819. https://doi.org/10.1080/07408170802165880

Hamiez, J. P., & Hao, J. K. (2004). A linear-time algorithm to solve the Sports League Scheduling Problem (prob026 of CSPLib). *Discrete Applied Mathematics*, *143*(1–3), 252–265. https://doi.org/10.1016/j.dam.2003.10.009

Horn, W. A. (1974). Some simple scheduling algorithms. *Naval*

Research Logistics, *21*(1), 177–185. https://doi.org/10.1002/nav.3800210113

Huang, Y. L. (2003). *An appointment order outpatient scheduling system that improves outpatient experience*.

Karger, D. ., Phillips, S. J., & Torng, E. (1996). A better algorithm for an ancient scheduling problem. *Journal of Algorithms, 20*, 400–430.

Kent, J. K., & Keith, A. . (2011). A decision support system for scheduling the Canadian Football League. In *CORS Bulletin* (Vol. 45, Issue 1, pp. 25–27).

Kostuk, K. J., & Willoughby, K. A. (2012). A decision support system for scheduling the Canadian Football League. *Interfaces*, *42*(3), 286–295.

Kyngäs, J., & Nurmi, K. (2009). Scheduling the finnish major ice hockey league. *2009 IEEE Symposium on Computational Intelligence in Scheduling*, 84–89. https://doi.org/10.1109/SCIS.2009.4927019

Kyngäs, J., Nurmi, K., Kyngäs, N., Lilley, G., & Salter, T. (2014). Scheduling a professional sports league using the PEAST algorithm. *10th International Conference of the Practice and Theory of Automated Timetabling*, 26–29.

Larson, J., & Johansson, M. (2014). Constructing schedules for sports leagues with divisional and round-robin tournaments. *Journal of Quantitative Analysis in Sports*, *10*(2), 119–129. https://doi.org/10.1515/jqas-2013-0090

Lawler, E. L., Lenstra, J. K., Kan, A. H. G. R., & Shmoys, D. B. (1993). Sequencing and Scheduling : Algorithms and Complexity. In S. C. Graves & A. de Kok (Eds.), *Handbooks in operations research and management science. Logistics of Production and Inventory* (Vol. 4, pp. 445–522). . Elsevier Science Publishers.

Leite, N., Melício, F., & Rosa, A. C. (2019). A fast simulated annealing algorithm for the examination timetabling problem. *Expert Systems*

With Applications, *122*, 137–151. https://doi.org/10.1016/j.eswa.2018.12.048

Leng, S., Graham, G., Sabar, N. R., & Abdullah, S. (2020). An effective hybrid local search approach for the post enrolment course timetabling problem. *Opsearch*, 1–33. https://doi.org/10.1007/s12597-020-00444-x

Lewis, R., & Thompson, J. (2011). On the application of graph colouring techniques in round-robin sports scheduling. *Computers and Operations Research*, *38*(1), 190–204. https://doi.org/10.1016/j.cor.2010.04.012

Liebchen, C., & Stiller, S. (2009). Delay resistant timetabling. *Public Transport*, *1*, 55–72.

Lim, A., Rodrigues, B., & Zhang, X. (2006). A simulated annealing and hill-climbing algorithm for the traveling tournament problem. *EJOR*, *173*(3), 1459–1478.

Megow, N., & Vredeveld, T. (2014). A Tight 2-Approximation for Preemptive Stochastic Scheduling. *Mathematics of Operations Research*, *39*(4), 1297–1310.

Nagar, A., Haddock, J., & Heragu, S. (1995). Multiple and bicriteria scheduling: A literature survey. *European Journal of Operational Research*, *81*(1), 88–104. https://doi.org/10.1016/0377-2217(93)E0140-S

Nemhauser, G. L., & Trick, M. A. (1998). Scheduling A Major College Basketball Conference. *Operations Research*, *46*(1), 1–8.

Nurmi, K., Goossens, D., Bartsch, T., Bonomo, F., Briskorn, D., Duran, G., Kyngäs, J., Marenco, J., Ribeiro, C. C., Spieksma, F., Urrutia, S., & Wolf-Yadlin, R. (2010). A framework for scheduling professional sports leagues. *AIP Conference Proceedings, American Institute of Physics*, *1285*(1), 14–28. https://doi.org/10.1063/1.3510542

Nurmi, K., Kyng, J., Goossens, D., & Kyng, N. (2015). Scheduling the Finnish major ice hockey league using the PEAST algorithm. *Transactions on Engineering Technologies*, 155–168. https://doi.org/10.1007/978-94-017-9588-3

Odedairo, B. O., & Oladokun, V. (2011). Relevance and Applicability of Multi-objective Resource Constrained Project Scheduling Problem. *Engineering, Technology & Applied Science Research*, *1*(6), 144–150.

Oke, S. A. (2004). Maintenance scheduling: description, status and future directions. *South African Journal of Industrial Engineering*, *15*(1), 101–117.

Oke, S. A., & Charles-Owaba, O. E. (2006). An approach for evaluating preventive maintenance scheduling cost. *International Journal of Quality & Reliability Management*, *23*(7), 847–879. https://doi.org/10.1108/02656710610679842

Oladokun, V. O., & Badmus, S. . (2008). An integer linear programming model of a university course timetabling problem. *Pacific Journal of Science and Technology*, *9*(2), 426–431.

Oladokun, V. O., Charles-Owaba, O. ., & Olaosebikan, F. O. (2011). A bi-criteria algorithm for the simultaneous minimization of makespan and number of tardy jobs on single machine with sequence dependent set-up time. *Research Journal of Applied Science, Engineering and Technology*, *3*(9), 1048–1051.

Oluleye, A. E., & Oyetunji, E. . (1999). Performance of some static flowshop scheduling heuristics. *Directions in Mathematics*, 315–327.

Oyetunji, E. O. (2011). Assessing solution methods to mixed multi-objectives scheduling problems. *International Journal of Industrial and Systems Engineering*, *9*(2), 213. https://doi.org/10.1504/IJISE.2011.042836

Oyetunji, E. O., & Oluleye, A. . (2010). Hierarchical minimization of total completion time and number of tardy jobs criteria. *Asian Journal of Information Technology*, *7*(4), 157–161.

Oyetunji, E. O., & Oluleye, A. E. (2012). A Generalized Algorithm for solving multicriteria scheduling problems. *Advanced Materials Research*, *36*(7), 653-666.

Pfund, M. E., Mason, S. J., & Fowler, J. W. (2006). Semiconductor manufacturing scheduling and dispatching. In *Handbook of production scheduling* (pp. 213–241). Springer.

Pinedo, M. L. (2008). *Scheduling:Theory,Algorihms,and Systems* (Third). Springer Science+Business Media.

Qi, J., Yang, L., Gao, Y., & Di, Z. (2019). Service-oriented train timetabling problem with consideration of women-only passenger cars. *Computers & Industrial Engineering*, *127*, 1164–1182. https://doi.org/10.1016/j.cie.2018.04.054

Rasmussen, R. V. (2008). Scheduling a triple round robin tournament for the best Danish soccer league. *European Journal of Operational Research*, *185*(2), 795–810. https://doi.org/10.1016/j.ejor.2006.12.050

Recalde, D., Torres, R., & Vaca, P. (2013). Scheduling the professional Ecuadorian football league by integer programming. *Computers and Operations Research*, *40*(10), 2478–2484. https://doi.org/10.1016/j.cor.2012.12.017

Ribeiro, C. C. (2012). Sports scheduling: Problems and applications. *International Transactions in Operational Research*, *19*(1–2), 201–226. https://doi.org/10.1111/j.1475-3995.2011.00819.x

Ribeiro, C. C., & Urrutia, S. (2012). Approach and Practice Scheduling the Brazilian Soccer Tournament : Solution Approach and Practice. *Interfaces*, *42*(3), 260–272.

Roboredo, M. C., Aizemberg, L., Pessoa, A. A., & de Mello, J. C. C. B. S. (2014). Scheduling the Brazilian Football League Minimizing

Extended Carry-Over Effects Associated To Strength Groups. *Engevista*, *16*(1), 102–110. https://doi.org/10.22409/engevista.v16i1.634

Russell, R. A., & Urban, T. L. (2006). A constraint programming approach to the multiple-venue, sport-scheduling problem. *Computers and Operations Research*, *33*(7), 1895–1906. https://doi.org/10.1016/j.cor.2004.09.029

Schonberger, J., Mattfeld, D. C., & Kopfer, H. (2004). Memetic Algorithm timetabling for non-commercial sport leagues. *European Journal of Operational Research*, *153*, 102–116. https://doi.org/10.1016/S0377-2217(03)00102-4

Skutella, M., Sviridenko, M., & Uetz, M. (2014). Stochastic Scheduling on Unrelated Machines. *31st International Symposium on Theoretical Aspects of Computer Science (STACS 2014)*, 639–650.

Stephen, R., & Sewell, E. C. (1997). Heuristic , optimal , static , and dynamic schedules when processing times are uncertain. *Journal of Operations Management*, *15*(1), 71–82.

Tavakkoli-Moghaddam, R., Jolai, F., Vaziri, F., Ahmed, P. K., & Azaron, A. (2005). A hybrid method for solving stochastic job shop scheduling problems. *Applied Mathematics and Computation*, *170*(1), 185–206. https://doi.org/10.1016/j.amc.2004.11.036

Thepphakorn, T., & Pongcharoen, P. (2020). Performance Improvement Strategies on Cuckoo Search Algorithms for Solving the University Course Timetabling Problem. *Expert Systems With Applications*, *161*, 113732. https://doi.org/10.1016/j.eswa.2020.113732

Urban, T. L., & Russell, R. A. (2003). Scheduling sports competitions on multiple venues. *European Journal of Operational Research*, *148*(2), 302–311. https://doi.org/10.1016/S0377-2217(02)00686-0

Van Bulck, D., Goossens, D. R., & Spieksma, F. C. R. (2018). Scheduling a non-professional indoor football league : a tabu search based approach. *Annals of Operations Research*, *275*(2), 715–730.

https://doi.org/10.1007/s10479-018-3013-x

Van Bulck, D., Goossens, D., Schönberger, J., & Guajardo, M. (2020). RobinX : A three-field classification and unified data format for round-robin sports timetabling. *European Journal of Operational Research*, *280*, 568–580. https://doi.org/10.1016/j.ejor.2019.07.023

Vieira, G. E., Herrmann, J. W., & Lin, E. (2003). *Rescheduling Manufacturing Systems : a Framework of Strategies , Policies , and Methods*. 39–62.

Wang, J., Zhou, L., & Yue, Y. (2019). Column Generation Accelerated Algorithm and Optimisation for a High-Speed Railway Train Timetabling Problem. *Symmetry*, *11*(8), 983.

Wong, R. C. W., Yuen, T. W. Y., Fung, K. W., & Leung, J. M. Y. (2008). Optimizing Timetable Synchronization for Rail Mass Transit. *Transportation Science*, *42*, 57–69.

Wren, A. (1996). Scheduling, timetabling and rostering - A special relationship? In R. P. (eds) Burke E. (Ed.), *IPractice and Theory of Automated Timetabling. PATAT 1995. Lecture Notes in Computer Science* (Vol. 1153, pp. 46–75). Springer. https://doi.org/10.1007/3-540-61794-9_51

Wright, M. B. (2006). Scheduling fixtures for Basketball New Zealand. *Computers & Operations Research*, *33*, 1875–1893. https://doi.org/10.1016/j.cor.2004.09.024

Wright, M. B. (2009). 50 Years of OR in Sport. *Journal of the Operational Research Society*, *60*(SUPPL. 1), 161–168. https://doi.org/10.1057/jors.2008.170

Zhang, H. (2002). Generating college conference basketball schedules by a SAT solver. *Proceedings Of The Fifth International Symposium on the Theory and Applications of Satisfiability Testing*, 281–291. http://gauss.ececs.uc.edu/Conferences/SAT2002/Abstracts/zhang.pdf

Zhang, Y., Peng, Q., Yao, Y., Zhang, X., & Zhou, X. (2019). Solving cyclic train timetabling problem through model reformulation : Extended time-space network construct and Alternating Direction Method of Multipliers methods. *Transportation Research Part B*, *128*, 344–379. https://doi.org/10.1016/j.trb.2019.08.001

Zhang, Yebin, Wu, X., & Zhou, X. (2013). Stochastic scheduling problems with general position-based learning effects and stochastic breakdowns. *Journal of Scheduling*, *16*(3), 331–336. https://doi.org/10.1007/s10951-012-0306-9

CHAPTER 7

The Role of Renewable Energy in Nigeria's Energy Transformation

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Abstract

The domination of the energy mix of most countries across the globe by fossil fuel has been having serious effects on the climatic conditions, resulting from constant emission of greenhouse gases, GHG. It has also been found to be detrimental to human health, and as such, not less than 5 million cases of premature deaths due to local air pollution are annually recorded. Therefore, to combat GHG emissions and air pollution, there is an urgent need to adopt clean sources of energy generation, such as the renewables. This chapter discusses the meaning, history and benefits of renewable energy, highlights the common forms and sources, dwells on energy trends in Nigeria, reflects on hydropower plants in relation to technology, material selection and efficiency, as well as draws conclusions from areas covered.

Renewable energy – What does it mean?

Renewable energy, also called clean energy, is that source of energy that is being constantly replenished, originates from natural sources or processes and does not bring any harm to nature (Shinn, 2018; Project Solar, 2018 and Quaschning, 2019). As defined in the national renewable energy and energy efficiency policy (NREEEP) of Nigeria, renewable energy is that energy obtained from energy sources whose usage will not lead to the depletion of the earth's resources (Kehinde *et.al.*, 2018). Examples are solar, hydro, wind, biomass energy and geothermal power. Another typical example is the bioenergy, which include biofuels, biopower and bioproducts (Bolarinwa, 2018). However, biofuel usage has been gaining popularity by the day, as biogas, a typical biofuel, is being increasingly used in both developed and developing countries. A major advantage of the renewable energy types is that they cannot undergo depletion (Shinn, 2018 and Project Solar, 2018).

As the world continues to move away from fossil fuel (oil, gas, coal and so on), into the clean energy era, consumption of renewable energy types increasingly gain global recognition (Bolarinwa, 2018). Although entirely new to many parts of the world in advanced forms, humans have been using renewable energy in different forms for heating (sunlight), as means of transportation (wind for sailing) and grinding (windmills) to mention a few (Shinn, 2018). Energy is of paramount importance, as it continuously plays key roles in the technological, industrial, economic and social advancement of any nation (Bolarinwa, 2018). Historically, adoption of renewable energy started in Europe more than two thousand years ago in the form of water wheels, which forms the principles guiding the hydropower (Project Solar, 2018). Although its use dated back to around 635 AD in the Middle East and Central Asia, its perfection took place in Netherlands. Table 1 shows the historical development of renewable energy across time.

Table 1: Historical development of renewable energy (Source: Richie, 2017; Project Solar, 2018; Nunez, 2019; OECD/FAO, 2019; Folk, 2020)

Year	Development that took place in relation to renewable energy.
1590	Windmills were the order of the day in Netherlands.
1839	Discovery of photoelectric effect by Edmond Becquerel.
1860	A famous French inventor, Augustin Mouchot perfectly developed the first solar energy system in the world.

1876	Kings College, London's professor of natural philosophy, William Grylls Adams used selenium to trap sunrays for electricity generation.
1882	The world's first hydroelectric power plant was in the United States, situated along the Fox River in Appleton, Wisconsin was commissioned.
1887	Wind turbines were built in Europe
1888	Charles F. Brush developed the first windmill for electricity generation. A total of 72 electricity generating wind turbines were available back then in Denmark.
1921	Perfection of photoelectric effect by the famous physicist, Albert Einstein.
1927	Wind turbines were commercialised in the United States to aid farming.
1930	Electricity generating wind turbines had widely spread across the United States.
1935	United States's largest hydroelectricity system, Hoover Dam was built in Colorado for water supply to South California, Arizona and later to Connecticut.
1958	The first United States's solar-powered satellite (Vanguard 1) was launched.
1978	The whole of Tohono Oodam reservation in Arizona was solar-electrified.
1996	Sodium nitrate and potassium nitrate were combined to enhance storage of solar energy for a longer time, especially after sunset.
2013	The world's largest solar plant (Ivanpah) was built in the Mojave Desert of South California on about 4,000 acres of land (with construction cost of about 2.2 billion dollars).
2016	About 341,320 electricity generating wind turbines were already functioning across the globe, creating up to 1.55 million jobs across the globe.
2019	7%, 2% and 1% of the World's energy; together with 16%, 5% and 2% of the World's electricity supply were

	respectively coming from hydropower, wind and solar energy.
2019	77% of the total biodiesel production, and 60% of the bioethanol production were already coming from vegetable oils and crops respectively.

Forms and sources of renewable energy

Renewable energy can come in different forms, depending on the primary source of the energy in question.

Solar energy is obtained by arresting the radiant energy from sunlight and transforming it into heat, electricity, or hot water (Just Energy, 2020). The use of photovoltaic (PV) systems help to convert direct sunlight into electricity through the use of solar cells (Just Energy, 2020). This form of energy has continued to gain global attention, that is, it is the fastest growing and most widely acceptable nowadays, due to its efficiency and convenience (Richie, 2019; Tesla, 2020).

Wind power is created when sunlight hits the earth's surface, causing a difference in temperature across different regions of the earth surface and resulting to movement of air molecules in the atmosphere (Nelson & Starcher, 2018). It is naturally harnessed using wind turbines, but requires a large region of area fields (Nelson & Starcher, 2018). In simple terms, mechanical energy is created with the wind going into the wind turbine and this energy is finally transformed to electricity (Tesla, 2020).

Hydroelectric power is the form of energy that can be harnessed using the kinetic energy of water to turn a turbine, which then generates electricity from the mechanical movement of the turbine blades, usually aided by generator in most cases (Grigsby, 2018; Tesla 2020). Although about a quarter of World's total electricity generation comes from renewables, hydropower is the biggest source of renewable energy, accounting for more than 60% of renewable energy generation (Ritchie, 2017). Hydropower energy is not only continuous, but can be predicted for proper management (Tesla, 2020).

Geothermal energy comes from heat trapped underneath the earth's crust and possibly from radioactive decay (Just Energy, 2020). This heat can cause volcanic eruptions and geysers when released at once naturally. It can however be arrested and used to generate geothermal energy, using the steam coming from the heated water pumping below the surface and rising to the top to operate a turbine (Just Energy, 2020; Tesla, 2020).
Other forms of renewable energy include biomass, hydrogen, fuel cells, hydrogen fusion, and ocean tides (Johansson *et. al.* 1993). The use of biomass, as renewable energy is not only common, but ancient (Ogunsola, 2007: Tesla, 2020). A typical example is the burning of wood. It involves using both organic and natural materials, which are later transformed into some other utilisable forms. The technologies adopted today are such that tend not generate CO_2 gas. Renewable energies supply up to 26% of the entire electricity presently available worldwide (Folk, 2020). This has been estimated by IEA to increase to about 30% by the year 2024. Figure 1 shows some common forms of renewable energy.

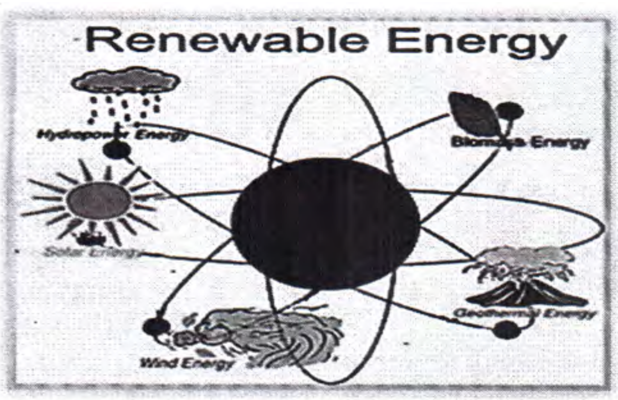

Fig. 1: Common forms of renewable energy (Source: Pazhamkavil, 2014)

Benefits of renewable energy

The major benefit of renewable energy is that since it does not undergo depletion, the problem of emission of greenhouse gases, hence global warming is not there (Bolarinwa, 2018; Tesla, 2020). This makes both the atmosphere and environment to be free from pollution. It also plays vital roles towards the survival of mankind. For instance, it is equally useful for cooking, heating of water and space, electrification, farming, industry, food processing and storage, education, mineral extraction and processing, water damming to mention a few (Asokoroogaji, 2011; Project Solar, 2018). Biomass helps to minimise landfills and produces no greenhouse gases (GHG). In more specific terms, benefits of renewable energy are numerous and include:

(1) Improved public health and environmental conditions.
(2) Constant availability and limitless supply.
(3) Reduction of energy costs.
(4) Creation of more employment opportunities.
(5) Possibly embarked upon on both small and large scales to cater for both domestic and industrial energy consumptions.

Nigeria and energy trends

While attainment of clean energy is one of the 17 sustainable development goals of the United Nations, of which Nigeria is a member, energy demand in Nigeria is still higher than the present supplies (Kehinde *et. al.,* 2018). Setbacks keep recurring in her energy sector (Nwagbo, 2017; EIA, 2020). In 2017, energy consumption in Nigeria was estimated to 1.5 quadrillion British thermal units, BTU (EIA, 2020). This is mostly derived from natural gas, petroleum and other liquids (97%). The remaining quota (3%) came from renewables, coal, biomass and waste. While Nigeria's electricity generation capacity was about 12,664 MW in 2017; 10,522 MW (83%) came from fossil fuels, 2,110 MW (about 16%) was from hydroelectricity. Only 32 MW (1%) came from solar, wind, biomass and waste (EIA, 2020). As a result of this under-capacity electricity generation, up till the end of 2018, just about 60% of Nigerians had access to electricity supply. In 2018, Nigeria was the highest producer of oil and natural gas in Africa, and was the fifth-largest exporter of liquified natural gas worldwide, coming after Qatar, Australia, Malaysia and United States (EIA, 2020). Her exportation of about 982 Bcf of LNG accounted for about 6.5% of the global LNG trade. While India was the largest importer of Nigerian crude oil, Spain emerged as the largest importer of her LNG, followed by India and France (EIA, 2020). The 2018 estimate of EIA indicated that while crude-oil is mainly used for backup power generation in Nigeria, most of the electricity generation coming from fossil fuel is from natural gas (EIA, 2020). These 2 products have remained the country's main source of income. IMF estimated that alone in 2018, Nigeria realised about $55billion from the sales of oil and gas. Unfortunately, the non-oil revenue constitutes just about 3.4% of gross domestic product (GDP), about the lowest in the world (EIA, 2020). Towards the end of 2019, while Nigeria's proved crude oil reserves was estimated to 37 billion barrels, her proved natural gas was estimated to 200.4 trillion cubic feet (Tcf), and marketed natural gas of about 1.6 Tcf (EIA, 2020). The country has since increased her LNG by about 365 billion cubic feet (Bcf). On the other hand, Nigeria ranked the 7th largest natural gas flaring nation in 2018, flaring up to 26.1 Bcf (EIA, 2020). Renewable energy from hydropower, which is the bedrock for electricity generation into the Nigeria national grid, has been in existence since around the middle of the twentieth century (IIED, 2012). Presently in Nigeria, there are three major hydropower plants all together generating about 1.9 GW hydropower capacity (Ufondu *et. al.*, 2019). These are located at Kainji, Jebba and Shiroro. Whereas, the extent of the industrial growth of a nation largely depends on available energy and its utilisation. Prospects exist for renewable energy in Nigeria due to its ability to provide energy in the remote areas (IIED, 2012). For instance, the technical potential of solar energy in Nigeria is estimated at 1.50×10^8 joule of useful energy annually on a 5% device conversion efficiency, which almost equals 258.62 million barrels of oil on annual basis (Nwagbo, 2017). Nigeria also has the capability to harness wind for electricity generation. While a wind data survey was conducted between 1979 and 1988, as at 2017, about 30 wind stations have been developed (Nwagbo, 2017). In the case of hydroelectricity, recent studies by experts show that only 24% of large and 4% of small possible hydropower generation in Nigeria have been embarked upon. Although renewable energy is undoubtedly available in Nigeria, it is yet to take its full course! Government policies are regularly put in place to coordinate the activities of this sector. For instance, the Nigerian government, in 2003 introduced renewable into the national energy grid. This came up again in the 2005/2006 renewable energy master plan (REMP), whose successful implementation means adequate wind, solar PV, solar thermal and hydroelectricity sources by 2025 in providing an equivalent of the capacity available in Nigeria today (Nwagbo, 2017; Ufondu *et. al.*, 2019). NREEEP to actualise the objectives of REMP and REAP (renewable energy activation plan). The government also came up with the national biofuel policy in 2007 and incentive for integrating the agricultural sector in order to improve the quality of automotive fossil-based fuels in Nigeria. Other governmental efforts put in place to develop the country's energy sector include the rural electrification strategy and implementation plan (RESIP) and the building energy efficiency code of 2017 to control the cost and availability of energy at domestic and industrial levels, as well as minimising wastage (Ufondu *et. al.*, 2019). Nigeria's energy problems are created by very poor maintenance of her power sector, especially the electricity facilities; bad electricity transmission and distribution network; as well as shortages in natural gas supply (EIA, 2020). Table 2 shows some of Nigeria's energy resources (Akorede *et. al.*, 2017).

Table 2: Energy Resources in Nigeria (Source: Akorede *et. al.*, 2017)

Resource	Reserves (natural units)	Production level (natural units)	Utilisation (natural units)
Crude oil	36.22 billion barrels	2.06 million bpd	445,000 bpd

Natural gas	187 trillion SCF	7.1 billion SCF/day	3.4 billion SCF/day
Coal and lignite	2.734 billion tonnes	Insignificant	Insignificant
Tar sands	31 billion barrels of oil equivalent	0	0
Large hydropower	11,250 MW	1,938 MW (167.4 million MWh/day)	167.4 million MWh/day
Small hydropower	3,500 MW	30 MW (2.6 million MWh/day)	2.6 million MWh/day
Solar radiation	3.5 – 7.0 kWh/m2/day	excess of 240 kWp of solar PV or 0.01 million MWh/day	excess of 0.01 million MWh/day solar PV
Wind	2 – 9 m/s at 10 m height	-	-
Biomass (Fuelwood)	11 million hectres of forest and woodland	0.12 million tonnes/day	0.12 million tonnes/day
Biomass (Animal waste)	245 million assorted animals in 2001	0.781 million tonnes of waste/day in 2001	not available
Energy crops and agric. residues	72 million hectares of agric. land and all waste lands	excess of 0.256 million tonnes of assorted crops residues/ day in 1996	not available

* SCF – standard cubic feet * bpd – barrel per day

Hydropower plants and available technology

Hydropower, produced from water's kinetic energy is one of the most reliable and efficient sources of renewable energy. (Elbatran *et. al.,* 2015). The amount of electricity possibly generated by one hydropower plant depends on the head and flow rate of the river being used, in addition to turbine efficiency and depth (Jawahar, 2017). The existence of hydropower can be traced back to the era during which it was used to grind millet and grain (Lewis *et. al.* 2014). The technology involved determines the resulting hydropower plant (Yaakob *et. al.,* 2015). Possibly available technology can be: (1) Run of River (RoR) (2) Pumped storage (3) Dammed reservoir.

(1) Run of River: This produces electricity by means of the water flowing from the natural range of the river topography, and as well utilises other components within the area. (Egré & Milewski, 2002).
(2) Pumped storage: This pumps water during off-peak hours when electricity is in excess, into an upper storage basin (Hadjipaschalis *et. al.,* 2009). Afterwards, the water flow is reversed, and as such, the water falling through a height creates enough kinetic energy to turn the turbines at the base and generate electricity during peak load. (Mahlia *et. al.*, 2014).
(3) Dammed reservoir: This utilises constructed dam(s) to generate electricity by creating a large mass of standing water known as a reservoir, once this body of water is released through the dam gates, electricity is generated by converting resulting kinetic energy and mechanical energy from the flowing water using turbine and generators. (Cernea, 1997).

In terms of capacity, the quantity of energy generated by the plant determines the size of the hydropower plant in question (Sopian and Razak, 2009). Based on this, hydropower plants can be categorized as:

1. Large hydropower plant: Capacity greater than 10 MW.
2. Small hydropower plant: Capacity ranging between 1 and 10 MW.
3. Mini hydropower plant: Capacity of 100 KW to 1 MW.
4. Micro hydropower plant: Capacity of 5 Kilowatt to 100 KW.
5. Pico hydropower plant: Capacity less than 5 KW.

The Pico hydro energy source is simple and economical to set up (does not require a dam) and with high efficiency rate (Basir and Othman, 2013). It is a form of clean energy source that does not rely on non-renewable energy sources, and most times use the run of river (ROR) technology. It can exhibit up to a maximum of 5 KW output of electricity output (Zainuddin *et. al.*, 2007; Basir and Othman, 2013). This energy source is useful for indoor and streets lightning, powering of TV and radio sets, telephones, refrigerators, farming purposes and poultry rearing, charging of mobile phones and so on. It can be adapted in communities wherein the energy consumption is not much, especially in villages and remote areas to which it is impossible or expensive to extend the national grid (Basir and Othman, 2013). The Pico hydropower system of electrification has been widely adopted in Malaysia (Basir and Othman, 2013), Thailand (Chuenchooklin, 2006) and Rwanda (Kabeja, 2018) in recent times. It is known as a versatile source of power (Chuenchooklin, 2006). Figure 2 shows the setup of a typical Pico hydropower plant.

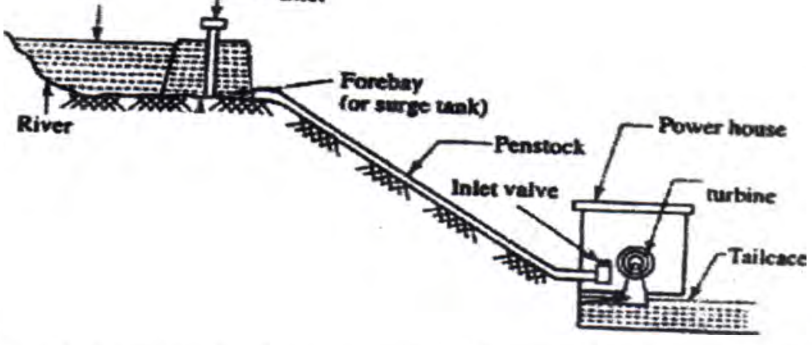

Fig. 2: The Pico hydropower plant (Source: Jawahar and Michael, 2017)

Components of the hydropower plant

The hydropower plant consists of the following components (Anupoju, 2020):

1) Forebay: Basin area of the hydropower plant which temporarily stores water before it is transported to the intake chamber.
2) Intake structure: Directs the water coming from the forebay to the penstock.
3) Penstock: Laid pipes, usually large, for sending water to the turbines.
4) Surge chamber: An open top cylindrical tank for controlling pressure in the penstock.
5) Turbines: Converts the resulting kinetic energy to mechanical energy.
6) Powerhouse: The building that houses the hydraulics and electrical parts for protection.
7) Draft tube: Particularly used with reaction turbines to connect the turbine outlet to tailrace to enable water discharge with safe velocity.
8) Tailrace: Channels the water from turbines to the stream to avoid plant damage, in the form of lowered efficiency, cavitation, damaged turbine blades, due to silting or scouring resulting from unguided flow of water from the powerhouse.
9) Generator: Converts generated mechanical energy to electrical energy.

The Turbine as a critical component

Without the turbine, generation of electricity would not have been possible. The reason is that it converts available mechanical energy to electrical energy by coupling to the generator, the shaft of turbine. It operates in such a manner that high pressure is generated, which in turn rotates the shaft and makes the generator to produce electrical energy (Anupoju, 2020). Turbine types can be:

1) Impulse turbine: Otherwise known as the velocity turbine. Example is the Pelton wheel (Figure 3). The impulse turbine operates by a principle based on the Newtons second law of motion, in which a water jet coming from a nozzle standing-still touches a properly designed blade which subsequently generates a turning force that spins the turbine, thus removing the kinetic energy of water touching the blade of the turbine. The blade movement then converts pressure into kinetic energy. The discharge the water pressure at atmospheric pressure (Benzon *et. al.*, 2016). The performance of impulse turbine is at its best when water head is high but water-flow is low. (Norman, 2003).
2) Reaction turbine: Otherwise known as the pressure turbine. Example is the Francis turbine. A reaction turbine builds torque as a result of the interaction between pressure and the weight of water. The principle of operation here is guided by Newton's third law of motion. (Paish, 2002). Reaction turbines become useful at sites with low head but high flow of water, unlike the impulse turbines. (Norman, 2003).

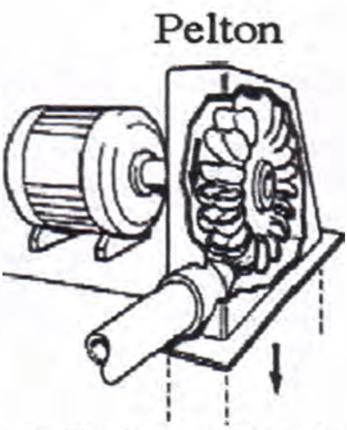

Fig. 3: The Pelton turbine (Source: Basil and Keroh, 2013)

Hydropower plant and material selection

Materials can be selected from a wide category of materials, such as metals, ceramics, polymers and composites. Selected materials must be able to serve the purpose for which they have been selected, and leave behind no limitations (Saidi *et. al.,* 2019). For example, in designing the turbine, selected material must be able to ascertain resilience and possess a high load bearing capacity. Where necessary, thick aluminium blades are utilised to resist wear and tear. Moreover, in order to reduce maintenance cost acquired from periodic painting, frames may be made with galvanised steel to avoid corrosion, at the expense of weight. In a nut shell, material selection is very crucial in the manufacture of hydropower plants, in order to ascertain good quality, durability, sights appeal, adequate in-built properties (physical and mechanical) and reasonable production cost. The selection is guided by number of factors, such as available technology, cost, available materials, product safety, expected functions and so on (Saidi *et. al.,* 2019). It is best done at the early stage of product development, especially when the expected functions of the system are being considered.

Hydropower plant and efficiency

Efficiency of the hydropower plant can be affected by the efficiency of the generator, penstock, design of the tailrace, as well as efficiency of the turbine, which itself is dependent on the nature of the water source available, that is, on the head and flow rater of the river in question (Basir and Othman, 2013; Anupoju, 2020). For instance, to maximise the output, a step-up transformer may be introduced in order to raise the output voltage. Also, the blades of the turbine can be provided with metal enclosure to increase efficiency. Where necessary, well lubricated ball bearings are to be used to overcome friction.

Nigeria and renewable energy

Despite the fact that renewable energy from hydropower has been in existence since around the middle of the twentieth century in Nigeria, serious explorations in different dimensions did not commence until around the end of the same century, particularly in the area of photovoltaic (PV) panel solar power (IIED, 2012). Although electricity generations from Nigeria's gas power stations would have overtaken that of her hydropower plants in terms of quantity, the gas stations continue to encounter problems due to unstable gas supplies and poor state of the national grid (IIED, 2012). The history of renewable energy in Nigeria is somehow short, with the public's opinion of seeing solar energy and wind power as the only available sources of alternative energy (IIED, 2012). Some of the achievements, successes and limitations of associated with renewable energy in Nigeria have been identified.

Achievements and successes of renewable energy in Nigeria

Water pumping: The use of renewable energy to power boreholes for the provision of clean and safe drinking water. This has come a long way in overcoming the problem of unstable electricity from the grid with which to operate boreholes, especially in towns and villages, as well as fueling generators where present. For example, the water borehole drilling projects of the Niger Delta Wetlands Centre (NDWC), using solar power since the mid-1990s (IIED, 2012). Figure 4 shows the basic components of a typical DC solar water-pumping system.

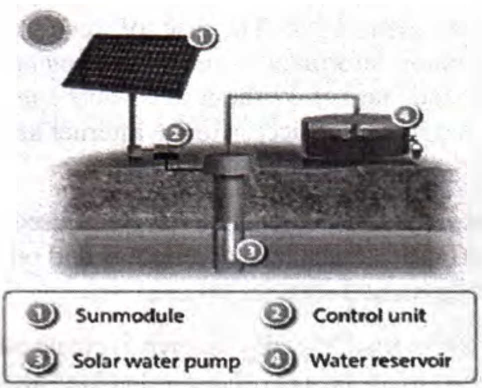

Fig. 4: Basic components of a DC solar water-pumping system (Source: IIED, 2012)

Lighting projects: Renewable energy has been in use for a while now in Nigeria for powering street lights, security lights around banks, schools, campuses, organisations, laboratories, hospitals and research institutes. This has helped to reduce the use of generators, hence noise and air pollution, as well as fueling and maintenance costs.

Hospitals and medical stores: Renewable energy has been useful in powering the theatre for surgical operations as well as refrigerating certain medicines and vaccines that require being stored well below room temperature in Nigeria. An example of such vaccine is the polio vaccine (IIED, 2012).

Household usage: Renewable energy is commonly used as an alternative to the national grid supply in some urban homes in Nigeria, and as source of electricity supply in rural areas not having access to the existing national grid to light house bulbs and power TV sets, radios, fans, *etc*.

Bank and office usage: Renewable energy is also used in Nigeria as an alternative to both national grid and generators for electricity supply to banks and offices to power computers, type-writers, printers, projectors, telephones, security doors and safes, fans, *etc.*

Information and communication technology: The use of renewable energy in Nigeria has been aiding information and communication networks by improving access to the internet. Without renewable energy as a stable option of electricity supply, eased access to the internet using band-widths, modems, WIFI, *etc.* would not have been possible.

Surveillance and security checks: Renewable energy has been used to power CCTV in some homes, offices, streets, banks, religious and other institutions in Nigeria for surveillance and security checks.

Job opportunities: Renewable energy installations continue to create jobs for the willing unemployed in Nigeria, especially those with skills along that area and others that have been able to acquire necessary skills through training by experts.

Some limitations associated to renewable energy in Nigeria

Set-up cost: The initial set-up cost is usually high, that is, it is capital-intensive and as such, not many people can afford it in Nigeria.

Maintenance cost: The maintenance cost is also on the high side, especially with solar systems in which batteries need to be replaced periodically.

Awareness: Renewable energy is still relatively new to many Nigerians, as a result of this, it is not wide-spreading as expected.

Destruction of aquatic lives: Aquatic lives are usually endangered or destroyed in places where the source of renewable energy is by means of river or dam.

Solution development to renewable energy problems in Nigeria

1) The government must pay special attention towards strengthening the growth of renewable energy in Nigeria by integrating existing projects and widening research scopes in the area of renewable energy (IIED, 2012).
2) Government can also release funds for the pursuit of major pilot projects, and incentives to researchers to boost their morale.
3) The general public need to be well sensitized by the government to increase awareness so that consumers can show better interest in digressing to renewable energy and investing therein.
4) Both policymakers and renewable energy experts need to work together to come up with best practices of renewable energy that will function effectively in specific areas, in particular the rural areas to cater for the necessary amenities, such as water, hospitals and schools (IIED, 2012).

5) Renewable energy education may as well be incorporated into schools curricular in order to encourage wide participation of the public towards developing renewable energy projects (IIED, 2012).

Conclusion

While availability of energy remains crucial towards the development of a nation's economic and industrial growth, means of overcoming the problems associated with fossil fuel consumption for energy generation have been traced to using renewable energy in its place. With examples including solar, hydroelectric power, wind, biomass energy and geothermal power, renewable energy is a safe source of energy because it is clean (neither harms nature nor undergo depletion) and also readily available. The consumption of renewable energy continues to increase as the world gradually digresses from the use of fossil fuels. Nigeria, although with 3 major hydropower plants still suffers from energy shortage due to under-capacity production of electricity and improper maintenance of available electricity facilities; poor electricity transmission and distribution network; as well as shortage of natural gas supply, as a result of gas flaring. Hydropower, as a renewable energy source is very reliable and efficient. The smallest available capacity, which is the Pico hydropower plant can be established on a small scale, especially in remote areas as it is simple to construct, economical, yet a very clean source of energy. To ensure high quality, durable and efficient hydropower plants, materials must be carefully selected, bearing in mind product safety, available technology, cost and expected functions at the early stage of the design. Aside renewable energy from hydropower, other notable projects did not kick until towards the end of the twentieth century. Despite the limitations of poor awareness and inadequate funding, the successes recorded so far with respect to renewable energy development in Nigeria have greatly contributed to provision of clean water supply, streets and security lights where desired, rural and urban electrification, improved ICT facilities, better surveillance and security systems and more jobs creation.

Finally, government, stakeholders, researchers/developers and the general public must all arise and diligently play their parts to encourage the full growth of renewable energy in Nigeria, for a successful energy transformation.

References

Akorede, M.; Ibrahim, O.; Amuda, S.; Otuoze, A. and Olufeagba, B. (2017). Current status and outlook of renewable energy development in Nigeria. *Nigerian Journal of Technology* (NIJOTECH). 36(1). Pp 196-212. Retrieved from, http://dx.doi.org/10.4314/njt.V36i1.25

Anupoju, S. (2020). Components of a hydropower plant and their functions. Retrieved from, https://theconstructor.org/structures/hydropower-plant-components-functions/19705/

Asokoroogaji, C. (2011). Importance of energy to the Nigerian economy. Retrieved from, http://www.comfortasokoroogaji.wordpress.com

Basir, M. F. and Othman, M. M. (2013). An overview of the key components in the Pico hydropower generating system: *Latest trends in renewable energy and environmental informatics.* RESEN-first.doc.

Basir, M. F. and Keroh, A. (2013). An overview of the key components in the Pico hydropower generating system. Retrieved from, https://www.wseas.us/e-library/conferences/2013/Malaysia/RESEN/RESEN-34.pdf

Benzon, D. S.; Aggidis, G. A. And Anagnostopoulos, J. S. (2016). Development of the Turgo Impulse turbine: Past and present. *Applied Energy*. 166. 1-18.

Bolarinwa, M. A. (2018). Techno-economic evaluation of biogas generation from selected substrates in a teaching and research farm in Ibadan, Oyo State, Nigeria. *International Journal of Innovative*

Science and Research Technology. 3 (7) Pp 699-704. Retrieved from, http://www.ijist.com

Cernea, M. M. (1997). *Hydropower dams and social impacts: a sociological perspective*. The World Bank.

Chuenchooklin, S. (2006). Development of pico-hydropower plant for farming village in upstream, Thailand – Prosperity and poverty in globalised world. "Challenges for agricultural research". Tropentag 2006, Bonn. Retrieved from, http://dox.doi.10.1.1.543.5497 PICO IN THAILAND.pdf

Egré, D. and Milewski, J. C. (2002). The diversity of hydropower projects. *Energy Policy*. 30.14; 1225-1230.

Elbatran, A. H.; Abdel-Hamed, M. W.; Yaakob, O. B. and Ahmed, Y. M. (2015). Hydro power and turbine systems reviews. *Jurnal Teknologi*.74.5.

Folk, E. (2020). The growth of renewable energy: What does the future hold? Retrieved from, https://earth.org/the-growth-of-renewable-energy-what-does-the-future-hold/#

Grigsby, L. L. (2018). *The Electric Power Engineering Handbook-Five Volume Set*. CRC press.

Hadjipaschalis, I.; Poullikkas, A. and Efthimiou, V. (2009). Overview of current and future energy storage technologies for electric power applications. *Renewable and sustainable energy reviews*. 13.6-7; 1513-1522.

International Institute for Environment and Development (IIED). (2012). Renewable energy potential in Nigeria: Low carbon approaches to tackling Nigeria's energy poverty. The Sungas project. Retrieved from, http://pubs.iied.org/GO3512.pdf.

Jawahar, C. P. and Michael, P. A. (2017). A review on turbines for micro hydro power plant. *Renewable and Sustainable Energy Reviews*. 72. 882-887. Science Direct. Retrieved from, https://www.sciencedirect.com/science/article/pii/S1364032117301454

https://doi.org/10.1016/j.rser.2017.01.133

Johansson, T. B., Kelly, H., Reddy, A. K., and Burnham, L. (1993). *Renewable energy: sources for fuels and electricity*. Island press.

Just Energy Group. (2020). 7 types of renewable energy: The future of energy. Retrieved from, https://www.justenergy.com/blog/7types-energy-future-of-energy.

Kabeja, B. B. (2018). Pico-hydro, a new source of energy in Rwanda. Energy, Work. Retrieved from, https://cleanleap.com/pico-hydro-new-source-energy-rwanda.

Kehinde, O.; Babaremu, K.; Akpanyung, K.; Remilekun, E.; Oyedele, S. and Oluwafemi, J. (2018). Renewable energy in Nigeria: A review. *International Journal of Mechanical Engineering and Technology*. 9(10). Pp 1085-1094. Retrieved from, http://www.iaeme.com/IJMET/index.asp

Lewis, B. J.; Cimbala, J. M. and Wouden, A. M. (2014). Major historical developments in the design of water wheels and hydroturbines. In *IOP Conference Series: Earth and Environmental Science*. 22.1. p. 012020. IOP Publishing.

Mahlia, T. M.; Saktisahdan, T. J.; Jannifar, A.; Hasan, M. H. and Matseelar, H. S. (2014). A review of available methods and development on energy storage: Technology update. *Renewable and Sustainable Energy Reviews*. 33. 532-545.

Nelson, V. and Starcher, K. (2018). *Wind energy: Renewable energy and the environment*. CRC press.

Norman, J. (2003). The world of hydropower. Retrieved from, https://www.tande.com.tw/rn-hydro/alaskan.pdf.

Nunez, C. (2019). Hydropower, explained: Benefits and pitfalls of generating electricity from waterways. Hydropower facts and information. National Geography. Retrieved from, https://www.nationalgeographic.com/contributors/n/christina-nunez.html.

Nwagbo, G. (2017). Renewable energy in Nigeria. Retrieved from,

https://large.stanford.edu/courses/2017/ph240/nwagbo2/#

OECD/FAO. (2019). Agricultural outlook, 2019 –2028. Retrieved from, https://www.fao.org/CA4076EN_Chapter9_Biofuels/pdf

Ogunsola, O. I. (2007). History of energy sources and their utilisation in Nigeria. *Energy sources*. 12(2). Taylor and Francis online. Retrieved from, https://www.tandonline.com/action/showCitFormats?doi=10.1080%2F00908319008960198

Paish, O. (2002). Small hydro power: Technology and current status. *Renewable and sustainable energy reviews*. 6(6). Pp537-556.

Pazhamkavil, S. (2014). Concept of renewable energy: Various forms of renewable energy – renewable energy sources. *Engineering, Technology, Business*. Retrieved from, https://www.slideshare.net/featured/category/engineering

Project Solar UK Limited (2018). The History of Renewable Energy: Where It All Began. Retrieved from, https://www.projectsolaruk.com

Quaschning, V. V. (2019). Renewable energy and climate change. Wiley.

Richie, H. (2017). Renewable energy. Published online at OurworldInData.org. Retrieved from, https://ourworldindata.org/renweable-energy

Saidi, T.; Dare, A. A.; Fasogbon, S. K.; Ewemoje, O.; Anyaeche, O.; Bolarinwa, M.; Adetoyi, O., Adewole, K.; Lawal, O. and Coker, A. O. (2019). Materials for Medical Devices. In Biomedical Engineering for Africa. T. S. Douglas Ed., Cape Town: University of Cape Town Library. Pp 55-61.

Shinn, L. (2018). Renewable energy: The clean facts. Retrieved from, https://www.nrdc.org.stories/renewable-energy-clean-facts/

Tesla, N. (2020). Other forms of renewable energy. Retrieved from, http://www.progressivesolarenergysystemsllc.com

Ufondu, I.; Ibeku, I. C. and Obetta, Felix (2019). Renewable energy in Nigeria. Retrieved from https://www.lexology.com/gtdt/workareas/renewable-energy

United States Energy Information Administration (EIA). (2020). International: Nigeria. *Independent Statistics and Analysis*. Retrieved from, https://www.eia.gov/international/#menu

Yaakob, O. B.; Elbatran, A. H.; Ahmed, Y. M. and Shabara, H. M. (2015). Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: a review. *Renewable and Sustainable Energy Reviews*. 43. 40-50.

Zainuddin, H.; Yahaya, M.; Lazi, J.; Basir, M. and Ibrahim, Z. (2009). Design and development of pico-hydro generation system for energy storage using consuming water distributed to houses. International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering. 3(11). World Academy of Science, Engineering and Technology. Retrieved from, https://www.researchgate.net/publication/280688181-Design-and-Development-of-pico-hydro-generation-system-for-energy-storage-using-consuming-water-distributed-to-houses/citation/download

CHAPTER 8

Application of Deep Learning in Disease Prediction

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1. Overview of Deep Learning

1.1 Definition of Deep Learning

Traditional computers are limited by their inability to reason like humans. With advancements in the field of Artificial Intelligences (AI), modern computers can be programmed to reason like humans with the ability to understand patterns and take decisions based on available information. An essential component of AI is machine learning (ML), generally defined as a field of AI that finds patterns from empirical data using algorithms (Wittek, 2014). Deep Learning (DL) is a very important branch of ML composed of artificial neural networks (ANNs).

In ANNs, learning could be deep or shallow. DL is a term that refers to a class of ML algorithms mostly ANNs that makes use of multiple layers in the extraction and transformation of higher level features from the raw input (Deng and Yu, 2012). DL involves learning with deep architectures. Deep learning originated based on the need to overcome the limitations of shallow architectures. Shallow architectures are not fully able to handle complex real-life problems due to their limited modelling and representation power. The substantial increase in the amount of data available, as well as improved computational power have necessitated the use of DL in recent times as traditional ML methods are incapable of handling big data efficiently (Aggarwal, 2018). The performance of DL networks is further aided by graphics processing units (GP.Us) in modern computers. DL proves very useful when simpler networks are unable to give the desired level of accuracy.

Interestingly, DL can be applied in several areas of human life such as in: speech and language processing, programming of driverless cars, customer relationship management, detection of financial fraud, healthcare and bioinformatics. For instance, in driverless cars, a huge amount of data can be fed into DL system which could be trained to function autonomously having learnt from experience.

1.2 Classical Deep Learning Neural Networks

Classical DL networks are made up of several features similar to conventional multilayer ANNs. The distinguishing features include the number of layers, GPUs, and the type of activation functions that enhance their performance. Common examples of DL networks are briefly described.

i. **AlexNet** – A Deep Convolutional Neural Network (CNN) model that was developed to classify about 1.2 million high resolution images in the ImageNet Large Scale Visuai Recognition Challenge (LSVRC) 2010 competition into the 1000 different classes. It was developed with the ReLU activation functions and consists 60 million parameters, 650,000 neurons in 8 layers (Krizhevsky *et al.,* 2012).

i. **GoogleNet** –This is a Deep CNN developed through a collaborative research partnership between Google and some universities developed for image classification and detection in the ImageNet Large-Scale Visual Recognition Challenge 2014 (ILSVRC14). The network is 22 layers deep and was developed using ReLU activation function. In addition, it performs dimension reduction 1×1 convolution with 128 filters (Szegedy *et al.,* 2015).

1.3 Activation Functions for Deep Learning

Activation functions enhance the ability of ANNs to handle complex problems by adding non-linearity to the network. The power of multilayer ANNs is increased by activation functions. Conventional activation functions are generally used in the initial development of ANNs. A well-known example is the Sigmoid activation function. However, their performance is limited by the vanishing gradient problem (VGP). The VGP is responsible for the difficulty in training ANNs with many layers, as it can cause the gradient of the loss function to be too small for training.

The Sigmoid activation function is calculated thus: (Wang *et al.*, 2020):

$$f(x) = \frac{1}{1+e^{x}} \tag{1.1}$$

The derivative of the activation can be written as:

$$\frac{dy}{dx} = \frac{exp(-x)}{(1+exp(-x))^{2}} \tag{1.2}$$

Tanh activation function is an improved version of Sigmoid activation function and is computed as:

$$f(x) = \frac{1-e^{-2x}}{1+e^{-2x}} \tag{1.3}$$

The gradient of Tanh activation function is computed as:

$$\frac{dy}{dx} = \frac{4.exp(2x)}{(exp(2x)+1)^{2}} \tag{1.4}$$

However, in DL and most multi-layered neural networks **Rectified Linear Activation function (ReLU)** and Hard tanh activation functions are mostly preferred.

1.3.1 Rectified Linear Activation Function

This refers to a piecewise linear function commonly used in DL to generate an output that is exactly the value of the input if it is positive, otherwise, it will output zero. ReLU is mostly preferred in networks with many layers due to its ability to overcome the VGP and given as (Wang *et al.*, 2020):

$$\text{RELU(x)} = \begin{cases} 0 \; if \; x < 0 \\ x \; if \; x \geq 0 \end{cases} \tag{1.5}$$

1.3.2 Leaky RELU

The Leaky RELU activation function is designed to return the same value if the input is a *positive* number, but it gives a *negative* value scaled by

0.01, if the input value is negative. It was initially developed to address the dying neuron problem of RELU (Iuhaniwal, 2019).

1.3.3 Hard Sigmoid

The Hard-Sigmoid function can be approximated to generate improved outputs than the Sigmoid. It is defined mathematically as (Nwankpa *et al.*, 2018):

$$f(x) = \max\left(0, \min\left(1, \frac{(x+1)}{2}\right)\right) \quad (1.6)$$

1.3.4 Hard Tanh Activation Function

Hard Tanh is a variant of Tanh Function used in DL applications. It is computationally cheaper and more efficient than Tanh Function with a range of between -1 and +1 (Ingole, 2020).

1.4 Backpropagation Algorithm

Backpropagation algorithm is often used in training multilayer neural networks to minimise the errors between desired and actual outputs by adjusting its weights and biases. For this to be achieved, it computes the partial derivative of the cost function using the chain rule by a combination of the forward and backward pass approaches (Aggarwal, 2018). The forward pass through the network computes the overall output across the various layers of the network which is then compared with the desired output. The derivative of the cost function is then computed. The Backward pass follows immediately thereafter with the application of the chain rule to learn the gradient of the cost function in the backward direction beginning from the output node (Goodfellow and Courville, 2016). Consequently, the weights are adjusted. Consider a multilayer feedforward neural network with an input vector x, an activation function, N layers, h^{N-1} hidden layers, $W_{jk}^{(i)}$ weights from node j in layer N-1 to node k in layer N,

The output of the first hidden layer is calculated as:

$$h^{(1)} = wx + b \quad (1.7)$$

The cost function, C is computed as:

$$C = \frac{1}{N}\sum_{i=1}^{n}(y - \hat{y})^2 \quad (1.8)$$

The cost function is minimised using the Gradient descent algorithm.

$$\frac{\partial C}{\partial w^N} = \frac{\partial C}{\partial \hat{y}} \cdot \frac{\partial \hat{y}}{\partial w^N} \tag{1.9}$$

The gradient in the penultimate layer is calculated as (Rawat and Wang, 2017):

$$\frac{\partial C}{\partial w^{N-1}} = \frac{\partial C}{\partial \hat{y}} \cdot \frac{\partial \hat{y}}{\partial h^{N-1}} \cdot \frac{\partial h^{N-1}}{\partial w^{N-1}} \tag{1.10}$$

The gradient in the layer before the penultimate layer is calculated as:

$$\frac{\partial C}{\partial w^{N-2}} = \frac{\partial C}{\partial \hat{y}} \cdot \frac{\partial \hat{y}}{\partial h^{N-2}} \cdot \frac{\partial h^{N-2}}{\partial w^{N-2}} \tag{1.11}$$

The gradient in the first layer is computed as:

$$\frac{\partial C}{\partial w^2} = \frac{\partial C}{\partial \hat{y}} \cdot \frac{\partial \hat{y}}{\partial h^2} \cdot \frac{\partial h^2}{\partial w^2} \tag{1.12}$$

1.5 Deep Learning Optimisation Algorithms

DL networks are trained to minimise the loss function using various optimisation algorithms. The most common are Gradient descent, Stochastic gradient descent (SGD), Newton's method, Batch stochastic gradient descent with momentum, Adagrad, Adaptive moment estimation (Adam), Adadelta and Root Mean Squared Propagation (RMSprop) (Sun and Scanlon, 2019).

1.5.1 Stochastic Gradient Descent

Stochastic Gradient Descent is an optimisation technique, that calculates the degree of change of a variable in response to the changes of another variable using a few randomly selected samples. In the conventional Gradient descent algorithm, the parameter θ, of the loss function, $J(\theta)$ is updated as (Sun *et al.*, 2018):

$$\theta = \theta - \alpha \nabla_\theta E[J(\theta)] \tag{1.13}$$

In equation (1.13), the expectation, E is obtained by estimating the cost and gradient on the entire training data. SGD eliminates the expectation in the update and calculating the gradient of the parameters using only a single or a few training examples as indicated in equation (1.14)

$$\theta = \theta - \alpha \nabla_\theta J\left(\theta; x^{(i)}, y^{(i)}\right) \tag{1.14}$$

1.5.2 Adaptive Moment Estimation (Adam)

The Adam optimisation algorithm is an adaptive moment estimation algorithm that combines the benefits of Adagrad and adaptive learning rates. Adaptive learning rates are considered to be modifications to the learning rate during the training phase by reducing it to a pre-defined value. Root Mean Squared Propagation, was designed to reduce the learning rate at a slower rate in relation to AdaGrad. The Adam optimisation algorithm developed by Kingma and Ba (2015) is shown in Figure 1.

Consider a stochastic scalar differentiable objective function $f(\theta)$ with each function $f_1(\theta),\ldots,, f_T(\theta)$ achieved at specific timesteps 1, ...T. The main aim is to minimise the expected value of the objective function, $E[f(\theta)]$.

The gradient at timestep, g_t is given by

$$g_t = \nabla\theta f_t(\theta) \qquad (1.15)$$

Let m_t represent exponential moving averages of the gradient, and v_t the squared gradient, where the hyper-parameters $\beta_1, \beta_2 \in [0, 1)$ control the exponential decay rates of these moving averages (Kingma and Ba, 2015).

The algorithm is summarised as:

Set initial parameter vector v_0
Initialise 1st moment vector, $m_0 \leftarrow 0$
Initialise 2nd moment vector, $v_0 \leftarrow 0$
Initialise timestep, $t \leftarrow 0$
While θ_t not converged do
$t \leftarrow t + 1$
Compute gradient, $g_t \leftarrow \nabla_\theta f_t(\theta_{t-1})$
Update biased first moment estimate, $m_t \leftarrow \beta_1 \cdot m_{t-1} + (1 - \beta_1) \cdot g_t$
Update biased second moment estimate, $v_t \leftarrow \beta_2 \cdot v_{t-1} + (1 - \beta_2) \cdot g_t^2$
Calculate biased corrected first moment estimate, $\widehat{m}_t \leftarrow {m_t}/{(1 - \beta_1^t)}$
Calculate biased-corrected second moment estimate, $\hat{v}_t \leftarrow {v_t}/{(1 - \beta_2^t)}$
Update parameters, $\theta_t \leftarrow \theta_{t-1} - \alpha \cdot {\widehat{m}_t}/{(\sqrt{\hat{v}_t} + \epsilon)}$
end while
return θ_t (Resulting parameters)

Fig. 1. Adam Optimisation Algorithm (Kingma and Ba, 2015)

2. Deep Learning Types and Architectures

2.1 Classes of Deep Learning Networks

The three major classes of DL networks are:

i. Deep networks for supervised learning
ii. Deep networks for unsupervised learning
iii. Hybrid deep networks

2.1.1 Deep Networks for Supervised Learning

Supervised learning is a learning technique that provides a target or set of examples for the network to learn from. It is also known as learning from examples or learning from the teacher. This is achieved by labelling each input with a desired output value, thereby providing a set of target values of output (Masolo, 2017). Deep networks for supervised learning are also known as discriminative deep networks as demonstrated by CNNs (Deng and Yu, 2012).

2.1.2 Deep Networks for Unsupervised Learning

In unsupervised deep learning, the deep network is only provided with a set of inputs with no target values. Learning is without the support of a teacher or examples. There is usually no feedback from the environment with regard to what should be the desired output and whether it is correct or incorrect. They are also referred to as generative networks because they have the ability to generate samples by sampling from the network. Common examples are autoencoders, deep belief networks and generative adversarial networks (Hinton *et al.,* 2012; Patterson and Gibson, 2020).

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2.1.3 Hybrid Deep Networks

Hybrid deep networks have a combination of discriminant and generative abilities associated with both supervised and unsupervised learning. For example, a speech recognition is generative in nature, nevertheless it may have parameters that are discriminative in translating speech to text (Deng and Yu, 2012).

2.2 Deep Feed-Forward Networks

In Feedforward Neural Networks (FFNs), successive layers feed into one another in the forward direction from input to output (Aggarwal, 2018). This is based on the assumption that all nodes in one layer are connected to those of the next layer. FFNs are acyclic graphs. Fig. 2 shows an FFN with 4 inputs, 4 hidden layers and an output layer.

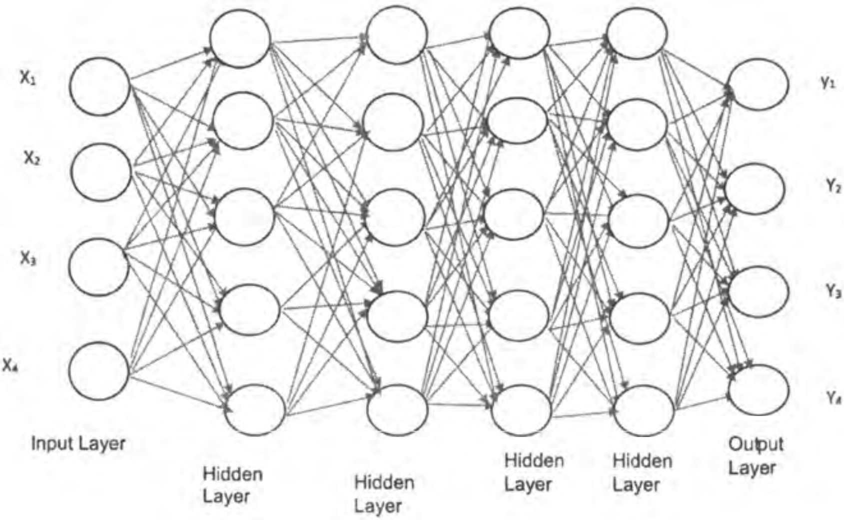


Fig. 2. Feedforward Neural Network

2.3 Deep Convolutional Neural Networks

Convolutional Neural Networks (CNNs) transform input data by p[illegible]lution operations in a minimum of one layer of the network. Convolution involves the application of a matrix to the input image to generate modified filtered data. Deep CNNs have several layers, with each layer able to compute convolutional transforms, after that non-linearities and pooling operators (Wiatowski and Bolcske, 2017). A typical CNN consists basically of convolution, pooling and full-connection (FC) layers (Wang *et al.,* 2020). The convolution layer consists of neurons organised as feature maps that are trained to extract features from the input data. Each neuron in a feature map is connected to other surrounding neurons in the previous layer known as a filter bank. All neurons within a feature map have approximately equal weights. The pooling layer decreases the spatial resolution of the feature maps (Rawat and Wang, 2017). High-level reasoning and the interpretation of feature representations are the main functions of the full-connection layer (Hinton *et al.,* 2012). CNNs are mostly applied in image classification and considered to work with grid-structured inputs (Aggarwal, 2018). A good activation function can efficiently map data in dimensions (Dubey and Jain, 2019). Figure 3 depicts a typical CNN architecture of an image classification problem. As the input image is fed into the network, the features are extracted at the convolution layer. The neurons at this layer form a feature map. The jth output Y_j of the feature map is given by:

$$Y_j = f(W_j * x) \qquad (2.1)$$

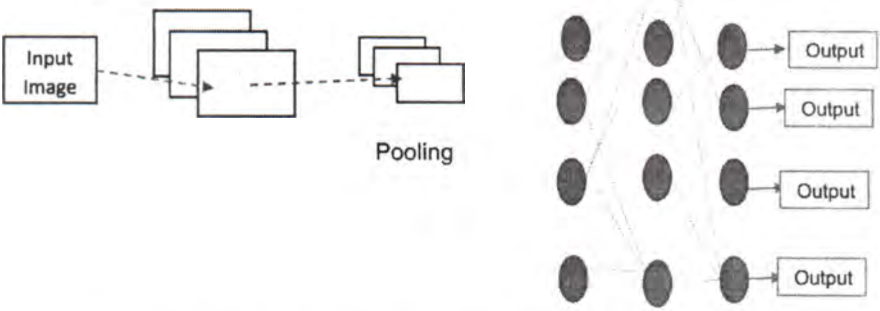


Fig. 3. Convolutional Neural Network Architecture (Rawat and Wang, 2017)

The next stage after convolution is pooling which aims to decrease the spatial resolution of the feature map (LeCun *et al.*, 2015). The output of the kth feature of the map is given by:

$$Y_{kij} = \max x_{kpq} \qquad (2.2)$$

Where x_{kpq} represents the element at location (p,q)

After the pooling operations, the fully connected layer performs the function of interpreting the features as well as high level reasoning (Hinton *et al.,* 2012). The Softmax operator is generally used for classification problems (Krizhevsky *et al.*, 2012).

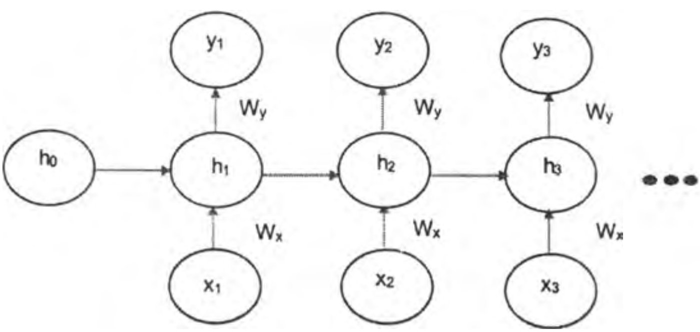
2.4 Recurrent Neural Networks

Recurrent Neural Networks (RNNs) are considered to accept a series of input with no fixed limit on size (Venkatachalam, 2019). RNNs are described as "the deepest of all ANNs due to their computing power and ability to process sequential information" (Siegelmann and Sontag, 1991; Schmidhuber, 1990a). RNNs use the inputs of the previous layer and previous information observed by the individual neurons because they also have the ability of memorising previous inputs (Wang and Huang, 2019). The performance of RNNs in time series data is known to be better than other neural network architectures like CNNs. RNNs are therefore used in the classification of biological sequences Fig. 4 is a typical architecture of an RNN that shows the input, hidden and output layers of the network. Inputs are fed into the network at specific timestamps. The output $y^{(t)}$ of an RNN given input x^t at time is computed as (Torti *et al.*, 2019):

$$y^{(t)} = wg\left(Wx^{(t)} + Uh^{(t-1)} + b\right) + c \qquad (2.2)$$

Where g is a nonlinear function while W, U, w, b and c represent network parameters. $h^{(t)}$ is the hidden state which is computed as:

$$h^{(t)} = g\left(Wx^{(t)} + Uh^{(t-1)} + b\right) + c \qquad (2.3)$$



Fig, 4. Recurrent Neural Network

2.5 Deep Learning Implementation

Deep Learning data computations can be performed with a variety of open-source and propriety software available for deep learning application. We shall focus on the use of Python software, a simple open-source programming software. Implementation of DL in Python is achieved with the following important libraries Numpy, Pandas, Keras, Scikit-lean, matplotlib. The file containing the datasets should be in csv format. The file is loaded using pandas followed by data normalisation (Zhang, 2019). The Keras library runs on Tensorflow or Theano and is used to develop the models including defining the layers. Keras is a DL application programming interface (API) designed to enhance the speed of computation. The main data structures of Keras are **layers** and **models**.

i. **Data Collection**

DL networks are usually implemented with large datasets and loaded into the software.

ii. **Data Pre-processing**

a. Missing Values

Various techniques are used to handle missing data.

b. Covariance Matrix

Covariance matrix is computed to determine variables that are highly correlated. The covariance of two random variables X and Y having values (x_i, y_i) with probability p_{ij} is defined as:

$$COV(X,Y) = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu_X)\left(y_j - \mu_Y\right) \quad (2.4)$$

c. Data Normalisation

Data normalisation is performed to ensure that all the features are measured on the same scale.:

iii. Feature extraction

Important features of the data are extracted leading to considerable reduction in the size of data to a controllable size and improved accuracy. Common feature selection techniques include correlation matrix, F-test, feature importance and variance thresholding.

iv. Splitting the dataset

The dataset is split into training and testing datasets. This is achieved with the train_test_split package imported from scikitilearn.

iv. **Building the model:**

This process involves creating the type of deep neural network, its network architecture and the activation functions to be used at the output of each layer of the network. Optimization technique to reduce cost function (error between the target output and the local output from each layer). Network structure is specified by importing dense from keras.layer (from keras.layers import Dense).

v. **Evaluating the model**

The performance of DNNs can be determined by the following evaluation metrics including, accuracy, sensitivity, specificity, positive predictive value, negative predictive values.

a. Accuracy is defined as the proportion of the total number of predictions that were correct.

$$\text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+TN+FP+FN}} \quad (2.5)$$

b. Sensitivity is defined as proportion of positive class correctly classified.

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP+FN}} \quad (2.6)$$

c. Specificity is defined as the ratio of true negatives, rightly predicted as a negative class or true negative.

$$\text{Specificity} = \frac{\text{TN}}{\text{TN+FP}} \quad (2.7)$$

d. Positive predictive value or precision is defined as the ratio of true positives to the sum of true positive and false positives.

$$\text{Precision} = \frac{\text{TP}}{\text{TP+FP}} \quad (2.8)$$

Where

TP = True positive value

TN = True negative value
FP = False positive value
FN = False negative value

3. Predictive Analytics in healthcare

In recent times, concerted efforts have been made to improve medical diagnosis through use of predictive analytics. This is borne out of the need to improve diagnostic accuracy and speed.

3.1 Overview of Predictive analytics

Predictive analytics are generally used to develop effective methods that can accurately predict future observations from historical data while also trying to understand the relationship between the features and response for scientific purposes (Bickel and Roy, 2008). The various applications of predictive analytics include forecasting of disease outbreaks and epidemics. disease diagnosis and therapy. The application of predictive analytics in big data has the potential not only to improve profits but also to minimise wastes in healthcare operations management. Deep learning as well as other machine learning algorithms are very useful tools in predictive analytics for disease classification. For instance, Nwaneri *et al.,* (2014) developed an ANN based model for the prediction of breast cancer.

3.2 Limitations of Predictive Analytics in Healthcare

Notwithstanding the several benefits associated with the use of predictive analytics in healthcare, it has the following limitations:

i. Data collection is often characterised by some challenges such as incomplete, inconsistent and heterogenous data.
ii. Data access is limited by privacy issues
iii. Predictive analytics of high dimensional data (data with too many attributes in relation to the number of observations) are usually susceptible to the "curse of dimensionality" problem (Dinov, 2016).
iv. Since large datasets is a major requirement for deep learning, the use of deep learning in healthcare is usually

limited by the availability of large amount of data from patients.

v. Deep neural networks are difficult to train as they are susceptible to overfitting.

3.3 Selected Deep Learning Applications in Disease Prediction

3.3.1 Application of Deep Learning in Diabetes Prediction

Diabetes mellitus (DM) is defined as "a chronic, metabolic disease characterized by elevated levels of blood glucose" (WHO, 2020). Therefore, early diagnosis and prediction of DM in persons with certain risk factors is necessary. Deep Learning algorithms can be used to develop predictive models for DM prediction based on certain risk factors of patients. In a typical DL model, the input nodes consist of risk factors such as age, weight, hypertension, family history of DM, waist circumference, consumption of sweet foods etc. The network is trained to help the network classify data as diabetic or non-diabetic. Various computations are done in the hidden layers with the results forwarded to the output layer which indicates if the person is diabetic or not.

3.3.2 Application of Deep Learning in Breast Cancer Classification

Breast cancer is a malignant tumour that affects mostly women. It accounts for 10.4% of all cancer incidences among women and is the fifth most common cause of cancer death globally (Sharma *et al.*, 2010). Early diagnosis of the disease is known to improve the chances of survival from the disease (Murtaza, 2019). Mammography is an imaging technique used in diagnosing breast cancer. However, diagnosis of mammographic breast images is subjective and difficult to interpret and requires a lot of skill and experience. Therefore, DL can be used in the prediction of the status of breast image to determine if it is benign or malignant. This is implemented by first digitizing breast images of fine needle aspirates of the breast mass of patients. Features of interest in the images are considered and their values computed. The features commonly used include uniformity of cell size, uniformity of cell shape, marginal adhesion, single epithelial cell size, bare nuclei, brand chromatin, and normal nucleoli (Dhanya 2020). The data are usually pre-processed. The features values are usually fed as inputs to the DL model. Activation functions are used in the computation of the output of the various layers of the model. The model trains the input data and generates the output which may be classified as a benign or malignant tumour. The models are evaluated in terms of the accuracy, specificity, sensitivity and positive predictive value (PPV).

3.3.3 Application of Deep Learning in Chronic Kidney Disease Prediction

Chronic Kidney Disease (CKD) refers to kidney damage or glomerular filtration rate (GFR) $< 60\ \mathrm{mL/min/1.73\ m^2}$ for three (3) months or more (Inker et al., 2014). It is associated with high rates of mortality and morbidity. Some of the risk factors of CKD include: high blood pressure, old age, heart and blood vessel disease, smoking, diabetes, obesity, abnormal urinary structure and history of family of kidney disease. Early diagnosis and detection of CKD helps patients to know their health status and commence early treatment in order to improve chances of survival and quality of life of CKD patients. Deep Learning algorithms can be used for early prediction of CKD. Chen *et al.,* (2020) developed an Adaptive hybridised deep CNN for early detection of CKD.

3.4 Data Computations and Results

Example 1: What is the output of a rectified linear unit of Deep Convolutional Neural Network if the input is:

(a) -550 (b) 500

Solution:

$$\mathrm{RELU(x)} = \begin{cases} 0 \ if\ x < 0 \\ x\ if\ x \geq 0 \end{cases}$$

Therefore, based on the above equation, the output is determined by the input. If the input is less than 0, the output is equal to zero. However, if the input is greater than or equal to zero, the output is equal to the input.

Therefore, (a) 0 (b) 500

Example 2: Consider a 4 by 4 matrix representing the patients and attributes in a dataset for the prediction of diabetes. Calculate the covariance between the 2nd (Age) and the 4th Column (Glucose).

Solution:

The covariance of two random variables X and Y having values (xi, yi) with probability pij is defined as:

$$COV(X,Y) = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu_X)(y_j - \mu_Y)$$

$$A = \begin{matrix} 3 & 28 & 10 & 90 \\ 5 & 39 & 12 & 88 \\ 8 & 45 & 8 & 120 \\ 6 & 65 & 6 & 130 \end{matrix}$$

Let 2nd column = X, 4th column =Y

$$X = \begin{matrix} 28 \\ 39 \\ 45 \\ 65 \end{matrix} \quad Y = \begin{matrix} 90 \\ 88 \\ 120 \\ 130 \end{matrix}$$

$E[X] = 44.25$

$E[Y] = 107$

$$COV(X,Y) = \frac{(28-44.25)(90-107)+(39-44.25)(88-107)+(45-44.25)(120-107)+(65-44.25)(130-107)}{4} = 212.86$$

Question 3: Compute the image X by convolving the image I of size 6×6 with a 2 × 2 filter.

I =

1	8	4	7	8	2
9	1	21	10	3	7
2	1	2	8	17	9
18	5	10	5	5	3
5	12	5	9	22	7
1	6	7	11	6	5

*

F =

1	0
1	1

Solution

$(1 \times 1 + 8 \times 0 + 9 \times 1 + 1 \times 1) = 11$
$(8 \times 1 + 4 \times 0 + 1 \times 1 + 21 \times 1) = 30$
$(4 \times 1 + 7 \times 0 + 21 \times 1 + 10 \times 1) = 35$
$(7 \times 1 + 8 \times 0 + 10 \times 1 + 3 \times 1) = 20$
$(8 \times 1 + 2 \times 0 + 3 \times 1 + 7 \times 1) = 18$
$(9 \times 1 + 1 \times 0 + 2 \times 1 + 1 \times 1) = 12$
.$(1 \times 1 + 21 \times 0 + 1 \times 1 + 2 \times 1) = 4$
$(21 \times 1 + 10 \times 0 + 2 \times 1 + 8 \times 1) = 31$
$(10 \times 1 + 3 \times 0 + 8 \times 1 + 17 \times 1) = 35$
$(3 \times 1 + 7 \times 0 + 17 \times 1 + 9 \times 1) = 29$
$(2 \times 1 + 1 \times 0 + 18 \times 1 + 5 \times 1) = 25$
$(1 \times 1 + 2 \times 0 + 5 \times 1 + 10 \times 1) = 16$
$(2 \times 1 + 8 \times 0 + 10 \times 1 + 5 \times 1) = 17$
$(8 \times 1 + 17 \times 0 + 5 \times 1 + 5 \times 1) = 18$
$(17 \times 1 + 9 \times 0 + 5 \times 1 + 3 \times 1) = 25$
$(18 \times 1 + 5 \times 0 + 5 \times 1 + 12 \times 1) = 35$
$(5 \times 1 + 10 \times 0 + 12 \times 1 + 5 \times 1) = 22$
$(10 \times 1 + 5 \times 0 + 5 \times 1 + 9 \times 1) = 24$
$(5 \times 1 + 5 \times 0 + 9 \times 1 + 22 \times 1) = 36$
$(5 \times 1 + 3 \times 0 + 22 \times 1 + 7 \times 1) = 34$
$(5 \times 1 + 12 \times 0 + 1 \times 1 + 6 \times 1) = 12$
$(12 \times 1 + 5 \times 0 + 6 \times 1 + 7 \times 1) = 25$
$(5 \times 1 + 9 \times 0 + 7 \times 1 + 11 \times 1) = 23$
$(9 \times 1 + 22 \times 0 + 11 \times 1 + 6 \times 1) = 26$
$(22 \times 1 + 7 \times 0 + 6 \times 1 + 5 \times 1) = 33$

After convolution the image is transformed to:

11	30	35	20	18
12	4	31	35	29
25	16	17	18	25
35	22	24	36	34
12	25	23	26	33

Example 4:

A deep CNN was recently developed for breast cancer screening. The model was tested on a large dataset comprising 10,000 digitised breast images of women who participated in a recent screening conducted in 3 tertiary hospitals in Southwest, Nigeria. Of the 10,000 breast images, 9100 were benign while 900 were confirmed to be malignant from confirmed biopsy procedures. The model correctly classified 8,950 breast images as benign, and 780 as malignant. It wrongly classified 120 images as benign and 150 as malignant. Calculate:

i. The accuracy ii. Sensitivity iii. Specificity iv. Precision

Solution

Total number of breast images =10,000
Total number of positive cases = 9100
Total number of negative cases = 900
True positive cases = 780
False positive cases = 150
True negative cases = 8,950
False negative cases = 120

i. $\text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+TN+FP+FN}} = \frac{780+8950}{10000} = 0.973$

ii. $\text{Sensitivity} = \frac{\text{TP}}{\text{TP+FN}} = \frac{780}{780+120} = 0.867$

iii. $\text{Specificity} = \frac{\text{TN}}{\text{TN+FP}} = \frac{8950}{8950+150} = 0.984$

iv. $Precision = \frac{\text{TP}}{\text{TP+FP}} = \frac{780}{780+150} = 0.839$

Example 5:

In a recent study, a deep learning model was used to predict CKD. The model was tested on a large dataset comprising 20,000 adults who participated in a nationwide screening conducted across the 6 geographical zones of Nigeria. Of the 200,000 subjects, 170,000 tested negative while 30,000 subjects were diagnosed with CKD. The model correctly classified 165,000 negative cases and 28000 positive cases. It misclassified 5000 samples as positive and 2000 as negative.

Solution

Total number of datasets =200,000

Total number of positive cases = 30,000

Total number of negative cases = 170,000

True positive cases = 28,000

False positive cases = 5,000

True negative cases = 165,000

False negative cases = 2,000

i. $\text{Accuracy} = \frac{\text{TP+TN}}{\text{TP+TN+FP+FN}} = \frac{28{,}000+165{,}000}{200000} = 0.965$

ii. $\text{Sensitivity} = \frac{\text{TP}}{\text{TP+FN}} = \frac{28{,}000}{28{,}000+2000} = 0.933$

iii. $\text{Specificity} = \frac{\text{TN}}{\text{TN+FP}} = \frac{165{,}000}{165{,}000+5000} = 0.971$

iv. $\text{Precision} = \frac{\text{TP}}{\text{TP+FP}} = \frac{28{,}000}{28{,}000+5{,}000} = 0.848$

4. Conclusion

Deep learning and its application in disease prediction have been discussed in this chapter. Deep learning was defined as a class of machine learning (ML) algorithms mostly artificial neural networks (ANNs) that make use of multiple layers in the extraction and transformation of higher level features from the raw input. Important deep learning concepts were extensively discussed and clearly illustrated with practical examples.

References

Aggarwal, C.C. (2018) Neural networks and deep learning. Springer International Publishing, NewYork.

Bickel, P.F. and Roy, L. J. editors. *(2008)* Discussion on the paper "Sure independence screening for ultrahigh dimensional feature space". *Journal of the Royal Statistical Society*: Series B 70(5):883–884.

Chapelle, O. Scholkopf, B. and Zien, A. (2009) Semi-supervised learning. *IEEE Transactions on Neural Networks*, 20(3):542–542.

Chen, G. Ding, C. Li, Y. Hu, X. *et al.,* (2020) Prediction of chronic kidney disease using adaptive hybridized deep convolutional neural network on the internet of medical things platform. *IEEE Access*, 8:100497-100508.

Deng, L. and Yu, D. (2012) Deep learning methods and applications. *Foundations and Trends in Signal Processing*, 7(3-4):198 -383.

Dhanya, R. Irene, R.P. Sai, S.A. Madhumathi, S. Jyothisha, J.N. (2020) F-Test feature selection in stacking ensemble model for breast cancer prediction. *Procedia Computer Science* 171:1561–1570.

Dinov, I.D. (2016) Methodological challenges and analytic opportunities for modelling and interpreting Big Healthcare Data. *Gigascience*, 5:12. Retrieved October 13, 2020, from https://gigascience.biomedcentral.com/articles/10.1186/s13742-016-0117-6

Dubey, A.K. and Jain, V. (2019) Comparative Study of Convolution Neural Network's ReLu and Leaky-ReLu Activation Functions. *In Applications of Computing, Automation and Wireless Systems in Electrical Engineering;* Springer: Singapore, 873–880. 23.

Deng, L. Yu, D. (2014). Deep Learning: Methods and Applications. *Foundations and Trends in Signal Processing*. 7 (3–4):1–199.

Goodfellow, I. and Bengio, Y. and Courville, A. (2016) *Deep Learning.* MIT Press: Massachusetts.

Hinton, G. E. Srivastava, N. Krizhevsky, A. Sutskever, I. and Salakhutdinov, R. R.
(2012). Improving neural networks by preventing co-adaptation of feature detectors.
Retrieved October 12, 2020, from https://arxiv.org/pdf/1207.0580.pdf

Hinton, G. Krizhevsky, A. and Wang, S. (2011) Transforming autoencoders. *In Proceedings of International Conference on Artificial Neural Networks,* 44-51.

Ingole, K. (2020) Performance Analysis of Various Activation Functions. *Journal of Emerging Technologies and Innovative Research*, 7(6):269 -276.

Iuhaniwal, V. (2019) Analyzing different types of activation functions in neural networks — which one to prefer? Retrieved October 5, 2020 from https://towardsdatascience.com/analyzing-different-types-of-activation-functions-in-neural-networks-which-one-to-prefer-e11649256209

Kingma, D. and Ba, J. (2015) *Adam: A method for Stochastic Optimization*. Retrieved October 5, 2020 from https://arxiv.org/pdf/1412.6980.pdf.

Krizhevsky, A. Sutskever, I. and Hinton, G. E. (2012) Imagenet classification with deep convolutional neural networks. ***Advances in Neural Information Processing Systems. 1: 1097–1105.***

LeCun, Y. Bengio, Y. and Hinton, G. (2015) Deep learning. *Nature*, *521*(7553):436–444.

Masolo, C. (2017) Supervised, unsupervised and deep learning. Retrieved October 3, 2020 from https://towardsdatascience.com/supervised-unsupervised-and-deep-learning-aa61a0e5471c.

Murtaza, G. Shuib, L. Wahab, A.W.A. Mujtaba, G. Mujtaba. G. Nweke, H.F. Al-garadi, M.A. Zulfiqar, F. Raza, G. and Azmi, M.A. (2019) Deep learning-based breast cancer classification through medical imaging modalities: state of the art and research challenges. *Artificial Intelligence Review* 53:1655–1720.

Nwaneri, S.C. Nwoye, E.O. Iruhe, N.K. Babatunde, A.M. (2014) Application of Artificial Neural Networks in Breast Cancer Classification: A Comparative Study. *University of Lagos Journal of Basic Medical Sciences*, 2(1):32 – 38.

Nwankpa, C.E. Ijomah, W. Gachagan, A. and Marshall, S. (2018) Activation Functions: Comparison of Trends in Practice and Research for Deep Learning. Retrieved October 8, 2020 from https://arxiv.org/pdf/1811.03378.pdf.

Patterson, J. and Gibson, A. (2020) *Deep Learning*. O'Reilly Media, Inc

Rawat, W. and Wang, Z. (2017) Deep Convolutional Neural Network for Image Classification: A Comprehensive Review. *Neural Computation*, 29:2352 – 2449.

Schmidhuber, J. (2015) Deep Learning in Neural Networks: An Overview. *Neural Networks*. 61:85–117.

Sharma, G.N. Dave, R. Sanadya, J. Sharma, P. and Sharma, K.K. (2010) Various types and management of breast cancer: an overview. *Journal of Advanced Pharmaceutical Technology and Research*, 1(2):109 – 126.

Siegelmann, H. T. and Sontag, E. D. (1991). Turing computability with neural nets. *Applied Mathematics Letters*, 4(6):77–80.

Sun, A.Y. and Scanlon, B.R. (2019) How can Big Data and machine learning benefit environment and water management: a survey of methods, applications, and future directions. *Environmental Research Letters*, Retrieved October 11, 2020, from https://iopscience.iop.org/article/10.1088/1748-9326/ab1b7d/pdf

Sun, S. Cao, Z. Zhu, H. and Zhao, J. (2019) A Survey of Optimization Methods from a Machine Learning Perspective. Retrieved October 6, 2020, from https://arxiv.org/pdf/1906.06821.pdf.

Szegedy, C. Liu, W. Jia, Y. Sermanet, P. *et al.*, (2015) Going deeper with convolutions, *2015 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, Boston, MA, 1-9.

Torti, E. Musci, M. Guareschi, F. Leporati, F. Piastra, M. (2019) Deep Recurrent Neural Networks for Edge Monitoring of Personal Risk and Warning Situations. *Scientific Programming*, Retrieved October 7,2020, from https://www.hindawi.com/journals/sp/2019/9135196/

Wang, Y. Li, Y. Song, Y. and Rong, X. (2020) The Influence of the Activation Function in a Convolution Neural Network Model of Facial Expression Recognition. *Applied Sciences*, 10(5): Retrieved October 2, 2020, from https://doi.org/10.3390/app10051897.

Wang, S. and Wuang, T. (2019) Application of Deep Learning in Biomedicine.
"About diabetes". *World Health Organization.*

World Health Organisation (2020) Diabetes. Retrieved October 5, 2020 from https://www.who.int/health-topics/diabetes.

Wittek, P. (2014) Quantum Machine Learning. Elsevier Inc.

Wiatowski and Bolcskei, (2017) A Mathematical Theory of Deep Convolutional Neural Networks for Feature Extraction. Retrieved October 8, 2020, from https://arxiv.org/pdf/1512.06293.pdf

Zhang, Y. (2019) Deep Learning in Wisconsin Breast Cancer Diagnosis. Retrieved October 5, 2020, from https://towardsdatascience.com/deep-learning-in-winonsin-breast-cancer-diagnosis-6bab13838abd.

CHAPTER 9

New Normal: Ergonomic Awareness For Telecommuters In Nigeria

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Abstract

The challenges faced by the ever-growing nature of work cannot be overemphasized, the complexities and uncertainties faced by organizations are not confined to the societal, economic and national borders. The emergence of COVID-19 was an eye-opener that the future of work is here. The definition of work is gradually shifting from being at an employer's location as it has been for decades. Many organizations and individuals are unprepared and some unaware of the ergonomic importance of telecommuting at this time.

An ergonomic awareness for telecommuters in the world and specifically in Nigeria will cause a shift in the design of our homes and our work environments to fit the job to telecommuters. This does not have to come at a high cost. This is why this study highlights trends in the new normal office by studying six predominant components of workstations (chair, work surface, type of workstation and computer system-screen, keyboard, mouse/touchpad) in the work environment of telecommuters in Nigeria.

The significance of this study can be adopted by well-adjusted telecommuters and potential ones. Organizations can leverage on this awareness to better improve the overall health of employees working in the new normal office. This should drive modification in budget

allocations to make provision for the ergonomics training and implementation of an ergonomic workplace for telecommuters.

1.0 Introduction

The Industrial Revolution came with leaving home and labouring in an outdoor work environment as its definition of work. Work in the 1990s was restricted to being in the four corners of a building, offices were mostly cubicles and c-suites. This work outside the home model with its 9-5 in-office work-hours is what many employers of labour still employ today, though it is increasingly becoming outdated. The history of telecommuting dates back as far as the 1970s when Jack Niles published a book called "The Telecommunications Transportation Trade-off-Options for Tomorrow" (Nilles *et al*, 1973) when there was a problem with the transportation of employees from one location to the other due to the scarcity of non-renewable energy sources.

Furthermore, the book recommended that either the jobs of employees be set up such that they can be done from each individual's location or a sufficiently sophisticated information-storage system and telecommunications be set up to allow for information transfer to be as effective as though employees were centrally located. Today, telecommuters have increased in number due to the available technological capabilities. In recent years, online start-ups like Freelancer (founded 2009), Fiverr (founded 2010) and Upwork (founded 2015) have enhanced telecommuting.

In Wuhan, China, coronavirus disease (COVID-19) emerged in December 2019 with various symptoms like cough, pneumonia, shortness of breath, fever and in some cases death. The World Health Organization by April 30, 2020, recorded over 3 million cases of the virus and 217,769 confirmed deaths (WHO, 2020a). With the high transmission rates in 214 countries, areas and territories, it was declared to be a Public Health Emergency of International concern (WHO, 2020b) This led to the declaration of a state of emergency or lockdowns by the governments of many nations (Kaplan, Frias, & McFall-Johnsen)

The temporary lockdown led to an unexpected working from home therefore leading to an increase in the number of telecommuters globally. The normal remote working may not apply because of the various work environments that employees are forced to work from, unprepared (Donnely & Proctor-Thompson, 2015). Some employees are working from kitchen tables, beds while other family members disturb them. With childcare and schools closed, parents juggle between work and childcare. While numerous researchers have studied remote work, few have considered it in the light of the challenges that came with COVID-19 without preparation. This "new normal" has changed the predominant work environment of employees to those that might not fit them ergonomically.

1.1 Background

Organizations are constantly faced with growing confusion and uncertainties, as the kind of problems faced is not typically confined to economic, national or societal borders (Eisenhardt, Graebner, & Sonenshein, 2016) (Ferraro, Etzion , & Gehman, 2015). These challenges are diverse and range from several issues like climate change, political instability to severe economic downturns (George, Howard-Grenville, Joshi , & Tihanyi, 2016)

The physical working environment can make a person misfit or fit their workplace. This working environment is known as an ergonomic workplace. Research on ergonomic workplaces for employees has to be done to help prevent nerve injuries (Cooper & Dewe, 2004). In addition, the elements in a working environment have to be proper, this will reduce their stress level while getting the job done (McCoy & Evans, 2005)

In Quebec Canada, 7% of employees that were absent from work for six months incurred 70% of the total cost for occupational back pain (Abenhaim & Suissa, 1987). This is just one of the various occupational health problems that have continually affected the workforce. Low back pain has specifically attracted the attention of many industrialized countries and governments due to the unreasonable costs it poses on compensation and health care systems (Crook, *et al*, 2002).

Brill, (1992) stated that the improvement of workplaces to make them ergonomically compatible can increase the productivity of employees from five to ten per cent. Working environments are those systems, processes, structures, work location, conditions or tools in the workplace that impact the productivity of each employee (Opperman, 2002). More attention should be given to identifying and dealing with the ever-changing nature of work environments (Noble, 2009) especially now with the presence of COVID-19 that has disrupted our workspaces. The pandemic is having a dramatic effect on livelihood, well-being and jobs of workers across the globe.

Towards this end, this study focuses on enlightening telecommuters and employers about the impact of COVID-19 pandemic on the need for ergonomic consideration in their design and choice of workstations. This awareness can help improve the overall health of well-adjusted telecommuters or those that became one as a result of the pandemic. Organizations can also leverage on this study to make an organizational schedule that suits their industry.

1.2 Study objectives

1. To assess the impact of the Covid-19 pandemic on the type and availability of ergonomically compatible workstations of Nigerian telecommuters in their various work environments.

2. To create ergonomic awareness to telecommuters concerning musculoskeletal disorders resulting from various work environments.

1.3 Limitations of the study

1. Due to social distancing and the national lockdown, participants of the survey were not examined in their workplaces physically to know how their working environments are.

2. As at the time the survey was sent, many telecommuters in Nigeria were already returning to work while some kept a flexible schedule as organized by their employers.

3. Due to the time frame of the study and cultural factors, telecommuters that met the inclusion criteria could not be reached in some geopolitical zones (North East, North West and South-South). Section 2.1 gives the full details.

2.0 Methods

2.1 Study participants

The survey went out to 1000 telecommuters across Nigeria. Some geopolitical zones in Nigeria were represented. However, 3 (North East, North West, and South-South) out of 6 were not present. The North East and North West region lacked telecommuters that met the inclusion and exclusion criteria due to cultural reasons and duration of the study. The South-South region had many manufacturing and production (example Oil and Gas Industry) companies that continued the business under COVID-19 guidelines as essential services firms during the lockdown. This limited the survey to telecommuters that had well-adjusted before the pandemic who did not meet the inclusion criteria. However, after cleaning the responses, the survey got fifty (N=50) responses suitable for use.

2.2 Study Design

An online survey research method (Google Forms) was used for the study for easy understanding and accessibility, considering the fact the target participants are telecommuters (that use a computer system, see section 2.2.1 for inclusion and exclusion criteria). The survey was to telecommuters online. The duration of the study was for 7 weeks from pre to post-survey (21, August to 15, October 2020). The survey was filled anonymously and no contact information was taken. For clarity sake, questions were asked in a way that differentiates between before and after the switch to telecommuting, especially during the national lockdown in Nigeria.

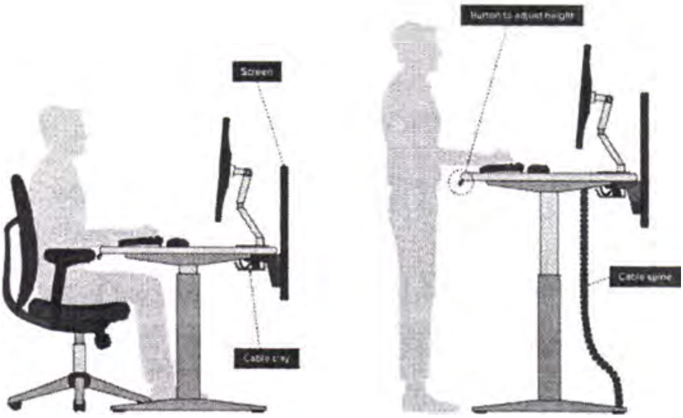

Fig. 1: Ergonomic Workstation, Source: https://www.cmd-ltd.com/advice-centre/ergonomics/office-ergonomics/#officeerg12

The survey also included traditional demographic variables like age, gender, education and profession. It goes further to ask how many people (including adults and children) the respondents live with and to ask if any of them has tested positive for COVID-19. To enable participants to respond to questions with proper understanding, two pictures of both a standing and sitting workstations (Figure 1) were included in the survey and referred to throughout the survey. Examples of such questions are: While you work from home,

1. Is your arm at 90^0 to your body as seen in Figure 1?

2. Are your feet rightly placed to the ground as seen in Figure 1?

3. Does your chair have lumbar (lower back) support as seen in Figure 1?

4. Is your hand in a natural position when you are using the mouse as seen in Figure 1?

5. Is your head at 90^0 to your body while working as seen in Figure 1?

6. Is your screen at your eye level as seen in Figure 1?

Also, questions around musculoskeletal disorders like back pain, eye strain, neck pain and shoulder pain were framed to ascertain any trend that might have surfaced after the shift in the work environment. Lastly, questions that border around locations employees worked from during the lockdown, their preference going forward, their work postures and how they have been making themselves comfortable while working from other locations asides the employer's location.

2.2.1 Inclusion and exclusion criteria

To get quality data, inclusion criteria had to be set up for participants. Respondents who did not meet these criteria either skipped to the end of the survey, or did not respond at all as it was made clear from the first section of the survey. Section 3.1 gives the provision made available to exclude responses that did not meet the criteria.

For Telecommuters, the inclusion criteria are:

1. Country: The telecommuter must be a Nigerian.

2. Location of work: The telecommuters must have changed the location of work during the national lockdown in Nigeria or worked from another location asides the employer's location.

3. The equipment used for job tasks: The telecommuter must have a computer system to fulfil daily tasks and responsibilities assigned by the employer.

2.2.2 Factors considered in the survey

A workstation is defined as an area with equipment for the performance of a specialized task, usually by a single individual. Three types of workstation was considered for this study:

1. Sitting Workstation
2. Standing workstation
3. Combination of both sitting and standing

Factors were categorized into various components in the workstation, which were then subjected to reviews by corresponding authors. Table 1 summarizes the category of factors considered for each component in the workstation.

Table 1: Summary of the category of factors considered for each component in the workstation

S/N	Chair	Work surface	Input devices (keyboard)	Input devices (mouse)	Screen/Monitor
1	Dining chair	Desk	Laptop keyboard	Laptop touchpad	Laptop screen
2	Couch	Centre table	External keyboard	External mouse	External monitor/screen
3	Office chair	Dining Table	Combination of both laptop and external keyboard	Combination of laptop touchpad and external mouse	Combination of both laptop screen and external monitor
4	Bed	Ironing board			
5	Others				

Furthermore, ergonomic considerations of various work environments revealed the following characteristics that were used in the survey as seen in Table 2. For the type of workstations, the following factors were considered in the survey.

1. Type of work station

2. Lighting of work station and
3. Glare at work station

Table 2: Summary of characteristics evaluated for each component in the workstation

S/N	Chair	Work surface	Input devices (keyboard)	Input devices (mouse)	Screen/Monitor
1	Type of chair	Type of work surface	Type of keyboard	Type of mouse	Type of screen
2	Elbow placed on the side while working	Material work surface is made up of	Keyboard fit without readjustments	Mouse fit	Body leaning towards the screen
3	Armrest present or absent	Shape of work surface	Keyboard setup for the dominant hand	Pressure points or drags while using the mouse	Head at 90^0 to the body while working

4	Armrest adjustabl e	Space under the work surface to change leg positions	Knowledge and use of hotkeys	Natural position of the hand while using the mouse	Screen at eye level
5	Lumbar (lower back) support present or absent	Space between the top of the thigh and undersid e of the forearm		Use of mouse outside the base of support	Use of secondary screen and its position
6	Feet rightly placed to the ground				Turning of neck to access secondary screen
7	Arm at 90^0 to the body				Optimize screen brightness to reduce glare

8	Hard or comfy surface to sit on				

3.0 Results and Discussion

3.1 Data Cleaning

The data collected was cleaned as follows:

1. Responses that do not meet the inclusion criteria were deleted
2. Timestamp fields were deleted to enhance confidentiality
3. All free-text responses were moved to a separate sheet
4. Exported all responses into a single excel file

3.2 Summary of survey responses

Table 3: Profile of telecommuters (n=50)

Age	%	Male/Female	%	Educational Attainment	%	Income	%
20-30	82%	Male	62%	Secondary school or less	6%	Under 50,000	28%
30-40	14%	Female	38%	University graduate	78%	50,001-100,000	42%
40-50	4%			Post graduate	16%	100,001 - 300,000	26%
						300,001 - 500,000	4%

Table 4: Profession of Telecommuters (n=50)

Consultant	IT Personnel /Software Engineer	Data Analyst and Financial Analyst	Educationalist (Teacher /Lecturer)	Graduate Trainee	Customer Care Representative, Entrepreneur and Student	Medical Professionals	Graphic designer, Agricultural Economist, Writer, Trader, Baker and Mining Engineer
30%	8%	6% each	10%	10%	4% each	6%	2% each

Table 5: Locations telecommuters worked from (n=50)

Location	%
Home	88%

Telework Centre	2%
Office	2%
Hospital (Employer)	2%
Client's location	6%

Table 6: Musculoskeletal disorders telecommuters experienced before and after the switch (n=50)

S/N	Musculoskeletal disorders	Before the lockdown		During/after the lockdown	
		Yes	No	Yes	No
1	Back pain	50%	50%	24%	76%
2	Eye strain	44%	56%	38%	62%
3	Neck pain	22%	78%	22%	78%
4	Shoulder pain	40%	60%	**54%**	**46%**

According to the study, the summary of the survey responses for each component in the workstation (Section 2.2.2) is summarised below

1. Type of Workstation

    a. Standing workstation 2

    b. Sitting workstation 36

    c. Combination of standing and sitting workstation 12

2. Workspace appropriately lighted 32

3. Glare in workstation 34

Table 7: Summary of survey responses of each component in the workstation (n=50)

S/N	Chair	Work surface	Input devices (keyboard)	Input devices (mouse)	Screen/Monitor
1	Dining chair-15	Desk-25	Laptop keyboard-43	Laptop touchpad-31	Laptop screen-46
2	Couch-6	Centre table-7	External keyboard-2	External mouse-13	Combination of both laptop screen and external monitor-4

3	Office chair-17	Dining table-10	Combination of laptop and external keyboard-5	Combination of laptop touchpad and external mouse-6	Move close to screen to see-18
4	Bed-10	Ironing board-2	Keyboard fit worksurface-42	Mouse fit the hand-41	Head at 900 to the body-21
5	Plastic chair-1	Stool-1	Keyboard setup for dominant hand-36	Mouse drag present-15	Screen at eye level-27
6	Dental chair-1	Pillow-1	Knowledge of hotkeys-26	Hand in natural position-34	Secondary screen present-47
7	Elbow placed on side-23	Floor-1	Use hotkeys-17	Reach outside base of support to use mouse-7	Glare present-33

8	Elbow not placed on side of body-27	Kid's table-1			
9	Armrest present-19	Bed-1			
10	Armrest absent-31	No work surface-1			
11	Adjustable armrest present-3	Wooden work surface-43			
12	Adjustable armrest absent-47	Glass work surface-5			
13	Lumbar support present-20	Metal work surface-2			

14	Lumbar support absent-30	Wooden surface tapered with leather-9			
15	Feet rightly placed on the ground-29	Rectangular work surface-42			
16	Arm at 90% to the body-20	Circular work surface-4			
17	Hard chair surface-21	L-shaped work surface-2			
18		Curved work surface-1			

19		Space underneath to change leg posture-36			
20		Space between the top of the thigh and underside of arm-37			

3.3 Ergonomic Fixes by Telecommuters in Nigeria

The survey revealed some ergonomic and economic fixes that telecommuters apply to their work stations to make them more comfortable and effective in delivering their tasks. Some of these fixes can also be applied by well-adjusted and new telecommuters. Table 8 shows the summary of these ergonomic fixes

1. Placing laptop on book or centre table: This raises the screen of the laptop to improve the eye level of the telecommuter. This was done by only 12% of telecommuters in the study, 10% placed their laptops on books to raise the height while 2% placed it on the centre table to match their eye level.

2. Use of speaker: Some of the telecommuters (4%) bought speakers to play background music as they work. This can be used to ease work stress especially while doing repetitive tasks.

3. Use of pillow/blanket: Majority of the telecommuters (26%) use pillow or blanket as a support for their lower back as many of their chairs lack lumbar support.

4. Did nothing: 22% of the telecommuters did nothing to improve their workstation, they simply worked with the pre-existing work condition in their workspaces.

5. Break: 4% of the telecommuters took intermittent breaks to relax.

6. Exercise: 54% of telecommuters started workouts during the lockdown, 38% performed it daily, 28% 2-3 times a week and 34% once a week. Only 10% of the telecommuters performed minor exercises at intervals during work hours like stretching and moving their legs.

7. Posture adjustment: Only 4% of telecommuters adjust their work postures during work hours to make themselves more comfortable. Some stand, while others walk out for a few minutes, out of which 36% change their work posture less than 5 times daily, 48% between 6 to 10 times daily, 16% over 10 times daily.

8. Footrest created from book: Some workers (2%) placed their feet on a pile of books to improve their comfort because their feet were not flat to the ground as they should be.

9. Leaning chair towards a pillar for stability: 2% leaned their chairs towards a pillar to give it stability and another 2% got comfortable chairs and table to work with.

10. Business casual dress: Some (2%) telecommuters wore long sleeves shirts to have a feel of being at work. This helped them to be more efficient and start the day with the right motivation.

Also, 2% take chilled drinks while they work, 2% adjust their screen brightness, 2% use glasses to reduce glare and 2% set up a mock workspace after working uncomfortably from their bed for some days.

Table 8: Ergonomic fixes by telecommuters in Nigeria (n=50)

S/N	Ergonomic fixes by telecommuters	%
1	Nothing	22%
2	Placing the laptop on a book or centre table	12%
3	Use of speaker	4%
4	Use of pillow/blanket	26%
5	Break	4%
6	Stretching/exercise	10%
7	Posture adjustment	4%
8	Footrest created from book	2%
9	Lean my chair towards pillar for comfort	4%

10	Take a drink	2%
11	Reduce screen brightness	2%
12	Business casual dress	2%
13	Use glasses	2%
14	Set up Mock workplace	2%

3.4 Significance of the Study to Employers/Human Resource Department in the New Normal

According to this study, from table 6, only shoulder pain increased by 14% mostly as a result of raised arms during work hours. The raised arm is as a result of work surfaces (desk, 50%, dining table 20%, centre table 14%, Ironing board 4%, kid's table 2%, stool 2%, bed, 2%, pillow 2%, floor, 2%) that are too high/low and chairs without adjustable armrest. Most telecommuters (62%) worked with chairs without armrest. 94% out of 38% had armrests that cannot be adjusted. It is recommended that employers and HR experts provide ergonomic chairs and tables (as seen in Figure 1) to their workers at any location. This will reduce the cost of health care schemes for the firm.

Furthermore, only 28% received ergonomic tips/training from their employer before the COVID-19 pandemic while 32% received ergonomic tip/training to navigate the ergonomic challenges they faced during the national lockdown. However, there was no test conducted to check the comprehension level of employees and only laptops were provided as the ergonomic tool for the period. From the study, there were no provisions made in the budget of most firms for the ergonomic concerns of their workforce as the global economy experienced a downturn as a result of COVID-19. In Nigeria, decision-makers of firms and employers should make provision for the ergonomic concerns of their telecommuters in the financial budget.

Finally, the study showed that 64% of employees will prefer working from another location asides employer's location while 86% of telecommuters prefer a flexible arrangement of switching between telework station and employer's location. This calls for modification of organizational framework and employee schedule to accommodate these differences. Millennials are more interested in achieving their personal goals alongside the goals of the organization. This kind of environment is what telework supports and the New Normal has shown the global world that it is possible.

4.0 Further Research

For researchers in Nigeria, this paper highlights a new area of interest that intersects disaster management, economic downturns and its impact on specific professions in Nigeria. There is no scarcity of data as regarding the impact of COVID-19 globally and how various countries reacted. These data can be merged with other datasets to investigate the impact of pandemics on various cultures, texts and professions. With adequate time, these impacts can be modelled for specific professions in Africa, unlike this study that dealt with telecommuters generally. Specifically for ergonomic researchers, the limitation of social distancing can be addressed because participants can be observed in their workspaces by a physical observation from an experienced ergonomist.

Studies have been done to access the working environment of telecommuters by snapping their pictures while they work in their workspaces. This makes the participant more conscious and not their natural selves in their workstations having a camera taking snapshots beside and behind them. Besides, it can lead to a breach of confidentiality agreements. More specifically, this research can be modified to discover the works of the future and how far telecommuters have adapted to it in various study locations.

5.0 Conclusion

The pandemic has created various challenges for families, organizations and nations of the world. Business closures, travel restrictions, absence of child care, educational and fitness facilities are some of the unique conditions COVID-19 brought. Working from home at this time (New Normal Office) is different from the usual remote working. This paper represents the first study in Nigeria that focuses on the ergonomic concerns raised in this time for telecommuters. It goes on to further enlighten telecommuters and employers about the trends in the New Normal offices in Nigeria, the ergonomic and economic fixes that can be used to reduce musculoskeletal disorders and the areas employers and HR experts can focus on.

References

Abenhaim, L., & Suissa, S. (1987). Importance and economic burden of occupational back pain: a study of 2,500 cases representative of Quebec. 29, 670-674.

Brill, M. (1992). How design affects productivity in settings where office-like work is done. Journal of Health Care Design(4), 11-16.

Cooper, C. L., & Dewe, P. (2004). Blackwell brief histories of psychology. Stress: A brief history. doi:https://doi.org/10.1002/9780470774755

Crook, J., Milner, R., Schultz, I. Z., & Stringer, B. (2002). Determinants of occupational disability following a low back injury: a critical review of the literature. 12(4), 277-295.

Donnely, N., & Proctor-Thompson. (2015). Disrupted work: home-based teleworking (hbtw) in the aftermath of a natural disaster. New Technology Work and Employment. 30(1), 47-61.

Eisenhardt, K., Graebner, M., & Sonenshein, S. (2016). Grand challenges and inductive methods: Rigor without rigor Mortis

. Academy of Management Journal (59), 1113-1123.

Ferraro, F., Etzion, D., & Gehman, J. (2015). Tackling grand challenges pragmatically: Robust action revisited. Organization Studies, 36(3), 363-390.

George, G., Howard-Grenville, J., Joshi, A., & Tihanyi, L. (2016). Understanding and tackling societal grand challenges through management research. Academy of Management Journal (59), 1880-1895.

Kaplan, J., Frias, L., & McFall-Johnsen, M. (n.d.). A third of the global population is on coronavirus lockdown, here's our constantly updated list of countries and restrictions. Retrieved from https://www.businessinsider.com/countries-on-lockdown-coronavirus-italy-2020-3?IR=T

McCoy, J. M., & Evans, G. (2005). Physical work environment. (I. J. Barling, E. K. Kelloway, & M. Frone, Eds.) Thousand Oaks, CA: Sage Publications.

Nilles, J. M., Roy Carlson, Jr, F., Gray, P., & Hanneman, G. J. (1973). The Telecommunications-Transportation Trade-off, Options for Tomorrow.

Noble, A. (2009). Building health promotional work setting: identifying the relationship work characteristics and occupational stress. Promotional International journal, 18(4), 351-359.

Opperman, C S. (2002) Tropical business issues. Partner Water House Coopers, Internationai Business Review.

WHO. (2020a). Coronavirus disease 2019 (COVID-19): Situational Report. Retrieved from https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200430-sitrep-101-covid-19.pdf?sfvrsn=2ba4e093_2

WHO. (2020b). Statement on the second meeting of the international health regulations (2005) emergency committee regarding the outbreak of novel coronavirus (2019-ncov). Retrieved from https://www.who.int/news/item/30-01-2020-statement-on-the-second-meeting-of-the-international-health-regulations-(2005)-emergency-committee-regarding-the-outbreak-of-novel-coronavirus-(2019-ncov)

CHAPTER 10

Model-Based Systems Engineering: Relevance and Applications in Contemporary Systems Design

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Abstract

With the increasing complexity of systems, models are now the primary means by which engineers communicate, especially during the design phase. The relevance of models is explored, as well as the application areas of modelling by systems engineers. Model-Based Systems Engineering (MBSE) has proven to generally promote safety, help in compressing time, reduce costs and complexity, as well as leveraging the capabilities of digital transformation. In contemporary times, MBSE is being applied in design, prototyping and lifecycle management of systems, processes and engineered products, in simulating complex and dynamic systems, in optimizing systems design, as well as in data-driven decision-making algorithms. Just like Engineering in general, MBSE continues to grow in definition, scope, acceptance and application.

1.0 Introduction

Complex systems are characterized by the inability to humanly overview and also keep an understanding of all the details at the same time (Ogren, 2000). Models are widely used among engineers for communication at different stages of the systems they deal with. Being abstractions of reality, models could be mathematical, iconic, graphical or analogue (Sargent, 2015). The relevance and application of models in systems engineering are discussed in this work.

1.1 Background information

Over the years, technological advancements have resulted in more complex systems and subsystems, which has seen the term *system of systems* more commonly adopted. With these complex systems comes the challenge of designing, analyzing, synthesizing, predicting, optimizing and controlling (Garnaey and Gani, 2010). This has made engineers resolve to use models as the primary means of communication throughout the lifecycle of these systems. In addition to having a common language of communication, models have been proven to be highly relevant in many other areas including analysis, synthesis, integration and prediction of systems.

1.2 Objectives

The objectives of this essay are to:

I. Review the relevance of model-based systems engineering in today's world.
II. Highlight the applications of model-based systems engineering in contemporary systems design.

2.0 Relevance of model-based systems engineering

Model-based systems engineering has witnessed increasing application in recent times. This is as a result of the fact that modelling has proven to be generally safe, time-efficient, cost-efficient, simple and digitally compliant in its application. The attributes of model-based systems engineering which makes it relevant are discussed below.

2.1 Safety dimension

With increasing costs of incidents ranging from direct costs which may include lost hours, sanctions, compensations and loss of human and material resources, to indirect costs which may be loss of morale, employee turnover and loss of public trust, system designers have resolved to use models as they are generally safer than physical interaction especially when testing out new scenarios of complex and potentially hazardous systems.

Application of models in structural analysis, integrity tests, mechanized combats, radioactive power plants and biomedical research has helped to prevent incidents that could have resulted in fatalities. Furthermore, models are useful in defining ergonomic parameters (Ismaila and Charles-Owaba, 2010), as well as in evaluating the safety performance of products, processes and systems (Charles-Owaba and Adebiyi, 2006) and (Adebiyi *et al.*, 2007).

2.2 Time dimension

Modelling generally helps in compressing the time required to study the behaviour of a system. More importantly, modelling can be applied in predicting future events or trends based on past observation by extrapolation. With the right data, tools and modelling approaches, reliable conclusions about system behaviour can be drawn in good time. Advances in digital technology even made it possible for models to be applied in guiding real-time decision making in areas such as recommender systems, precision manufacturing, automatic guided vehicles and other smart objects.

2.3 Cost dimension

Given that organizations are facing increasing pressure to cut down costs (Novak *et al.*, 2017), modelling has grown in application among engineers and other professionals. It is cost-effective to use models and prototypes during preliminary testing and analysis of systems and engineered products such as aircraft and ships, rather than subject expensive materials to destructive testing. Computer-aided design helps in making functional models which are then subjected to different types of stress.

2.4 Complexity dimension

Models help to reduce the complexity of systems such as power plants, refineries, submarines, ships and aircraft. The Boeing 747, for instance, is made up of 6 million distinct parts. One impressive use of model-based systems engineering is in the design and operation of the international space station by NASA, in conjunction with Boeing researchers and experts from Massachusetts Institute of Technology (Cates and Mollaghasemi, 2005). Although this is quite rare in the real world, models help to achieve simplification by making it possible to study, analyze or focus on a subsystem or system component at a time, as if other components of the system are constant. The summation of the behaviour of the entire components is then used to estimate or predict the system behaviour with an acceptable degree of accuracy.

2.5 Digital transformation

The increased availability of personal computers and other smart devices, coupled with the development of digital technology fields such as Big Data, Data Science, Analytics, Internet of Things, Edge Computing, Cloud Technology, Machine Learning and Artificial Intelligence has made data available in digital format which makes them easy to store, retrieve, transform, analyze and deployed in various models. Big data is particularly characterized by the 3 Vs, referring to the volume, velocity and variety of data that is being generated by these advanced technologies (Johnson *et al.*, 2017).

3.0 Application of model-based systems engineering

This section seeks to examine various areas in which systems engineers have successfully applied modelling techniques in the design, analysis, synthesis and control of modern systems and engineered products.

3.1 Design, prototyping and lifecycle management

Models are particularly helpful in the lifecycle management of engineered products, processes and systems (Gernaey and Gani, 2010). Every stage in the life cycle including design, deployment, scaling, failure, recycling, etc. can be effectively modelled before the actual product is launched. This helps to achieve improved planning that gives rise to resilient systems and durable products.

3.2 Simulation modelling

Engineers have found an important and increasing use for models in simulating real-life scenarios (Tisza, 2004). Simulation models are used to estimate stochastic or deterministic parameters using random sampling techniques (Ghiocel, 2004). Popular systems that are usually simulated include service queues, equipment failure and availability, quality control, fleet management, software processes and professional training.

3.3 Optimization modelling

A very important application of models is in determining the optimal combination of inputs to yield the best desirable output. Optimization models generally consist of the objective function to be optimized by combining the decision variables in a way that satisfies the constraints (Taha, 2017). Optimization models are used in material selection, production planning, structural designs, logistics systems, computer programming routines, as well as government and military operations.

3.4 Data-driven decision making

The world today is full of intelligent systems capable of making decisions with little or no assistance from humans (Duan *et al.*, 2019). At the heart of these systems are models that help in guiding the decision-making process of systems like automated guided vehicles, digital assistants and digital maps. Also, Business Intelligence has opened an entirely new frontier whereby the historical data of an enterprise can be mined and wrangled to produce valuable insights that would drive improved business performance (Brynjolfsson *et al.*, 2011), as well as predicting future events such as employee attrition, customer churning and sales outcomes after training and testing machine learning models.

4.0 Conclusion

The dimensions that make modelling relevant in systems engineering have been discussed, as well as the areas in which models are deployed to help engineers build and manage effective and efficient systems. As the need for technology-based solutions continues to grow, more complex systems are being built which would require more complex models, or even entirely new modelling approaches, hence, model-based systems engineering continues to grow in definition, scope, acceptance and application.

References

Adebiyi, K. A., Charles-Owaba, O. E., & Waheed, M. A. (2007). Safety performance evaluation models: a review. *Disaster Prevention and Management, 16*(2).

Brynjolfsson, E., Hitt, L. M., & Kim, H. H. (2011). Strength in Numbers: How Does Data-Driven Decision Making Affect Firm Performance? https://ssrn.com/abstract=1819486

Cates, G. R., & Mollaghasemi, M. (2005). A discrete event simulation model for assembling the international space station. *Proceedings of the Winter Simulation Conference.*

Charles-Owaba, O. E., & Adebiyi, k. A. (2006). The development of manufacturing safety programme simulator. *Journal of Modelling in Management, 1*(3), 270-290.

Duan, Y., Edwards, J. S., & Dwivedi, Y. K. (2019). Artificial intelligence for decision making in the era of Big Data – evolution, challenges and research agenda. *International Journal of Information Management, 48*, 63-71.

Gernaey, K. V., & Gani, R. (2010). A model-based systems approach to pharmaceutical product-process design and analysis. *Chemical Engineering Science, 65*(21), 5757-5769.

Ghiocel, D. M. (2004). *Engineering Design Reliability Handbook.*

Ismaila, S. O., & Charles-Owaba, O. E. (2010). A Review of Manual Load Lifting Models. *Leonardo Journal of Sciences*, (16), 47-58.

Johnson, J. S., Friend, S. B., & Lee, H. S. (2017). Big Data Facilitation, Utilization, and Monetization: Exploring the 3Vs in a New Product Development Process. *Journal of Product Innovation Management, 34*(5), 640-658. https://doi.org/10.1111/jpim.12397

Novak, P., Dvorsky, J., Popesko, B., & Strouhal, J. (2017). Analysis of overhead cost behaviour: case study on decision-making approach. *Journal of International Studies*, *10*(1), 74-91.

Ogren, I. (2000). On Principles for Model-Based Systems Engineering. *Systems Engineering*, *3*, 38-49.

Pitt, M., Monks, T., & Crowe, S. (2016). Systems modelling and simulation in health service design, delivery and decision making. *BMJ Quality & Safety*, *25*, 38-45.

Sargent, R. G. (2015). Types of Models. In *Modeling and Simulation in the Systems Engineering Life Cycle* (pp. 51-55). Springer.

Taha, H. (2017). *Operations Research: An Introduction* (10th ed.). Person.

Tisza, M. (2004). Numerical modelling and simulation in sheet metal forming. *Journal of Materials Processing Technology*, *151*(1-3), 58-62.

CHAPTER 11

The Impact of Covid-19 Pandemic on Sustainable Supplier Selection Process

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Abstract

Maintaining a sustainable supplier network is pivotal in businesses that are in pursuit of steady growth and remarkable corporate relevance. The dreadful impact of the COVID-19 pandemic outbreak has grossly shaken the global supply chain networks, and the post-pandemic realities are presumably going to be more severe on the developing economies.A lot of businesses are shutting-down leading to an incredibly high record of unemployment statistics, and inflated delivery cost of products. Panic buying among consumers and firms has distracted the usual consumption patterns and created market anomalies. The supply chains have been adversely impacted and plagued by uncertainties and have defiantly affected the manufacturing supply chains. However, the COVID-19 pandemic has presented opportunities for manufacturing supply chains to shift towards more resilient and authentic sustainable supplier selection. As observed in these recent happenings, organizations that had resisted change suddenly found themselves embracing it. The economic impacts of the pandemic on the emerging economies were adequately described in this work. Most of the recent studies that are related to sustainable supplier selection process in the manufacturing sector during the pandemic situation are detailed. A framework for determining the impact of the COVID-19 pandemic on the sustainable supplier selection process for effective supply chain management in the manufacturing sector was revised and proffered. Illustratively, a multi-criteria decision approach of Analytic Hierarchical Process (AHP) was applied to determine the impact of the pandemic on sustainable supplier selection in the manufacturing sector of the emerging economy.

Keyword: Supply chain, COVID-19 Pandemic, sustainability, emerging economy.

1 Introduction

The outbreak of COVID-19 pandemic in Wuhan City of China in December 2019 hasvirtually spread all over the world and has become an international health issue (Elavarasan and Pugazhendhi, 2020). The presence of this highly infectious disease has become a serious health and economic problems because of various global social and environmental transformations which have occurred as a result of economic development (Tisdell, 2020). Hence, the scientific research community are making consistent efforts since the onset of the COVID-19 pandemic, to provide insights on various issues that relate mechanism of the spread of the virus, its adaptation plans and policies and of course its impact on various organizations. The COVID-19 pandemic has generated a unique era in the world with consequences in different aspects of our daily life

(Rizou *et al*., 2020), posing a severe threat to the healthy lives and well-being of millions of people around the world (Pan and Zhang, 2020) even though resulting in positive environmental implications due to the nationwide lockdowns (Sharma *et al*., 2020). The pandemic has far-reaching consequences beyond the primary health threat. Inflation is witnessed as the cost of local production goes up due to the travel ban, trade and transport restrictions. Noticeably, this disruption has bullwhip effects on incomes, particularly for informal and casually-employed workers. Most businesses have started to engage in cost-cutting measures, withdrawal of some of their employee's entitlements and even taking slices on dividend payments (Meester andOoijens, 2020). A lot of businesses are shutting-down leading to an incredibly high record of unemployment statistics, and inflated delivery cost of products. Various enterprises are facing serious difficulties as a result of the COVID-19 pandemic including a decrease in demand, supply chain disruptions, cancellation of export orders, raw material shortage, and transportation disruptions, among others (Shafi*et al*., 2020). Organizations that had resisted change suddenly found themselves embracing it. A deep contraction is recorded in the manufacturing sector, with the automotive industry having the lowest production index since 1987. Panic buying among consumers and firms has distracted the usual consumption patterns and created market anomalies. All these observed trade anomalies has influenced many organizations into changing their key business strategies and procedures of doing things(Dwivedi*et al*., 2020).

The COVID-19 has unveiled unforeseen and unprecedented fragilities in all areas of life; supply chains in particular (Ivanov *et al*., 2020). The supply chains have been adversely impacted and plagued by uncertainties, and this situation has been particularly witnessed in the manufacturing supply chains. This might be attributable to the huge role that that manufacturing sector plays in being a rapidly growing sector producing a vast variety of products to meet dynamic consumer requirements and increasing environmental pollution. Notably, the manufacturing sector is a product system that relates directly and indirectly to economic wealth creation, impact on the natural environment and social systems along the product's life cycle (Kusi-

Sarpong*et al*., 2019). Foreign direct investment (FDI) will likely shrink due to witnessed distortions in the manufacturing sector, as a result of the COVID-19 pandemic.Many countries and firms are concerned about their response to the COVID-19 in their supply chains which entails the manufacture and transport of personal protective equipment (PPE) which are essential frontline healthcare employees to fight disease (Sharma *et al*., 2020). The high rate of infections and death from COVID-19 has been blamed on the unavailability of PPE and still, a lot of people think that many countries have inadequate masks to effectively control the spread of the virus. For instance, China- the factory of the world and the sole producer of about 50% of masks have been restricted from exporting necessary medical supplies due to the vulnerabilities created in the supply chains during the pandemic. The post COVID-19 era is expected to make the supply and production system more resilient (Sarkis *et al*., 2020; Yaker andAhn, 2020). Our heightened skepticism is on how sustainable the post-pandemic production activities will be, now that most organizations are striving against being drowned.Amidst the high level of optimism the envisaged innovative ideas and supply chain concepts would offer, the socio-economic impact of this pandemic will still be felt long after the virus reign. The vulnerability of centralizing material/component sources in one location is clearly shown with the recent happenings. Undoubtedly, the virus outbreak has awakened latent curiosity among academicians and practitioners in supply chain management tenets on how to deal with large-scale supply chain disruptions. Likely, most organizations may not find their foot in the competitive market again. A good number of SME(s) has shut-down their production line as a result of the reduced workforce, increased production cost, high cost of material, drop in market demand, increased reward programs etc. However, it is simply not practical to go from today's crisis to immediate, full operation (Wilding *et al*., 2020).

Nevertheless, the COVID-19 pandemic presents huge opportunities for manufacturing supply chains to shift towards more genuine and authentic sustainable supplier selection. And contribute to accelerating sustainability transitions by reducing negative environmental and social consequences. Sustainable supplier selection is essential for the success and survival of the organization in the rapidly dynamic market environment that is constantly under pressure to be sustainably compliant, more so in the current COVID-19 pandemic. Sustainable supplier selection is one of the key parts of any sustainable supply chain which has gained popularity due to the growing awareness about the environmental and social issues, and pressures from relevant stakeholders (Jain and Singh, 2020). In such a context, how to balance the economic benefits and sustainable development has become a crucial issue for manufacturing firms during production operations management (Li *et al.*, 2019). Indeed, sustainable supplier selection hasbecome a decisive variable in the manufacturing firm's success in the face of a complex and dynamic market environment (Orji and Wei, 2015). The wave of megatrends, such as globalization, advances in technologies, environmental concerns, changing demographics, urbanization, the global pandemic crisis, and other forces are some of the contributing factors to the dynamic market environment (Lee and Trimi, 2020). Moreover, sustainable supply chain management has become complex due to the globalization, trade liberalization, fierce competition and rising sustainability-related needs of customers (Yadavalli *et al.*, 2019). Almost every decision to be made in sustainable supply chain management is affected by the supplier selection process, thus a high rated discourse on sustainability attainment among companies (Ghadimi *et al.*, 2019). This might be attributable to the fact that suppliers are located in the upstream part of the supply chain and are the first step in sustainable supply chain management. All the same, the supplier performances also play a critical role in the downstream part of the supply chain with regards to the economic, environmental and social aspects. Manufacturing companies need to evaluate their sustainable supplier selection process in the current pandemic crisis to avoid perpetual reaction to future pandemics and likewise get fully prepared to handle disruptions in other to ensure sustainable supply chain management and global competitiveness. Therefore, we have discussed the economic impact of COVID-19 pandemic on emerging economies and presented some of the studies that relate to the sustainable supplier selection process in the manufacturing sector during the pandemic situation. We have presented the revised framework for determining the impact of the sustainable supplier selection process for effective supply chain management in the manufacturing sector during the COVID-19 pandemic.

2 Literature Review

Various approaches have been successfully applied by different academic researchers to investigate supply chain management issues during the pandemic situation. The preparedness in the supply chain networks of organizations amidst the COVID-19 pandemic situation is universally inadequate. Although, it is right to strongly believe on effective utilization of some established theories in supply chain literature as solutions to myriads of problems that characterize this COVID-19 pandemic era. Craighead *et al.*, (2020) recommended Ten (10) theoretical perspectives as supply chain tools box that organizations should study and adopt/adapt to quench the effect of the odd pandemic situation. Besides, the researchers affirm that these theories have not been leveraged much, perhaps could offer a solution to challenges posed by the pandemic. Specifically, Cappelli and Cini (2020) encouraged for reinforcement of local micro-economy to improve the food supply chain and local production to cushion the effect of the international restrictions in the turbulent Covid-19 situation. According to the researchers, research activities have to be strengthened to provide a technical solution to improve the food supply chain and increased local production. Likewise, Sharma *et al.*, (2020) gave a strategic insight in terms of major issues firms are facing and strategic options contemplated by firms in the height of the global pandemic. In their study, some firms were selected; text analytics tools were used to analyze the challenges faced by selected firms in terms of demand-supply mismatch, technology and development of a resilient supply chain, futuristic strategic recommendations were made for the rebuilding of the supply chain network. Ivanov (2020) introduced a new supply chain model-Viable supply chain (VSC). The model is aimed at helping firms in their decision on recovery and re-building of their supply chains after the global long-term crisis. The principal ideas of the VSC model are multiple structural supply chain designs for supply-demand matching and most importantly, establishment and control of adaptive mechanisms for a transition between the structural designs. Zu*et al*., (2020) addressed the relationship between supply chain operations and the ongoing COVID-19 pandemic in the light of the prevailing shortages in essential items. The connection between the said shortages and supply chain issues were discussed. Recommendations that will ameliorate the pernicious effects of the pandemic on supply value were made. Conspicuously, there is sign of heavydisruptions in demand and supply chain within the fashion industry. Berg *et al*., (2020) assessed the impact of the crisis on sourcing operation through a large scale survey among sourcing executives and group stakeholders in a cloth-manufacturing outfit.

Furthermore, there have been successful and quite extensive attempts by researchers within the sustainable supply chain management domain to provide some practical insights for effective decision making during the pandemic situation. For instance, Karmaker*et al*., (2020) investigated the drivers of the sustainable supply chain to tackle supply chain disruptions in a pandemic situation in the context of a particular emerging economy with the aid of a methodology. Their findings reveal that financial support from government bodies and supply chain stakeholders is essential to tackle the immediate shock on supply chains during the pandemic. In the same vein, Hendiani *et al*., (2020) developed a generic Fuzzy-based assessment approach for measuring the current sustainability status in manufacturing companies, by encapsulating the sustainability criteria/sub-criteria. The research findings recommend viable directives for both the policymakers and decision-makers on ways to assess the sustainability status of the manufacturing system and improve their performances. Likewise, Jabbour *et al*., (2020) addressed the prioritization and focus of supply chain managers after coronavirus disease. Concepts and trend on resilient and sustainable supply chain were systematized, presenting main trends in the sustainability of the supply chain in the wake of the pandemic. The findings of the study provide formidable guidelines and technologies (such as; Digital technologies, such as cyber-physical system, sensors, and barcodes, Internet of things, collaboration portals and cloud computing etc.) that will aid to build a smarter and more resilient supply chain. Majumdar *et al.*, (2020) in their research aimed to understand the reasons behind the lack of social sustainability in the clothing supply chain operation in an emerging economy and suggested ways for appropriate redressal. Their study findings among many suggest developing supplier selection and the order allocation policies of the brands to facilitate the security of workers while also encouraging the participation of NGOs and labor unions. Also, Bui *et al.*, (2020) presented a data-driven literature review of sustainable supply chain management trends toward ambidexterity and disruption with the review detailing temporal trends and geographic distribution of the literature. Their main study contribution is the identification of the knowledge frontier, which leads to a discussion of prospects for future studies and practical industry implementation. Also, Klemes*et al.*, (2020) have provided an overview of invested energy sources and environmental footprints in fighting COVID-19 and further explored the protecting efficiency returned on environmental footprint invested for masks. Their study findings indicate that with a proper design standard, reusable PPE could be an effective option with lower environmental footprint and this includes energy stemming from emergency and later managed supply chains. In a similar vein, Quieroz*et al.*, (2020) proposed a framework in their study for operations and supply chain management at the times of COVID-19 pandemic spanning six perspectives, i.e., adaptation, digitalization, preparedness, recovery, ripple effect and sustainability. Research questions generated on the course of their study was quite unique, and inspiring for further exploration on the subject area.

2.1 The Economic Impact of COVID- 19 on Emerging Economies

The economic impact of the lockdown and social distancing policy stemming from the COVID-19 pandemic has been extremely devastating on business organizations (Sheth, 2020). Its impact will be endured for an elongated duration, swiping across; social, political, economic and cultural divides (He and Harris, 2020).The emergent of the pandemic has induced the worst economic downturn, and its startling effect will be felt for a longer time. Its impact is myriad and the post-pandemic realities are supposedly going to be more lethal. The knock-on effect will be felt virtually in all the sectors. The public health crisis which has seen China's exports fall by more than 17% in early 2020 and world trade projected to decline by 13% and 32% in 2020 has impelled and will likely continue to drive a global economic catastrophe (Sarkis*et al.*, 2020). Emerging economies are always known to have a weaker institutional and legal setting, lack of social welfare programs, lower levels of economic development, and higher levels of financial and social risk. They are also affected by the contraction of international trade, fall of commodity prices, reduced international investment, dwindling remittances, rising foreign debt burden, currency devaluation, and disruptions to the global supply chain. "Just as the health crisis hits vulnerable people hardest, the economic crisis hits vulnerable countries hardest" (Georgera, 2020). The impact will predominantly increase poverty and inequalities in emerging countries. It will be more lethal for economies that are dependent on exports and their government budget is heavily dependent on the export of raw materials. Poor housing and sanitary condition are common in emerging economies as people predominantly live nearby. This poses a bigger challenge in realizing the positive goal of social distancing. The knock-on effect of this pandemic on some emerging economy will also be seen in form of agitations and protest against marginalization. This in turn will further jeopardize the aim of social distancing as containment measures, thus decimating hope of earnest recovery. The level of development in a country plays an important role in prolonging economic crises or in facilitating economic recovery (Ozil, 2020). Emerging economies have less scope for working remotely and a reasonable number of jobs that can be done from home are much smaller. With the social distancing measures, lots of businesses were left out of operations in emerging economies because they have smaller financial markets. The weak and limited digital economy in emerging markets is preventing businesses from moving to e-commerce or other online platforms to maintain a level of continued consumption (Intelligence Brief, 2020). These odd features of emerging economies also made it worst for a record recovery from the impact of this health woos. With the recent slump in oil prices and eminent foreign exchange constraints, most developing countries are farther distanced from the slim possibility of bouncing back homogenously with their developed counterparts. The on-going crunch in the price of oil invariably affects currency strength and with the accumulation of the oil inventories, market demand has increasingly being dampened. The financial turmoil from this crisis has already triggered sharp currency devaluations in developing countries, which makes servicing their debts and paying for necessary imports for their industrial activity more difficult. The oil price will go further dip down if the restriction is protracted. More so, the pandemic will seriously affect most emerging economies capacity to service their previous loans, thus constraining eligibility to borrow more.

The COVID-19 pandemic affects a nation's fiscal reserves, in terms of palliative measures. The governments in emerging countries have only limited fiscal space due to a high debt level, higher dependent on commodity exports and reliance on foreign financing. The fiscal deficit to GDP ratio is projected to rise from 4.9 to 10.6%, in emerging economies, thereby increasing their debt burden and raising prospects of default or debt rescheduling (IMF, 2020, P.6). The current pandemic will have severe and long-lasting socio-economic impacts as a result of recurrent political and economic shocks that exist in those emerging countries. The health crisis, the sharp downturn activity, and turmoil in global financial markets caught emerging markets and developing economies at a bad moment (Kose*et al.*, 2020). The restrictions on economic activity fall more heavily on these economies which have a large informal sector, and a smaller scope for working remotely (Hevia andNeuyemer, 2020). Countries are now facing a synchronized global recession, investment decisions are being postponed. Incessant order cancellations and potential re-evaluation of supply chain are commonly noticed among the emerging economies (Dailly, 2020).The severity of the crisis in the emerging economies largely depends on what happens to global growth and on the effectiveness of their central banks measures (Ruiz andVillafranca, 2020).

The pandemic has re-awakened the urgent need to address the health demands of emerging economies. The obvious fact is that the emerging markets should be in line to benefits from the experience and scientific advances of those countries now moving on toward recovery. Although there is no one-size fits all remedy for this crisis across countries, but recovery of these countries will depend on the damage incurred and the available liquidity to reduce the impact of the pandemic (Tridos Investment Management, 2020). In advanced economies, the hope was that once countries brought the public health crisis under control, they would manage the economic crisis. Governments continued assistance towards manufacturers and the establishment of dependable infrastructure are seen in developed economy. The aggressive fiscal packages that the US and European countries have passed to support their economies may interfere with recovery in emerging economies as they may make it harder for emerging economies to attract capital. Though, it is imperative for developed nations to support developing countries during and after this pandemic, to avert the increased migration pressure and overburden of European economy due to asylum population. The economic future of developing countries will depend also on how trade and immigration policies evolve in advanced economies in the coming months or years (Goldberg and Reed, 2020). Major global institutions like the World Bank, International finance corporation (IFC), International Monetary Fund (IMF), ECB, African devélopment bank (AFDB) has pledged fiscal responses to emerging economies to contain the effect of the pandemic. The emerging economies of the world have succeeded in generating financial gains through their manufacturing sector as the backbone of the economy; but, it is important to notice that these nations have been far away from achieving sustainability within their system (Yadav *et al.*, 2020). Furthermore, the manufacturing sector in emerging economies is highly dependent on routine business transactions and some customers which were disrupted during the pandemic due to the lockdown that led to movement restrictions (Shafi*et al.*, 2020). Given the severe economic impacts of the pandemic on the manufacturing sector of the emerging economies, it becomes a challenging situation that presents an urgent need to revise the framework for sustainable supplier selection process as a critical step to improve sustainable performance and increase competitiveness.

2.2. The Criteria for Sustainable Supplier Selection during a Pandemic

Sustainable development requires immediate action from the industry, government and the society and to achieve this global agenda, sustainable supplier selection must be implemented (Ahmadi *et al.*, 2020). The sustainable supplier selection process involves identifying the appropriate supply partners of an organization with the most beneficial monetary value while diminishing the various effects of its operations on society and environment thereby being a critical process for sustainable development (Moheb- Alizadeh and Handfield, 2019). Indeed, sustainable supplier selection is a critical decision that affects the overall sustainability performance of organizations through a competitive bidding process for partnering (Khan *et al.*, 2018). It becomes critical for companies to consider sustainable supplier selection during decision for sustainability transitioning to actualize global competitiveness. Sustainable supplier selection process can be regarded as a multi-criteria decision-making process which uses the criteria that are classified under the triple bottom line (TBL) and comprise of performance criteria in addition to practicing criteria. The sustainable supplier selection process becomes more challenging with the high number of criteria and coupled with their conflicting nature which necessitates the use of multi-criteria decision-making methods. To select the right suppliers, various criteria should be urgent and effectively considered and analyzed concerning each supplier's characteristic. The three sustainability pillars (Economic, environmental and social), i.e the triple bottom line (TBL) of sustainability are considered always when selecting a supplier that is line with all the acknowledged sustainability principles (Ecer and Pamucar, 2020). This entails establishing the relevant factors that relate to economic, environmental and social aspects. Any problems with the sustainability aspects of supplier operations may simply not be tolerated by stakeholders, due to the damage this may impose on the purchaser's corporate environmental image and reputation (Rashidi *et al.*, 2020). Firms are increasingly relying on their suppliers for improved performance and global competitiveness and thereby laying high emphasis on sustainable supplier selection. Furthermore, sustainable supplier selection is fast becoming an essential milestone in designing a robust sustainable supply chain as firms are increasingly depending on purchased material and outsourcing of production to third parties (Khan *et al.*, 2018). Thus, effective sustainable supplier selection initiatives can aid companies to prevent some adverse pitfalls that are detrimental to business growth and overall competitiveness. Moreover, it is highly critical for manufacturing firms to select the suppliers that have a strong orientation towards sustainability issues so that effective sustainable supplier selection can be encouraged within the stages of partnership in the supply chain network. Explicitly, the process of sustainable supplier selection consists of two parts namely: the determination of sustainable criteria weights and the prioritization of suppliers (Chen *et al.*, 2020). Certain criteria that are relevant to sustainable supplier selection in the manufacturing sector are stratified and grouped into four dimensions as presented in Table 1.

Table 1 Criteria for the sustainable supplier selection process during a pandemic situation

Dimension	Criteria	Definition	References
Economic (**EC**)	Reduced cost/ price of a product	Product price is reduced by firms	Amindoust *et al.*, 2012; Chen *et al*, 2020; Ecer&Pamucar, 2020; Orji and Wei, 2015; Rashidi *et al.*, 2020
	Presence of efficient production technology	Availability of efficient production technology	
	Financial capability	Firms have sufficient finance	
Environmental (**EV**)	Technical competence of employees	Employees are highly skilled	Kusi- Sarpong *et al.*, 2019; Moheb-

	Development of sustainability abilities	Firms can acquire capabilities for sustainability	Alizadeh and Handfield, 2019; Moktadir *et al*, 2019; Rahidi *et al*., 2020; Stevic *et al*., 2020; Yadav *et al*., 2020; Yadavalli *et al*., 2019
	Sustainable product design	Products are designed for environment protection	
	Regular environmental audits	Available environmental management system	
Social (**SC**)	Health and safety standards	Firms abide by safety standards	Ahmadi *et al*., 2020; Ghadim*et al*., 2019; Janin and Singh, 2020; Kusi-Sarpong*et al*., 2019
	Policy formulation and compliance	Firms formulate policies and are compliant	
	Social responsibility	Firms ensure responsibility to customers and market	
Pandemic (**PN**)	Changing regulations	Regulatory changes affect firm operations	Dwivedi*et al*., 2020; Klemes*et al*., 2020; Sheth, 2020
	Health threats	Firms are prone to health and disease threats	

3 Determining the Impact of COVID- 19 on Sustainable Supplier Selection in the Manufacturing Sector

Multi-criteria decision-making methods are very useful tools for daily decision- making in different fields particularly in determining an acceptable solution for different factors which is a demanding and difficult task (Stevic *et al.*, 2020). The multiple natures of the criteria for sustainable supplier selection in the manufacturing sector of an emerging economy during a pandemic make a multi-criteria decision making problem. It becomes essential to determine each criterion's relative importance for the possible evaluation of the suppliers in the decision scenario. Utilizing the multi-criteria decision-making methods remains a successful approach to effective decision making in such scenarios. Multi-criteria decision-making methods are generally gaining popularity and extensively applied in various research domains including the sustainable supply chain management domain since they aptly proffer solutions to increasingly complex problems involving conflicting and multiple objectives requiring trade-offs. The analytical network process (ANP), analytical hierarchy process (AHP), scoring models, outranking, fuzzy logic, goal programming, expert systems, data envelopment analysis (DEA) etc. are some of the widely Each of these methods has its characteristics and strengths (Mardani *et al.*, 2015) but also share some common characteristics such as conflict among criteria and incomparable units (Orji *et al.*, 2020). For instance, the Scoring Models are widely applied and has the potential to produce a portfolio that is strategically aligned and sheds light on the spending priorities of businesses thereby providing effective decisions that can lead to projects of great value (Cooper, 2003). Also, the outranking approaches consist of an absent underlying aggregative value function and the yield of the analysis is not usually a value for each alternative but an outranking relation of various alternatives. An alternative *a* is said to outrank another alternative *b* if, considering all available information with regards to the decision problem and the decision maker's opinions or preferential judgments, there is a very strong argument to in favour of the conclusion that *a* is at least as good as *b* and no strong argument to the contrary (Belton & Stewart, 2002). Similarly, some outranking methods of decision making such as PROMETHEE & ELECTRE has gained wide application in diverse fieldsas reported in practitioners and academic literatures respectively (Herva and Roca, 2013).

Multi-attribute utility theory (MAUT), also part of the MCDM/A, is a performance aggregation-based approach, which is focused on identifying the utility functions and weights for each attribute that can be coupled in a unique synthesizing criterion, with the additive and multiplicative aggregations of the weights being the most widely applied in different research domains (Cinelli *et al.*, 2014). DEA is another MCDM that can evaluate the performance (efficiency) of a set of the homogenous decision- making units (DMUs), with multiple inputs and multiple outputs, and categorizes DMUs using linear programming into two mutually exclusives and collectively exhaustive groups and measures the performance value of each decision- making units (Khezrimotlagh *et al.*, 2019). Although, DEA is characterized of over generalization of values, it evenly generalizes efficiency value of a unilateral unit among the possible efficient units (Blas *et al.*, 2018). Goal programming (GP), also part of the MCDM/A group can be thought of as an extension or generalization of linear programming to handle multiple and conflicting objectives problem solution (Huang *et al.*, 2017). However, the lack of an efficient approach to providing suitable weights remains the main disadvantage of the GP approach (Chen and Xu, 2012). Also, an expert system can help in tuning down the time it requires to solve MCDM problems and address concerns more effectively by integrating machine intelligence and expert knowledge to reduce human error and bias and effectively increase accuracy (Gu *et al.*, 2019). Likewise, simulations are decision- based support systems that not only provide the optimal option but rather robust options, i.e. less sensitive to uncertainties (Chandrasekaran and Goldman, 2007). But, then it is considered impossible or highly improbable to develop simulations models that provide an exact prediction of outcomes for running different scenarios (Schubert *et al.*, 2015). The AHP is the most widely applied multi-criteria decision-making method particularly in the supply chain domain due to its simplicity. We contemplate using AHP to determine the impact of the pandemic on sustainable supplier selection in the manufacturing sector of the emerging economy. More details on the AHP framework are presented in the next section.

3.1. AHP Method

In the AHP, a hierarchy with a goal, criteria and alternatives is first constructed and then the decision-makers evaluate all the criteria, sub-criteria and alternatives and express such evaluations as pairwise comparisons from which the local and overall priorities of the alternatives can be obtained (Dong and Cooper, 2016). The AHP method decomposes and structures a complex problem into a hierarchy with the goal at the top, criteria and sub-criteria at levels and sub-levels respectively and the alternatives at the bottom (Orji *et al.*, 2020). Elements at each given hierarchical level, using a linguistic scale, are pairwise compared to determine their relative importance with regards to each of the elements of immediate higher level (outer dependencies). The pairwise comparisons in the AHP model though high in number are the most transparent and technically technique for estimating weights that indicate the relative importance of alternatives and criteria. Given the complexity of the problem and the consequent risk of inconsistency, another reason to choose AHP is the flexibility of its consistency thresholds, against other methods that need perfect consistency to calculate weights (Calabrese *et al.*, 2018).

Generally, the AHP process comprises of the following steps (Moktadir *et al.*, 2019):

Step 1: *Define the goal of the current research*

The goal of the current study is to investigate the impact of the pandemic on sustainable supplier selection in the manufacturing sector of an emerging economy.

Step 2: *Construct the pairwise comparisons matrix*

In this step, with the opinions of different experts, a pairwise comparison matrix (B) of identified dimensions and criteria is developed with the aid of the Saaty's scale having preference judgment of 'Equally important' with score 1 and 'Extremely important' with score 7. Scores 2,4,6,8 and 9 are regarded as intermediate values between adjacent scale values in the Saaty's scale. In the matrix B, the element b_{ij} shows the relative importance of the i^{th}sustainable supplier selection criterion with respect to the j^{th}sustainable supplier selection criterion. The notation is presented as follows: $B = [b_{ij}]$. Each entry in matrix B is positive ($b_{ij} > 0$) (An *et al.*, 2017; Jaberidoost*et al.*, 2015). The pairwise comparison of the identified criterion x, can be shown in Eqn. (1):

$$B = \begin{bmatrix} 1 & b_{12} & \dots & b_{1x} \\ b_{21} & 1 & \dots & b_{2x} \\ \dots & \dots & \dots & \dots \\ b_{x1} & b_{x2} & \dots & 1 \end{bmatrix} \quad (1)$$

Where b_{ij} represents the relative importance of the i^{th}sustainable supplier selection criterion with respect to the j^{th}sustainable supplier selection criterion. The relative importance of criterion$j$ can be computed using Eqn. (2):

$$b_{ij} = \frac{1}{b_{ij}}; \; b_{ij} > 1 \; i,j = 1, 2, 3, \dots x. \quad (2)$$

Step 3: *Compute the priority weights*

This step involves determining the pairwise comparison matrices of the dimensions and criteria are used to compute the eigenvalues and eigenvector. This is followed by computing the weights of the antecedents using Eqn. (3):

$$\begin{bmatrix} 1 & b_{12} & \dots & b_{1x} \\ b_{21} & 1 & \dots & b_{2x} \\ \dots & \dots & \dots & \dots \\ b_{x1} & b_{x2} & \dots & 1 \end{bmatrix} \times \begin{bmatrix} y_1 \\ y_2 \\ \dots \\ y_x \end{bmatrix} = \lambda max \begin{bmatrix} y_1 \\ y_2 \\ \dots \\ y_x \end{bmatrix} \quad (3)$$

Where, λmax represents the maximum eigenvalue of the matrix B, which can be computed from the eigenvector $Y_{max} = [y_{1,} y_2, \dots, y_x]$

The normalized value of the criteria for sustainable supplier selection in the manufacturing sector during a pandemic can be computed by utilizing Eqn. (4):

$$Y = \left[\frac{y_1}{\sum_{i=1}^{x} y_i}, \frac{y_2}{\sum_{i=1}^{x} y_i}, \dots, \frac{y_x}{\sum_{i=1}^{x} y_i}\right]^{\mathrm{T}} \quad (4)$$

Where Y represents the vector coefficient weight while w_i denotes the weights of the criteria and x signifies the total number of the criteria in the current study.

Step 4: *Investigate the ratio of consistency*

The ratio of consistency of pairwise comparison matrices can be determined using the equation below:

$$RC = RI/CI \quad (5)$$

Where RC signifies the ratio of consistency, RI signifies the index of consistency and CI signifies the random index of consistency. The values of the random index of consistency CI are presented in Table 2. The value that is determined for RC is preferably less than 0.10 in other to attain a greater level of consistency. Thus, the RI values are calculated using the following equation:

$$RI = \frac{\lambda_{max} - m}{m-1} \quad (6)$$

Table 2 Random index of consistency

m	1	2	3	4	5	6	7	8	9	10
CI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.2. An Illustrative Example

We consider some expert opinions within the manufacturing sector of an emerging economy on the impact of the COVID-19 pandemic on sustainable supplier selection using AHP design questionnaires. A minimum of 10 completed AHP designed questionnaires is considered sufficient for effective and reliable decision making on the impact of the pandemic on the sustainable supplier selection in the manufacturing sector (Dong and Cooper, 2016; Moktadir*et al.*, 2019). A simple arithmetic mean is utilized to aggregate the responses of the experts in the manufacturing sector within the job categories of production manager, operations manager, purchasing manager and general manager into a pairwise comparison matrix. Table 3 shows the initial step in the AHP computations which comprises of the pairwise comparison matrix of the dimensions for the experts.

Table 3 Pairwise comparison matrix of the dimensions

Dimension	EC	EV	SC	PN	Relative	Rank
EC	1	1/3	3	1/3	0.1507	3
EV	3	1	5	3	0.4909	1
SC	1/3	1/5	1	1/5	0.0670	4
PN	3	1/3	5	1	0.2913	2

Maximum Eigen value= 4.1981; *RC*= 0.0742; *RI*= 0.0660

Table 3results show that 'Environmental dimension' is the most important dimension with a relative weight of 0.4909. This is followed by 'Pandemic dimension' which has a relative importance weight of 0.2913. The third in rank is the 'Economic dimension' which has a relative weight of 0.1507, while the least ranked is 'Socialdimension' with a relative weight of 0.0670. These pinpoint the high impact that the environmental and pandemic dimensions have on the decision to implement sustainable supplier selection in the manufacturing sector of the emerging economy. Following the results in Table 3, the economic dimension might not exhibit a high influence/ impact on the sustainable supplier selection unlike the environmental and pandemic dimension. The least impacting of the dimensions on the sustainable supplier selection process during a pandemic situation is the social dimension according to Table 3 results. Likewise, the pairwise comparison matrix for the criteria in each dimension and their respective relative importance weights were determined by the decision group of experts in the manufacturing sector of the emerging economy using the proposed AHP equations (See Section 3.1). The global weight of the dimensions and criteria are determined from the pairwise comparisons which were developed using the responses of the experts in the study survey. Ultimately,the global ranking of the specific criteria is determined from the global weight by finding the product of the relative weight of the dimension and each criterion and presented in Table4.

Table 4 Global ranking of the criteria for sustainable supplier selection during a pandemic

Dimension	**Relative weight**	**Factor**	**Relative weight**	**Relative rank**
Economic (**EC**)	0.4909	Reduced price/ cost of a product (**EC1**)	0.1858	2
		Presence of efficient production technology (**EC2**)	0.0960	3
		Financial capability (**EC3**)	0.2108	1
Environmental (**EV**)	0.1507	Technical competence of employees (**EV1**)	0.0358	4
		Development of sustainability abilities (**EV2**)	0.1400	2
		Sustainable product design (**EV3**)	0.0890	3
		Regular environmental audits (**EV4**)	0.4482	1
Social (**SC**)	0.0670	Health and safety standards (**SC1**)	0.1062	3
		Policy formulation and compliance (**SC2**)	0.2605	2
		Social responsibility (**SC3**)	0.6333	1
	0.2913	Changing regulations (**P1N**)	0.0716	2

Pandemic (**PN**)	Health threats (**PN2**)	0.2620	1

As can be seen from the Table 4 results, the financial capability of the firm, the reduced price of products and health threats are highly critical and impactful on the sustainable supplier selection process during a pandemic situation. This is deduced from the global ranking of the criteria with the highest-ranked criteria notably the criteria that has the highest impact on the sustainable supplier selection process during a pandemic. This further buttresses the fact that health threats are very impactful on company operations particularly the sustainable supplier selection process during a pandemic situation. During the pandemic, health concerns are critical in most firms' decisions and companies are mandated to make plans to identify and eliminate operations and materials that pose a direct health risk from the COVID-19 to the company's employees and consumers (Sheth, 2020). Also, firms can imbibe behavioural changes that are related to pandemic outbreaks which seem to be connected with personal protection such as the use of masks (Klemes*et al.*, 2020). The financial capability of the firm is also critical for effective sustainable supplier selection as sufficient budgetary allocation is highly essential in sustainability investments (Kusi-Sarpong*et al.*, 2019). In addition, the reduced price of products can induce sales growth and influence the sustainable supplier selection process during the pandemic that is laden within uncertainties and dynamic product demands.

4 Conclusion

Globally, companies are facing increasing pressure from the government regulatory agencies and other relevant stakeholders to actualize sustainability development in their supply chains. Notably, the manufacturing sector is a product system that relates directly and indirectly to economic wealth creation, impact on the natural environment and social systems along the product's life cycle (Kusi-Sarpong*et al.*, 2019).Sustainable supplier selection remains the initial point of sustainable supply chain management as companies consider ways to effectively implement sustainable supplier selection. The COVID-19 pandemic presents numerous opportunities to implement sustainable supplier selection in the manufacturing sector. This might be attributable to the huge role that manufacturing sector plays in producing a vast variety of products to meet dynamic consumer requirements. The emerging economies of the world have succeeded in generating financial gains through their manufacturing sector as the backbone of the economy; but, it is important to notice that these nations have been far away from achieving sustainability within their system (Yadav *et al.*, 2020). Furthermore, the widely imposed lockdown and movement restrictions have distorted the usual routine business pattern ofmost manufacturing sectors in the emerging economies (Shafi *et al.*, 2020). Manufacturing companies in the emerging economies need to evaluate their sustainable supplier selection process in the current pandemic crisis. The wealth of solutions is expected from this present odd situation, posed by the recent pandemic outbreak, to be best equipped to contain such outbreak in the future and still maintain a sustainable supply chain network. The proposed framework for determining the impact of the pandemic on the sustainable supplier selection process in the manufacturing sector can be applied to other industrial sectors that seek for ways to select the right suppliers with sustainable development in mind. Industrial managers can utilize the framework to evaluate other strategic decisions that might be related to the sustainability dimensions and criteria for improved performance and increased global competitiveness. The pandemic and environmental dimensions are much more impactful in implementing sustainable supplier selection in the manufacturing sector in a pandemic situation. This calls for more theorization and exploration of the issues in various industrial settings in emerging economies for a fair generalization. Specifically, the health threats in addition to the reduced price of products and firms' financial capability also have a huge impact on the sustainable supplier selection process amongst other criteria during the COVID-19 pandemic. In the future, research efforts can be garnered towards proposing other multi-criteria decision-making method earlier mentioned (See Section 3) to provide another perspective on the impact of the pandemic on the sustainable supplier selection process. Also, presenting an outlook on different emerging economies and comparing such proposed frameworks and results, can be another interesting research agenda.

References

Ahmadi .H.B., Lo H-W., Gupta H., Kusi- Sarpong S., Liou J.J.H. (2020). An integrated model for selecting suppliers on the basis of sustainability innovation. *Journal of Cleaner Production*, 277, 123261. http://eprints.soton.ac.uk/id/eprint/442581

Amindoust, A. Ahmed. S. Saghafinia.A, Bahreininejad. A. (2012). Sustainable supplier selection. A ranking model based on Fuzzy Inference System. *Applied soft computing* 12(2012) 1668-1677. https://doi.org/10.1016/j.asoc.2012.01.023

Berg. A, Haug, L, Hedriech.S. Magnus.K (2020). *Time for change: How to use the crisis to make fashion sourcing more agile and sustainable; McKinsey & Company.* Retrieved from https://www.mckinsey.com/~/media/McKinsey/Industries/Retail/Our%20Insights/Time%20for%20change%20How%20to%20use%20the%20crisis%20to%20make%20fashion%20sourcing%20more%20agile%20and%20sustainable/Time-for-change-How-to-use-the-crisis-to-make-fashion-sourcing-more-agile-and-sustainable.pdf.

Bretas, V. P. G., &Alon, I. (2020). The impact of COVID-19 on franchising in emerging markets: An example from Brazil. *Global Business and Organizational Excellence*, *39*(6), 6–16. https://doi.org/10.1002/joe.22053

Bui T-D., Tsai F.M., Tseng M-L., Tan R., Yu K.D.S., Lim M.K. (2020). Sustainable supply chain management towards disruption and organizational ambidexterity: a data – driven analysis. *Sustainable Production and Consumption*, https://doi.org/10.1016/j.spc.2020.09.017.

Calabrese A., Costa R., Levialdi N., Menichini T. (2018). Integrating sustainability into strategic decision- making: A fuzzy AHP method for the selection of relevant sustainability issues. *Technological Forecasting and Social Change*, 139, 155- 168.

Chen Z., Ming X., Zhou T., Chang Y. (2020). Sustainable supplier selection for smart supply chain considering internal and external uncertainty: An integrated rough- fuzzy approach. *Applied Soft Computing*, 87, 106004.

Craighead, C. W., Ketchen, D. J., & Darby, J. L. (2020). Pandemics and Supply Chain Management Research: Toward a Theoretical Toolbox*. *Decision Sciences*, *51*(4), 838–866. doi.org/10.1111/deci.12468

Dailly, R. (2020). *Featured in Business Times Discussing the Impact of COVID-19 on Emerging Economies, 9–11*. Retrieved from https://www.kroll.com/en/about-us/news/richard-dailly-featured-business-times-impact-covid-19-emerging-economies

Dong Q., Cooper O. (2016). An orders- of- magnitude AHP supply chain risk assessment framework. *International Journal of Production Economics*, 182, 144- 156.

Dwivedi Y.K., Hughes D.L., Coombs C., Constantiou I., Duan Y., Edwards J.S., Gupta B., Lal B., Misra S., Pranshant P., Raman R., Rna N.P., Sharma S.K., Updahyay N. (2020). Impact of COVID- 19 pandemic on information management research and practice: Transforming education, work and life. *International Journal of Information Management*, 102211.

Ecer F., Pamucar D. (2020). Sustainable supplier selection: A novel integrated fuzzy best worst method (F- BWM) and fuzzy CoCoSo with Bonferroni (CoCoSo' B) multi- criteria model. *Journal of Cleaner Production*, 266, 121981.

Elavarasan R.M., Pugazhendhi R. (2020). Restructured society and environment: A review on potential technological strategies to control the COVID- 19 pandemic. *Science of the Total Environment*, 725, 138858.

Georgieva. K. (Presenter). (2020 April 9). AM: *Confronting the COVID-19 Crisis.* [Audio podcast]. Retrieved from https://www.imf.org/en/News/Podcasts/All-Podcasts/2020/04/09/md-curtain-raiser-2020-sms

Ghadimi P., Wang C., Lim M.K., Heavy C. (2019). Intelligent sustainable supplier selection using multi- agent technology: Theory and application for Industry 4.0 supply chains. *Computers & Industrial Engineering*, 127, 588- 600.

Gondwe.G. (2020). Assessing the impact of COVID-19 on Africa's Economic Development. *United Nations Conference on Trade and Development (UNCTAD/ALDC/MISC/2020/3)*. Retrieved fromhttps://unctad.org/en/PublicationsLibrary/aldcmisc2020d3_en.pdf

Govindan, K., Mina, H., &Alavi, B. (2020). A decision support system for demand management in healthcare supply chains considering the epidemic outbreaks: A case study of coronavirus disease 2019 (COVID-19). *Transportation Research Part E: Logistics and Transportation Review*, *138*(May), 101967. https://doi.org/10.1016/j.tre.2020.101967

He H., Harris L. (2020). The impact of COVID- 19 pandemic on corporate social responsibility and marketing philosophy. *Journal of Business Research*, 116, 176- 182.

Hendiani, S., Liao, H., Bagherpour, M., Tvaronaviĉiene, M., Banaitis, A., &Antucheviciene, J. (2020). Analyzing the status of sustainable development in the manufacturing sector using multi-expert multi-criteria fuzzy decision-making and integrated triple bottom lines. *International Journal of Environmental Research and Public Health*, *17*(11). https://doi.org/10.3390/ijerph17113800

Hevia .C. &Neuyemer. A. (2020). *A perfect storm: COVID-19 in emerging economies.* Retrieved from https://voxeu.org/article/perfect-storm-covid-19-emerging-economies

Intelligence Brief (2020). *How is Covid-19 affecting emerging markets? Mobile world live.* Retrieved from https://www.mobileworldlive.com/blog/intelligence-brief-how-is-covid-19-affecting-emerging-markets

International Monetary Fund (2020). *World Economic Outlook : The Great Lockdown.* Retrieved from https://www.imf.org/en/Publications/WEO/Issues/2020/04/14/weo-april-2020

Ivanov D., Dolgui A. (2020). OR- methods for coping with the ripple effect in supply chains during COVID- 19 pandemic: Managerial insights and research implications. *International Journal of Production Economics*, 107921.

Ivanov, D., & Das, A. (2020). Coronavirus (COVID-19/SARS-CoV-2) and supply chain resilience: A research note. *International Journal of Integrated Supply Management*, *13*(1), 90–102. https://doi.org/10.1504/IJISM.2020.107780

Ivanov. D. &Dolgui, A. (2020): A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0, *Production Planning & Control*, DOI: 10.1080/09537287.2020.1768450

Ivanov.D. (2020). Viable supply chain model: Integrating agility, resilience and sustainability perspectives-Lessons from and thinking beyond the COVID-19 pandemic. *Annals of operations research.* https://doi.org/10.1007/si0479-020-03640-6.

Jabbour, L.D, Beatriz,.A, Jabbour, C. C., Martin.H. (2020). *Sustainability of supply chains in the wake of the coronavirus (COVID-19/SARS-CoV-2) pandemic: lessons and trends. Modern Supply Chain Research and Applications* . pp. 1-10. ISSN 2631-3871 https://doi.org/10.1108/MSCRA-05-2020-0011

Janin N., Singh A.R. (2020). Sustainable supplier selection under must-be criteria through Fuzzy inference system. *Journal of Cleaner Production*, 248, 119275.

Javaid, M., Haleem, A., Vaishya, R., Bahl, S., Suman, R., &Vaish, A. (2020). Industry 4.0 technologies and their applications in fighting COVID-19 pandemic. *Diabetes and Metabolic Syndrome: Clinical Research and Reviews*, *14*(4), 419–422. Retrieved from https://doi.org/10.1016/j.dsx.2020.04.032

Khan S.A., Kusi- Sarpong S., Arhin F.K., Kusi- Sarpong H. (2018). Supplier sustainability performance evaluation and selection: A framework and methodology. *Journal of Cleaner Production*, 205, 964- 979.

Klemes J.J., Fan Y.V., Jiang P. (2020). The energy and environmental footprints of COVID- 19 fighting measures- PPE, disinfection supply chains. *Energy*, 211, 118701.

Kose .M.A, Ohnsorge, F. Nagle.P. Sugawara, N (2020). *Caught by the Cresting Debt wave: Past debt crises can teach developing economies to cope with COVID-19 financing shocks: Finance & development.* Retrieved from https://www.imf.org/external/pubs/ft/fandd/2020/06/pdf/COVID19-and-debt-in-developing-economies-kose.pdf

Kumar, A., Luthra, S., Mangla, S. K., &Kazançoğlu, Y. (2020). COVID-19 impact on sustainable production and operations management. *Sustainable Operations and Computers*, *1*(May), 1–7. https://doi.org/10.1016/j.susoc.2020.06.001

Kusi- Sarpong S., Gupta H., Sarkis J (2019). A supply chain sustainability innovation framework and evaluation methodology. *International Journal of Production Research*, 57 (7), 19900- 2008.

Lee S.M., Trimi S. (2020). Convergence innovation in the digital age and in the COVID- 19 pandemic crisis. *Journal of Business Research*, 123, 14- 22.

Majumdar A., Shaw M., Sinha S.K. (2020). COVID- 19 debunks the myth of socially sustainable supply chain: A case of the clothing industry in South Asian countries. *Sustainable Production and Consumption*, 24, 150- 155.

McKibbin, W. J. and Fernando, R, (2020, March 2). The Global Macroeconomic Impacts of COVID-19: Seven Scenarios. Scenarios. CAMA Working Paper No. 19/2020, *Electronic Journal*, (March), 1–43. https://doi.org/10.2139/ssrn.3547729

Meester, J.&Ooijens .M. (2020, June 24). COVID-19 Impact on the Value Chain – Conceptual paper. *CRU Policy Brief*,.https://www.researchgate.net/publication/342439183_COVID-19_Impact_on_the_Value_Chain_-_Conceptual_paper

Moheb- Alizadeh H., Handfield R. (2019). Sustainable supplier selection and order allocation: A novel multi- objective programming model with a hybrid solution approach. *Computers & Industrial Engineering*, 129, 192- 209.

Moktadir M.A., Ali S.M., Paul S.K., Shukla N. (2019). Barriers to big data analytics in manufacturing supply chains: A case study from Bangladesh. *Computers& Industrial Engineering*, 128, 1063- 1075.

Orji I.J., Kusi- Sarpong S., Huang S., Vazquez- Brust D. (2020). Evaluating the factors that influence blockchain adoption in the freight logistics industry. *Transportation Research Part E: Logistics and Transportation Review*, 141, 102025.

Orji I.J., Wei S. (2015). An innovative integration of fuzzy- logic and systems dynamics in sustainable supplier selection: A case on manufacturing industry. *Computers & Industrial Engineering*, 88, 1- 12.

Ozil.P.K (2020). Covid-19 pandemic and economic crisis: The Nigerian experience and structural causes: Munich Personal RePEc. Retrieved from htps://mpra.ub.uni-muenchen.de/99424/

Pan, S. L., & Zhang, S. (2020). From fighting COVID-19 pandemic to tackling sustainable development goals: An opportunity for responsible information systems research. *International Journal of Information Management,* 102196.

Quieroz M.M., Ivanov D., Dolgui A., Wamab S.F. (2020). Impacts of epidemic outbreaks on supply chains: mapping a research agenda amid the COVID-19 pandemic through a structured literature review. *Ann Oper Res* (2020). https://doi.org/10.1007/s10479-020-03685-7.

Rahidi K., Noorizadeh A., Knnan D., Cullinane K. (2020). Applying the triple bottom line in sustainable supplier selection: A meta- review of the state-of-the art. *Journal of Cleaner Production*, 269, 122001.

Rizou M., Galankis I.M., Aldawoud T.M.S., Galanakis C.M. (2020). Safety of foods, food supply chain and environment within the

COVID- 19 pandemic. *Trends in Food Science & Technology*, https://doi.org/10.1016/j.tifs.2020.06.008.

Ruiz.A&Villafranca B. 2020. Emerging countries and Covid-19: on the brink of a financial crisis? Retrieved https://www.caixabankresearch.com/en/economics-markets/financial-markets/emerging-countries-and-covid-19-brink-financial-crisis.

Sarkis J., Cohen J., Dewick P., Schroder P. (2020). A brave new world: Lessons from the COVID- 19 pandemic for transitioning to sustainable supply and production. *Resources, Conservation and Recycling*, 159, 104894.

Shafi M., Liu J., Ren W. (2020). Impact of COVID- 19 pandemic on micro, small, and medium- sized Enterprises operating in Pakistan. *Research in Globalization*, 2, 100018.

Sharma A., Adhikary A., Borah S.B. (2020). Covid- 19's impact on supply chain decisions: Strategic insights from NASDAQ 100 firms using Twitter data. *Journal of Business Research*, 117, 443- 449.

Sharma H.B., Vanapalli K.R., Cheela V.S., Ranjan V.P., Jaglan A.K., Dubey B., Goel S., Bhattacharya J. (2020). Challenges, opportunities, and innovations for effective solid waste management during and post COVID- 19 Pandemic. *Resources, Conservation and Recycling*, https://doi.org/10.1016/j.resconrec.2020.105052.

Sheth J. (2020). Business of business is more than business: Managing during the Covidcrisis.*Industrial Marketing Management*, 88, 261-264.

Stevic Z., Pamucar D., Puska A., Chatterjee P. (2020). Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to

Compromise solution (MARCOS). *Computers & Industrial Engineering*, 140, 106231.

Tisdell (2020). Economic, social and political issues raised by the COVID- 19 pandemic. *Economic Analysis and Policy*, 68, 17- 28.

Tridos Investment Management (2020). *Mixed impact and common goal after COVID-19: Emerging markets outlook.*,https://www.triodos-im.com/articles/2020/emerging-markets-outlook---june-2020. Ludena .M.C.

Wilding. R., Dohrmann. K., Wheatley .M (2020). *Post-Coronavirus supply chain recovery. The Journey towards the new normal. A DHL perspective on the impact of the COVID-19 pandemic on supply chain and logistics.* Retrieved from https://www.dhl.com/content/dam/dhl/global/core/documents/pdf/glo-core-post-covid-eme-white-paper.pdf

World Economic Forum (2020) *The Impact of COVID-19 on the Future of Advanced Manufacturing and Production Insights from the World Economic Forum's Global Network of Advanced Manufacturing Hubs.* Retrieved from http://www3.weforum.org/docs/WEF_AMHUB_Insight_Paper_2020.pdf

Yadav G., Kumar A., Luthra S., Garza- Reyes A., Kumar V., Batista L. (2020). A framework to achieve sustainability in manufacturing organizations of developing economies using industry 4.0 technologies' enablers. *Computers in Industry*, 122, 103280.

Yadavalli V.S., Darbari J.D., Bhayana N., Agarwal V. (2019). An integrated optimization model for selection of sustainable suppliers based on customers' expectations. *Operations Research Perspectives*, 6, 100113.

Yaker, F., &Ahn, J. H. (2020). *Making sustainable public procurement part of the COVID-19 fiscal response*. Retrieved from https://www.greengrowthknowledge.org/blog/theme/23

Zhu, G., Chou, M. C., & Tsai, C. W. (2020). Lessons Learned from the COVID-19 pandemic exposing the shortcomings of current supply chain operations: A long-term prescriptive offering. *Sustainability (Switzerland)*, *12*(14), 1–19. https://doi.org/10.3390/su12145858

CHAPTER 12

The Traveling Salesman Problem: Algorithms, Sub-tours and Applications in Combinatorial Optimization

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Abstract

The importance of the traveling salesman problem (TSP) in combinatorial optimization and its application and adaptability to numerous real-life problems has led to the development of a wide range of algorithms. A major issue in the development of TSP algorithm involves how to handle the large number of subtour eliminating constraints which contribute to the exponential growth of computational time associated with TSP algorithms. In this chapter, basic concepts, development and many numerous research efforts of Professor O.E. Charles-Owaba on TSP were discussed; some of his works on the concept of the TSP set sequencing algorithm were highlighted.

Keywords: Traveling Salesman Problem, Subtour, Machine setup problem, Set Sequencing Algorithm, Combinatorial optimization, Sequence dependent setup, Charles-Owaba

1.0 Introduction

The need to determine the minimum total length of the route while visiting every point once in a given set gives rise to the traveling salesman problem (TSP). The TSP is an important and popular problem in combinatorial optimization that has attracted a lot of interests in operations research, mathematics, computer science, engineering and other research areas (Ezugwu & Adewumi, 2017; Kieu, 2019; Oladokun & Charles-Owaba, 2011). TSP can be stated as:

"Given N cities and the distance or cost between each pair of cities, a salesman starting in one city wishes to visit each of N-1 other cities once and only once and return to the starting point. In what order should he visit the cities to minimize the total distance travelled?" Mathematically, the problem can be stated as: Given a 'cost (distance) matrix' C = (C_{ij}), where C_{ij} is the cost (distance) of traveling from city i to city j (i, j = 1, 2, . . ., n), find a permutation $(i_1, i_2, i_1, \ldots, i_n)$ of the integers from 1 through n that minimizes the quantity

$$C_{i_1 i_2} + C_{i_2 i_3} + \ldots + C_{i_n i_1}.$$

Historically, the TSP has assumed many interesting names such as the laundry van problem, and the messenger problem. From a scheduling perspective, TSP is equivalent to the sequence-dependent single machine setup problem or simply referred to as machine setup problem (MSP). The TSP which was first formulated in the 1930s, came to prominence in the United States of America, in the 1950s, when solving a 33-city problem instance was used as a promotional contest by Soap Company for a price of $10,000.00.

2.0 Traveling Salesman Problem and Applications

The TSP as a combinatorial optimization problem has an associated decision problem that seeks to determine the cheapest cost route (i.e. route/distance) available to a salesman to visit a specified number of cities and return to the beginning city. This unique problem description of TSP has attracted numerous attention and research efforts from scientists across the globe. Apart from its theoretical importance, countless numbers of practical and interesting problems across several industries have been formulated as a TSP model within the context of optimization. The TSP is popular because of its practical relevance and application in many areas such as routing of vehicle, manufacturing and assembly of parts, manufacturing of electronic board manufacturing, scheduling of jobs in the production system, andgroup technology (GT) approach to manufacturing. The varied applications of the model remain the key motivating factor in the continued interests of many researchers in TSP. For example, in printed circuit boards (PCBs), the objective is to determine an optimal sequence for drilling circuit board holes considered as cities to be visited by drilling machine head (salesman) to reduce machine travel time or its associated cost (Grostchel, *et al.*, 1991). In inventory order picking problem, a server or attendant (salesman) need to travel within the warehouse to collect a series of orders (cities) to minimise lead-time. Given the arrival of an order for a subset of items stored in a warehouse, an attendant/automated vehicle/server has to move strategically to collect these items before shipping it to customers. The objective here is to minimize the lead time of services to customers. Other applications include the sequencing of tasks on a weaving machine with set-up costs, the order spread elimination problem in cutting-stock model encountered in glass manufacturing, the problem of crystal orientation time reduction during the study of the atomic structure of crystals with x-ray diffractometers, efficient manpower utilization associated with the rostering of duties in public transport system (Bard *et al*, 1994; Foulds and Hamacher, 1980; Keuthen, 2003; Ohno *et al*, 1999; Rajkumar & Narendran, 1996; Al-Haboub & Shorik, 1993; Madsen, 1988; Ferreir, 1995). Also, there are research work that has emanated from the contributions of Professor Charles-Owaba to the traveling salesman problem. One is the simultaneous optimization of makespan (C_{max}) and the number of tardy jobs (NT) in a single machine problem with sequence-dependent setup time as described in Oladokun *et al* (2011). Another interesting application of TSP is in the music industry where the problem of generating harmonious song-list was modeled as a single machine setup problem with accompanying solution software (Oladokun *et al.*, 2011).

2.1 The Single Machine Setup Problem

In a general-purpose work facility, the set-up time is an interval of time between the end of a job's processing and the beginning of the next available job. The machine setup can be sequence-dependent and sequence-independent. A schedule maps (or allocates) resources to tasks (or activities) over a specified period while a sequence involves the ordering of activities through machines or resources. The sequence-dependent machine setup problem minimizes a pre-defined cost or time objective of re-setting a facility by determining the optimal sequence required to perform a set of N operations. For a single machine commissioned to process job *i* and *j*, the scheduling problem of optimising the makespan, C_{max} (or completion time) with sequence-dependent machine setup times S_{ij} (j is processed immediately after i) is the single machine setup problem (MSP). In MSP, the sequence of X (stations) parts being processed by a single machine to minimize C_{max} can be likened to the traveling salesman problem. In scheduling, the modeling structure of the TSP is also referred to as sequence-dependent MSP. In many contexts, terms such as MSP and TSP are used interchangeably.

In a static single machine scheduling scenario with no sequence-dependent setup times, makespan minimization is a trivial problem because C_{max} is the same irrespective of the sequence adopted. However, in many practical scheduling problems with sequence-dependent setup times, makespan becomes a function of the job sequence. A classical example of such a single facility problem is found in the mixing of different paints produced repeatedly on one machine in fixed sequence per production cycle. The setup time corresponds to the cleaning time of the machine between colours changes; this depends on the time required for the colour to be removed, and the start of production for the next colour. Another example is the group technology (GT) approach to manufacturing systems design using TSP set-up time reduction principle, this exploits the sequence dependency of set-up times of some part families (Charles–Owaba & Lambert, 1988; Karabat & Akkan, 2006).

2.2. Other Variants of TSP

TSP can be categorised as symmetric and asymmetric. For the symmetric case, the distance (or equivalent cost) of travelling from the station (or city) i to station j is the same as travelling vice-versa (i.e. city j to city i) i.e. $C_{ij} = C_{ji}$. However, the asymmetric TSP is more generic in that $C_{ij} \neq C_{ji}$, and this portrays the real-life scenarios or problems such as when the to and fro trip fares are different for the pair of cities (Oladokun & Charles-Owaba, 2008). The TSP can also occur as cyclic when the salesman returns to the starting city or acyclic when the salesman stops at last city without 'return home' (Charles–Owaba, 2001). The Minimum Latency Problem (MLP) is another variation of the TSP, which aims to minimize the sum of arrival times at vertices, or the sum of clients waiting time to receive service and other many practical applications (Silva *et al*, 2012). The Time-Dependent TSP is a generalized TSP where the costs between pair of cities depend on their position in the sequence (Abeledo *et al*, 2013) while in the Time-Dependent TSP with Time Windows variant the time dependence is captured by considering variable average travel speeds Montero *et al* 2017). There is another variant in the context of maritime transportation called the TSP with Draft Limits (TSPDL) that is modelled to account for restrictions on the port infrastructures (Battarra *et al*, 2014).

3.0 Solving Travelling Salesman Problem

The TSP was infamous amongst scientists in early developmental years due to lack of scientific methodology for solving the problem. In TSP and other real-life instances of combinatorial problems, as soon as the number of cities increases, more computational resources will be required to solve the problem effectively and efficiently. Early solution approach includes a simple method of randomly chosen locations in the Euclidean plane as proposed in 1938 to a TSP application in farm survey, making a finite number of trials, with rules that may reduce the number of trials, and a modified assignment problem algorithm (Robinson, 1949). The TSP camouflage its computational complexity with a deceptively easy to grasp definition and remains a very attractive and productive platform for developing and testing many combinatorial optimization procedures.

The invention of the linear programming simplex algorithm ushered in a new world of possibilities when Dantzig *et al* (1954) formulated the TSP as an integer linear program and used the cutting plane method to find an optimal solution for a 49-city problem. There have been several adaptations of the LP algorithms for TSP, such as the use of dual LP algorithm for LP relaxations and max-flow algorithm for identifying violated sub tour inequalities of TSP model. There were applications of branch-and-bound algorithms that adopted an assignment problem (Eastman, 1958), the minimum spanning trees problem or similar relaxations as lower bounds. The branch-and-bound algorithm by Little *et al* (1963) was one of the most popular implicit enumeration approaches for the TSP. Other early exact algorithm approaches include dynamic programming algorithm (Bellman, 1960) and integer programming formulation solved with the Gomory's cutting-plane algorithm (Lambert, 1960). For small problem size, exact methods have proven to be effective. However, in TSP and other real-life instances of combinatorial problems, as soon as the number of cities increases, more computational resources will be required to solve the problem effectively and efficiently.Several heuristics have also been developed and applied to solve the TSP (Hossam *et al*, 2018; Almufti *et al*, 2019). Some of the widely known local optimization techniques and variants like simulated annealing, tabu search, neural networks, genetic algorithms and ant colony algorithm have adopted the TSP as a challenging playground for evolution and testing (Xu *et al*, 2018; Qaiduzzaman, et al., 2020; Rossman, 1958; Tian & Yang, 1993; Walshaw, 2002; Riera-Ledesma, 2005). The cheapest-insertion heuristic (Karg &Thompson 1964), and the Lin *k*-opt heuristic (Lin, 1965) were some of the earliest heuristic approaches to the TSP. A chronological review of the evolution of these algorithms and heuristics is contained in Oladokun and Charles-Owaba (2011).

3.1 Computational Complexity

A computational problem can be defined as a function *f* required to map each input *x* within a given domain to an output *f* (*x*) in a given range. Computational complexity considers the number of steps an algorithm needs to take to solve an instance of a problem (Oladokun, 2006; Oladokun & Owaba, 2011). Because the computer execution time required for solving a problem is a function of the number of computational steps, the performance of an algorithm is, therefore, measured as the maximum number of steps it requires for any instance of size N expressed as a function of N. A polynomial algorithm bounded by a polynomial function of instance size N is considered efficient, while an exponential algorithm bounded by an exponential function of instance size N is considered inefficient or computationally expensive (see Cook *et al*, 1998; Garey & Johnson, 1979; Johnson & Papadimitriou, 1985; Walshaw, 2001; Walshaw, 2002; Saadani *et al*, 2005). Hence, a problem is considered easy if there is a polynomial-time algorithm to solve it and hard otherwise (Cook *et al*, 1998; Marcotte *et al*, 2004; Gamboa *et al*, 2006). The TSP is classified as a hard combinatorial optimization problem with no polynomial-time optimizing algorithm (see Lawler *et al*, 1985; Applegate *et al*, 2004; Zhang, 2004). The TSP and its variants belong to a class of computationally complex problems called NP-complete. The class of P and NP problems can be solved by a non-deterministic polynomial (NP) time algorithm in polynomial time. This implies that if a polynomial-time algorithm is found for the TSP, it means all other NP-hard is solvable in polynomial time. This theoretical importance has been a key driver for the TSP research interests (Roberts & Flores, 1966; Fischetti & Toth, 1992; Dorigo & Gambardella, 1997; Applegate *et al*, 2004; Zhang 2004).

3.2 Algorithms and Heuristics

Like all other NP-hard discrete optimization problems, there are two classes of solution methods for the TSP problem: exact or optimization algorithms and heuristics also known as approximation algorithms. While exact algorithms are designed to contain a proof of optimality of the resulting solution; and have a mechanism to obtain the so called global optimal solution, they are computationally expensive and bounded by an exponential function of instance size N. TSP heuristics or approximation methods, on other hand, are designed to obtain a good solution without the confirmation of optimality and are mostly polynomial-time methods. Many heuristics are modified exact algorithms designed by jettisoning their optimality mechanisms as trade-off for achieving computational efficiency.

Since the TSP is a discrete optimization problem with a finite number of possible solutions, though this number is an exponential function of the problem size N, the complete enumeration is guaranteed to yield an optimal solution. However exponential growth renders this approach not practicable for even 2-digit size problems. For instance, an explicit enumeration algorithm running on the fastest computer would need about two days to find an optimal solution for a (N=20) problem size while for a (N=25) problem size the time grows to 400 centuries! Hence, practical algorithms are based on implicit enumeration which does not search through all solution space. Many existing algorithms are based on methods such as Integer Linear Programming method which formulate the TSP as a linear programming problem in zero-one variables and attempt to prove optimality using the concept of cutting planes. The TSP has been solved using dynamic programming formulation, branch and bound algorithm. While these algorithms are not efficient for practical problems they have been the basis for very good non-optimizing heuristics.

The Nearest Neighbour Algorithm is an example of such heuristics with easy to implement variations like multi-start approach Nearest Neighbour (see Johnson *et al*, 1997; Charles-Owaba & Oladokun, 1999; Hurkens & Woeginger, 2004). There are insertion methods (Karg &Thompson, 1964), the 2-opt and 3-opt heuristic which works as tour improvement methods using the deletion and replacement of 2 non-adjacent edges. The Lin-Kernighan k-opt method is a generalized implementation of the 2-opt tour improvement method (Lin & Kernighan, 1973; Chandra *et al*, 1999; Helsgaun, 2000).

There are also search heuristics such as genetic algorithm, simulated annealing, and tabu search. The genetic algorithm and many of its variations developed for the TSP are designed to mimic the biological evolution concepts that support the evolution of improved population of solutions. This improvement is achieved by mathematically mirroring evolution concepts such as survival of the fittest, crossover or reproduction, genetic mutation and migrations and similar evolution concepts (Charterjee *et al.* 1996; Johnson & McGeoh, 1997). The tabu search is another popular general heuristic procedure used for the TSP. Tabu search solves the problem of infinite cycling associated with improving search procedure by forbidding some moves, 'taboo moves', that will return to immediately previously visited point in the solution space (Radin, 1998; Kolohan & Liang, 2000). Simulated annealing is a search technique that controls cycling by mimicking the annealing process for improving the strength of steel (Tian & Yang, 1993; Johnson & McGeoh, 1997; Radin, 1998).

3.3 Feasibility and Sub tours in TSP Solutions

Feasibility due to subtour occurrence is a major issue in the formulation of the TSP or similar permutation sequence problem. Design of subtour constraints is a major challenge in model and algorithm development for the TSP. While it is easy to understand subtours, crafting subtour elimination constraints remains a difficult and challenging task (Radin, 1998; Oladokun and Charles-Owaba, 2011). Hence, theoretical principles for crafting these constraints within the context of algorithm development has been the thrust of many TSP works such as Crowder and Paderg(1980) which adopted a linear programming relaxation, Grötschel (1980) which used a cutting-plane algorithm with cuts involving sub tour inequalities, Hong (1972) used the Ford-Fulkerson max-flow algorithm for finding violated sub tour inequalities. In fact, the method for handling sub tour occurrences is what distinguishes one solution method from another and has influenced the various solution approaches. Meanwhile, the large number of sub tour elimination constraints, even for a modest number of points, makes the problem practically intractable.

The enormous number of computations required to solve such system of equations does not allow for the direct utilization of the ILP for TSP. However, researchers have adopted the idea of using the ILP to find good lower bound for the TSP. This lower bound procedure can then be used for assessing the effectiveness of heuristics solutions. For example, for the 380 cities record-breaking work of Crowder and Paderg (1980), a linear programming relaxation was adopted. An integer-programming solver was used to carry out a branch-and-bound search on the final linear programming relaxation. If the solution found using this search does not produce a tour, the subtour inequalities violated by the solution obtained is added back again using cutting-plane algorithm (Grötschel,1980). Subtours constraints require huge computational efforts. One approach to minimize these efforts in heuristics procedures is to adopt TSP formulation with simpler constraints such as formulating the TSP as quadratic assignment problem (QAP) and some adaptations of improving search methods on the QAP formulation. Oladokun and Charles-Owaba (2011) described some graph theoretic concepts for dealing with these sub tours constraints within the context of the set sequence algebra.

4.0 The Set Sequencing Algorithm (SSA)

Charles–Owaba (2001, 2002) proposed the set sequencing algorithm as a basis for the TSP solution. The set sequencing procedure describes a complete TSP sequence or tour as a set of N TSP matrix elements (links). The procedure then defines as the transformation of a known sequence (S_{i-1}) to a new sequence (S_i) by feasibly replacing a subset of its links (Lr) with an equal number (M) of candidate links (Lc) using a recursive function $Va(S_i) = Va(S_{i-1}) + \Delta(Lr, Lc, M)$. Where $Va(S_i)$ and $Va(S_{i-1})$ are the respective solution sequence values and $\Delta(Lr, Lc, M)$ is the exact amount $Va(S_i)$ is changed by the replacement operation. However, the original SSA had the challenge of feasibility; it sometimes results in infeasible solutions or subtours. The redesign of the SSA to develop a subtour-free set sequencing algorithm was the focus of a PhD thesis (Oladokun, 2006) supervised by Professor O.E Charles-Owaba in the Department of Industrial Engineering, University of Ibadan (see Oladokun & Charles-Owaba, 2011).

While implicit enumeration algorithms and heuristics view the machine setup problem in terms of the individual sequences and are designed to search through N factorial possible sequences (Charles-Owaba, 2001). The set sequencing concept addresses the machine setup problem differently, by searching for optimal elements among N(N-1) TSP matrix elements. A set of candidate links are used to replace some or all of the links of a given sequence to iteratively form improved sequences (Kwon *et al*, 2005). The SSA represents a major contribution of Professor O.E Charles-Owaba to the literature of the travelling salesman problem.

5.0 Conclusion

The traveling salesman problem has attracted quite a lot of interests for several decades evident by its wide practical applications such as routing, logistics, drilling, surveying, genetics, manufacturing, telecommunication, neuroscience, scheduling, to mention just a few. In scheduling, the traveling salesman problem or the sequence-dependent machine setup problem is an attempt to determine the minimum- total-length route while visiting every point once in a given set. In this chapter, the numerous research efforts of Professor Charles-Owaba to model and solve the different variants of the traveling salesman, such as the simultaneous optimization of makespan (C_{max}) and the number of tardy jobs (NT) in a single machine problem, group technology (GT) approach to manufacturing systems design using TSP set-up time reduction principle, and graph theoretic concepts for dealing with sub tours constraints within the context of the set sequence algebra were highlighted.

These research efforts were discussed by considering the single machine set-up problem (MSP) and other variants of TSP, the need to eliminate sub tour occurrences in the search for an optimal tour, which grows exponentially as the size of the problem grows. This difficulty brings to fore the concept of computational complexities, algorithms and heuristics available to solve TSP.

References

Abeledo, H., Fukasawa, R., Pessoa, A., & Uchoa, E. (2013). The time dependent traveling salesman problem: polyhedra and algorithm. *Mathematical Programming Computation* , *5* (1), 27-55

Al-Haboub-Mohamad, H.& Shokrik, Z. (1993). A Sequencing Problem in the Weaving Industry. *European Journal of Operational Research. 66* (1), 65-71.

Almufti, S.,Marqas, R., & Asaad, R. (2019). Comparative study between elephant herding optimization (EHO) and U-turning ant colony optimization (U-TACO) in solving symmetric traveling salesman problem (STSP). *Journal Of Advanced Computer Science & Technology* , *8* (2), 32

Applegate, D., Bixby, R.., Chvatal, V., Cook, W. & Helsghaun, K. (2004). The Sweden Cities TSP Solution' Available at www.tsp.gatech.edu//sweeden/cities/ cities.htm.

Bard, J.F., Clayton, R.W. and. Feo T. A. (1994). Machine Setup and Component Placement in Printed Circuit Board Assembly. *International Journal of Flexible Manufacturing Systems*. *6*, 5-31.

Battarra, M., Pessoa, A. A., Subramanian, A., & Uchoa, E. (2014). Exact algorithms for the traveling salesman problem with draft limits. *European Journal of Operational Research* , *235* (1), 115-128.

Bellman, R. (1960). Dynamic Programming Treatment of the TSP. *Journal of Association of computing Machinery*. 9,66.

Charles-Owaba, O.E & Oladokun, V.O (1999). A Set Sequencing Heuristic and the Computer Code for the TSP. *Proceedings of NIIE conference on Manufacturing Engineering, 1*,135-146

Charles-Owaba, O. E. & Lambert, B.K. (1988). Sequence-Dependent Set-up Times and Similarity of Parts: A Mathematical Model. *Operation Research Special*. *20*(1).

Charles–Owaba, O. E. (2001). Optimality Conditions to the Acyclic Travelling Salesman Problem. *Operational Research Society of India*, *38*(5).

Charles–Owaba, O. E. (2002). Set-sequencing Algorithm to the Cyclic TSP. *Nigerian Journal of Engineering Management*, *3*(2), 47-64.

Charles-Owaba, O. E. & Oladokun V.O. (1999). A Set Sequencing Heuristic and the Computer Code For The TSP. *Proceedings of NIIE Conference on Manufacturing Engineering*, *1*, 135-146.

Chandra, B., Karloff H. & Tovey, C. (1999). New results for the old k-opt algorithm for the TSP. *SIAM Journal on Computing*, 28(6), 1998-2029.

Cook, W.J., Cunningham, W.H., Pulleyblank, R.W. & Schrijve, A. (1998). *Combinatorial Optimization* John &Sons, Inc New York

Crowder, H. & Padberg M.W (1980). Solving large-scale symmetric travelling salesman problems to optimality, *Management Science*, *26* 495-509.

Dantzig, G.B., Fulkerson D.R. & Johnson S.M.(1954). Solution of a Large-Scale Traveling-Salesman Problem. *Operations Research*, *2*, 393-410.

Dorigo, M. & Gambardella, L. M. (1997). Ant colony system: A cooperative learning approach to the traveling salesman problem. *IEEE Transactions on Evolutionary Computation, 1* , 53-66.

Eastman, W.L. Linear programming with Pattern Constraints, Ph.D. Dissertation, Harvard 1958.

Ezugwu, A. E., & Adewumi, A. O. (2017). Discrete symbiotic organisms search algorithm for travelling salesman problem. *Expert Systems with Applications* , *87*, 70-78

Ferreir, J. V. (1995). A travelling salesman model for the sequencing of duties in bus crew rotas, *Journal of Operational Research Society*, *46* (4), 415-426.

Fischetti, M. & Toth, P. (1992). An Additive Bound Procedure for the Asymmetric Traveling Salesman Problem., *Mathematical Programming*, 53, 173-197.

Foulds, L. R. & Hamacher, H. W (1993). Optimal bin location and sequencing in printed circuit board assembly. *European Journal of Operational Research* (Netherlands). *66*(3), 279-290.

Gamboa D., Rego C. & Glover, F. (2006). Implementation Analysis of Efficient Heuristic Algorithms for the Traveling Salesman Problem, Computers and Operations Research. *33* (4), 1154-1172.

Garey, M. R. & Johnson, D. S. (1979). *Computers and Intractability: A Guide to the Theory of NP-completeness*, Freeman, San Fransisco.

Grötschel, M. (1980). On the Symmetric Travelling Salesman Problem: Solution of a 120-city problem. *Mathematical Programming Study*, *12*, 61-77.

Grötschel, M. (1991). On the Symmetric Travelling Salesman Problem: Solution of a 120-City Problem". Mathematical Programming Study, *12*, 61-77.

Helsgaun, K. (2000). An effective implementation of the Lin-Kernighan Traveling Salesman Heuristic. *European Journal of Operational Research*. 126, 106-130.

Hong, S. (1972). A Linear Programming Approach for the Traveling Salesman Problem, Ph.D. Thesis, The Johns Hopkins University. Hossam, A., Bouzidi, A., & Riffi, M. E. (2018).

Hossam, A., Bouzidi, A., & Riffi, M. E Elephants herding optimization for solving the travelling salesman problem. *International Conference on Advanced Intelligent Systems for Sustainable Development* (pp. 122-130). Springer, Cham

Hurkens, C.A. J. & Woeginger G. J. (2004). On the Nearest Neighbor Rule for the Traveling Salesman Problem. *Operations research Letters*, *32* (1), 1-4.

Johnson, D.S. & Papadimitriou, C. H. (1985). Computational Complexity in Lawler E. J, Lenstra J. K, Rinnoy Kan A.H.G, and Shmoys D.B. (eds). The Traveling Salesman Problem: *A Guided tour of combinatorial optimization*, 145-180. John Wiley & Sons.

Johnson, D.S. & McGeoh, L. A. (1997). The Traveling Salesman Problem: A Case Study in Local Optimization., In E. Aarts and J.K. Lenstra, editors, Local Search in Combinatorial Optimization, John Wiley and Sons, London, 215-310.

Karabat, S. & Akkan, C. (2006). Minimizing Sum of Completion Times on a Single Machine with Sequence-Dependent Family Setup times. *Journal of Operation Research Society*, *57*(3), 271-280.

Karg, R.L. & Thompson, G.L. (1964). A heuristic approach to solving travelling salesman problems. *Management Science,* 10, 225-248.

Keuthen, R. (2003). Heuristic Approaches for Routing Optimization. A PhD thesis at the University of Nottingham.

Kieu, T. D. (2019). The travelling salesman problem and adiabatic quantum computation: an algorithm. *Quantum Information Processing*, *18* (3), 90

Kolohan, F. & Liang, M. (2000). Optimization of hole making: A Tab search approach. *International Journal of Machine Tools and Manufacture*, 50, 1735-1753.

Kwon, S.. Kim H. & Kang, M. (2005). Determination of the Candidate Arc Set for the Asymmetric Traveling Salesman Problem, *Computers and Operations Research*, *32*(5), 1045-1057.

Lambert, F. (1960). The Traveling-Salesman Problem, *Cahiers du Centre de Recherche Opèrationelle.* 2, 180-191.

Lawler, E.J., Lenstra J.K., Rinnoy Kan, A.H.G & Shmoys, D.B. (1985). *The Travelling Salesman Problem: A Guided Tour of Combinatorial Optimization*, John Wiley & Sons.

Lin, S. & Kernighan, B.W. (1973). An effective heuristic algorithm for the Traveling-Salesman Problem. *Operations Research*, *21*, 498-516.

Little, J.D.C., Murty, K.G., Sweeney, D.W., & Karel, C. (1963). An Algorithm for the Traveling Salesman Problem, *Operations Research*, *11*, 972-989.

Madsen, O.B.G. (1988). An Application of Travelling Salesman Routine to Solve Pattern Allocation Problem in the Glass Industry. *Journal of Operational Research Society*, *39*(3), 249-256.

Marcotte, P., Savard, G. & Semet, F. (2004). A BiLevel programming Approach to the Travelling Salesman Problem, *Operations Research Letters*,*32*(3), 240-248.

Montero, A., Méndez-Díaz, I., & Miranda-Bront, J. J. (2017). An integer programming approach for the time-dependent traveling salesman

problem with time windows. *Computers & Operations Research* , *88*, 280-289.
Ohno, K., Jin, Z. and Elmaghraby, S. E. (1999). An optimal assembly mode of Multi-Type printed circuit boards. Computers & Industrial Engineering *36*, 451-471.
Oladokun, V.O. (2006). *The Development of a Subtour-Free Set Sequencing Algorithm and the Software for Solving the Machine Set-Up Problem*. Ph.D. thesis at the University of Ibadan: Ibadan, Nigeria.
Oladokun, V.O. & Charles-Owaba O.E. (2008). The Sequence Dependent Machine set Up Problem: A Brief Overview. Pacific Journal of Science and Technology, *9*(1), 36-44.
Oladokun, V.O & Charles-Owaba, O.E (2011). *The Sequence Dependent Single Machine Set-Up Time Problem: The Subtour – Free Set-Sequencing Algorithm Solution Approach.* LAP Lambert Academic Publishing GnbH & Co. KG, Dudweiler Landstr Deutschland.
Oladokun, V.O., Charles-Owaba,O.E. & Nnzeribe, T.M.C (2011) Harmonious Song-List Generation: An Application of the Sequence Dependent Machine Set Up Time Problem Model, *International Journal of Industrial Engineering and Technology. 3* (3), 229-234.
Oladokun, V.O., Charles-Owaba, O.E. & Olaosebikan, F.O. (2011). A Bi-Criteria Algorithm for the Simultaneous Minimization of Makespan and Number of Tardy Jobs on a Single Machine with Sequence Dependent Set-up Time. *Research Journal of Applied Science, Engineering and Technology*, *3*(9), 1048-1051.
Padberg, M.W & Hong S. (1980). On the Symmetric Travelling Salesman Problem: A Computational Study. *Mathematical Programming Study*, 1, 78-107.
Qaiduzzaman, K. M., Khatun, S., Afsa, M., Sobhan, S., Hossain, M. E., Shaharum, S. M., et al. (2020). A Mutation Triggering Method for Genetic Algorithm to Solve Traveling Salesman Problem. In M. Mohd Razman, J. Mat Jizat, N. Mat Yahya, H. Myung, A. Zainal

Abidin, & M. Abdul Karim, *Embracing Industry 4.0* (pp. 159-170). Singapore: Springer

Radin, L.R. (1998). Optimisation in Operations Research" Prentice Hall Inc. New Jersey USA.

Rajkumar, K. & Narendran, T. T. (1996). A Heuristic for Sequencing PCB Assembly to Minimize Set-up times. *Production Planning & Control*, *9*(5), 465–476.

Razman, J. Mat Jizat, N. Mat Yahya, H. Myung, A. Zainal Abidin, & M. Abdul Karim, *Embracing Industry 4.0* (pp. 159-170). Singapore: Springer

Riera-Ledesma, J. & Salazar-González, J.J. (2005). A Heuristic Approach for The Travelling Purchaser Problem, *European Journal of Operations Research*, *162*(1), 142-152.

Roberts, S.M. & Flores, B. (1966). An Engineering Approach to the Traveling Salesman Problem. *Management Science*, *13*, 269-288.

Robinson, B. (1949). On the Hamiltonian game (A Traveling Salesman Problem), *RAND Research Memorandum*

Rossman, M.J & Twery, R. J. (1958). A solution to the Traveling salesman problem. *Operations Research*, *6*, 687.

Saadani, N.E., Guinet A. & Moalla, M. (2005). A Travelling Salesman Approach to Solve the *F*/No-Idle/*C*max Problem. *European Journal of Operations Research*, *161*(1). 11-20.

Silva, M. M., Subramanian, A., Vidal, T., & Ochi, ,. L. (2012). A simple and effective metaheuristic for the minimum latency problem. *European Journal of Operational Research* , *221* (3), 513-520.

Tian, P. & Yang, S. (1993). An Improved Simulated Annealing Algorithm with Generic Characteristics and Travelling Salesman Problem. *Journal of Information and Optimization Science*.14 (3). 241-254.

Walshaw, C. A. (2001). *Multilevel Lin-Kernighan-Helsgaun Algorithm for the Traveling Salesman Problem.* CMS press Centre for Numerical Modelling and Process Analysis. University of Greenwich, London.

Walshaw, C. A. (2002). Multilevel Approach to the Travelling Salesman Problem". *Operations Research.50*(5), 862-877.
Xu, J., Pei, L., & Zhu, R. Z. (2018). Application of a genetic algorithm with random crossover and dynamic mutation on the travelling salesman problem. *Procedia computer science , 131*, 937-945
Zhang, W. (2004). Phase Transitions and Backbones of the Asymmetric Traveling Salesman Problem, *Journal of Artificial Intelligence Research, 21*. 471-497.

CHAPTER 13

On Safety, Health, Productivity and National Development

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Abstract

Occupational health and safety has become an important subject of discourse globally. The aim is to safeguard the safety, comfort and well-being of the workforce of any nation. This is applicable to all branches of industry, business and commerce, information technology establishments, recreational facilities without leaving out domestic activities. As a result of the effect of this subject on the economy and national development together with the challenges involved, the issue has attracted the attention of many stakeholders including government, management of work organisation, researchers among others. In this chapter, the combined impact of safety, health, productivity and national development is conversed. It is concluded that for a nation to develop, productivity must grow steadily and one of the key ways to attain this, is that the health, safety and well-being of the workers who are the drivers of development must be guaranteed in any workplace.

1.0 Introduction

The issue of health and safety has become a worldwide subject. The reason is that safety, comfort and well-being of the workforce of any nation is very germane to the goal of attaining national development. Safety and health matters are important to any area of human endeavours and are applicable to business and commerce, information technology establishments, recreational facilities and even domestic activities. As a result of the impact of this subject on the economy of any nation and by extension, national development together with the challenges involved, the issue has attracted the attention of many stakeholders including researchers, management of work systems and government agencies.

In virtually all countries of the world occupational safety and health is an important subject matter as efforts are made to for the safety and well-being of people at work. The importance of safety and health cannot be overstressed, so also is productivity. Work as noted by Charles-Owaba (2010) is very vital for any nation to achieve development as it is the only known bridge between human desire and its fulfillment. Hence for an individual or nation at large, any meaningful development cannot take place unless work is done. In this chapter, the synergy between safety, health, productivity and national development is discussed.

2.0 Safety, Health and Productivity

Though the keywords stated here may not be unfamiliar to most readers, it may still not be out of place to make attempt to describe them.

2.1 Safety and Health

Safety according to OSHA 1800 1 as quoted by Paul (2013) is a tool or device designed to prevent accidents, incidents and injuries which can be achieved by eliminating or reducing hazards and risk involved in every working activities that are conducted on industrial or work premises. In occupational safety and health, safety is seen as state of being safeguarded against occupational accident,damage, injury, death and other detrimental circumstances while at work. Furthermore, it is where known hazards that may be present in a work environment are reduced.

Hughes and Ferrett (2011) define health as the protection of the bodies and minds of people from illness resulting from materials, processes or procedures used in workplace, while WHO statedthat health is a state of complete mental, physical and social well-being and not merely the absence of disease or infirmity. Eurofound (2015) was of the view that health and safety is not just prevention of accidents and disease but also consists of every aspect of workers' comfort. The definition of ILO and the WHO reiterated that health and safety regulations are aimed at advancement and sustenance of:

(i) The maximum degree of mental, physical, and social well-being of all employees in every occupation.

(ii) The avoidance of workers leaving work as a result health challenges due to their working conditions.

(iii) The security of workers in their occupation from risks coming from factors hostile to health;

(iv) Every worker is placed in an environment that is adapted to his or her physiological and psychological capabilities (Eurofound, 2015)

Based on the aforementioned definitions and others from the literature, Molamohamadi and Ismail (2014) submitted that two major objectives of occupational safety and health and sustainable development maybe highlighted as:

(i) Protecting the workers' mental and physical health by averting work related accidents, injuries, and diseases and making work environment safe.

(ii) Focusing on the nature and the environment by forbidding and or controlling the usage of injurious objects to the environment, decreasing environmental effluences, and using resources prudently.

2.2 Concept of Productivity

Like any other subject, productivity has been defined in several ways. European Productivity Agency (EPA) explained productivity as an attitude of mind. It is deliberately making efforts to make progress, constant advancement of what is in existence. It is the conviction of ability to get better than yesterday and always. It is the continuous adaptation of economic and social life to changing conditions and continual efforts to apply new procedures and techniques. Another definition is that productivity is the relationship between the output of a production or service system and the input available to generate this output hence productivity is defined as the efficient and effective use of resources (Charles-Owaba, 2004). And resources include, land, labour, energy, information, materials e.t.c. in the production of goods and services.In addition, itis not only determinedby quantity and quality, but also by the valuethe customer gains. This is particularlytrue for the service industry. Perhaps an all encompassing description of productivity is by Prokopenko (1987) who stated that on a general note, productivity may be seenas a comprehensive assessmentof how an organization meet somestandards stated as follows: (i) Objectives- which indicate the extentto which the objectives are attained. (ii) Efficiency: How wellthe resources are utilisedi.e. doing things rightand (iii) Effectiveness: This is comparing what is achieved to what is possible, i.e. doing the right things.

Productivity is important to the life of industrial firm and the economic progress of a country. It is expected thatwhen productivity is growing in every facet of the economy, the standard of living of citizens should improve.

3.0 Work system, Safety, Health and Productivity

Workers (man) and workplace are two words that appear common to all the terms either implicitly or explicitly. Safety and health are addressing issues that have to do with man while at work, and productivity has to do with performance of work systems where man works. It is imperative to examine on the roles of man and the work system.

3.1 Man and Work system

Production of goods and services take place in a work system. This indicates that productivity would be affected by the environment and the way a work system operates. A work system is a system in which man is one of the main components interacting with facilities, materials, information, energy and finance to perform any of the these objectives:
(i) Transform raw materials into finish goods
(ii) Extract raw materials in their natural state and
(iii) To perform predetermined service or an item or people.
Any industrial set-up or establishment would be involved in any of the three objectives of work system. Furthermore in a worksystem, work would either be performed by man or machine and or combination of the

two. A combination of the two is termed man-machine work system. Charles-Owaba (2010) defines man-machine worksystem as the combination of humans and machines as well as their mutual interrelations in the effort to receive and utiliseinput resources to attain desirable outputs. In another words man-machine system is anarrangement in which one or more human beings together with at least one physical componentwith interrelationship to bring out from given set of inputs, some desired outputs. Itcan vary from a simple structure to a very complex one.Irrespective of whether a worksystem is simple or complex, man at work is the main focus. It is man that drives work systems, hence his safety and health are paramount.

3.2 Man-Machine Work system

On a general note, the main goalof designing anywork system is to determine suitable man-machine combinationsthat most effectively and efficiently make use of information, material, energy and finance to accomplish relevant tasks for the achievement of set goals and objectives. . During the designing process, parameters that relate to man should be regarded as constants while those havingto do with facilities, material, energy, information, finance and environment are considered as variables. Hence, to put in place a work system with the desired level of productivity in view, the systems variable values are chosen to suit the nature of man, his abilities, capabilities and limitations. The reasons for this approach aredue to the following:

(i) In virtually all work systems, man acts as the controller, to ensure effective and efficient control therefore the designer is constrained by the capabilities and limitations of man. A designed work system that does not take this into consideration may not be controllable or usable.

(ii) The designer can at will restructure the machine and the material information system and the environment if need be. However, to redesign a man is an impossible and infeasible task.

Thus, man components are regarded as the most critical or importantinany work system and it is necessary that this prominence is given to man in everywork system.In any work system/workplace safety practitioners must be concerned with the operations in the work system in such a way as to ensure that the main principle of Human Factor Engineering/Ergonomics of "fit the task to the man and not the man to the task" is maintained. It should be noted that this principle is applicable in manufacturing and commercial environment as well as service industries including hospitals, education, sports as well as domestic and leisure activities. Upholding this principle in workplace would lead to higher productivity, safety of the workers and reduction in rate of accidents while failure to adhere to this will lead to negative impacts of various forms of musculoskeletal disorder and cardiovascular problems,increases possibility of operator-related health hazards together with decrease in productivity.

3.3 Man-Machine Work system and Environment

Whether or not man performs effectively and efficiently in his workplace to ensure increase in productivity and guarantee his safety and health will depend on some factors. These factors to some extent will determine the health, well-being, safety and efficient performance in working place as well as everyday activities. Ergonomists have identified these to include general environment, immediate environment and personal inherent limiting factors in man(Murrell, 1965; Groover, 2007)

3.3.1 General Environment

This refers to ambient conditions in the workplace and includes such as lighting conditions, background colour, heat or cold, noise, humidity, pollution, wind velocity, pressure, vibrations, and radiations. These general environments have to be conducive to the body requirement so that man can work effectively and efficiently. One of the tasks of management is to determine the value of the above which will be conducive to the productivity of the work system.

3.3.2 Immediate Environment

The immediate environment include such things as tools, materials, machines, space, posture, displays, clothing, controls and other men. In specified immediate environment, the main task is that of stating the number, types, sizes and relative position of each.

3.3.3Personal Limiting Factor

Apart from environmental, anatomical and physiological as well as psychological factors inherent in man that serve to limit or enhance his performance are some characteristics inherent in an individual that contribute to his good or poor performance. Some of these are anthropometric structure, physical work capacity, mental capacity, motivation, gender, age and rest activities.

These ergonomic factors interact in affecting human performance. When these factors are appropriate and conducive for a worker in a work system, his safety and comfort would be guarantee and would be productive.Figure 1 presents a summary of how these factors interact to affect human performance and productivity.

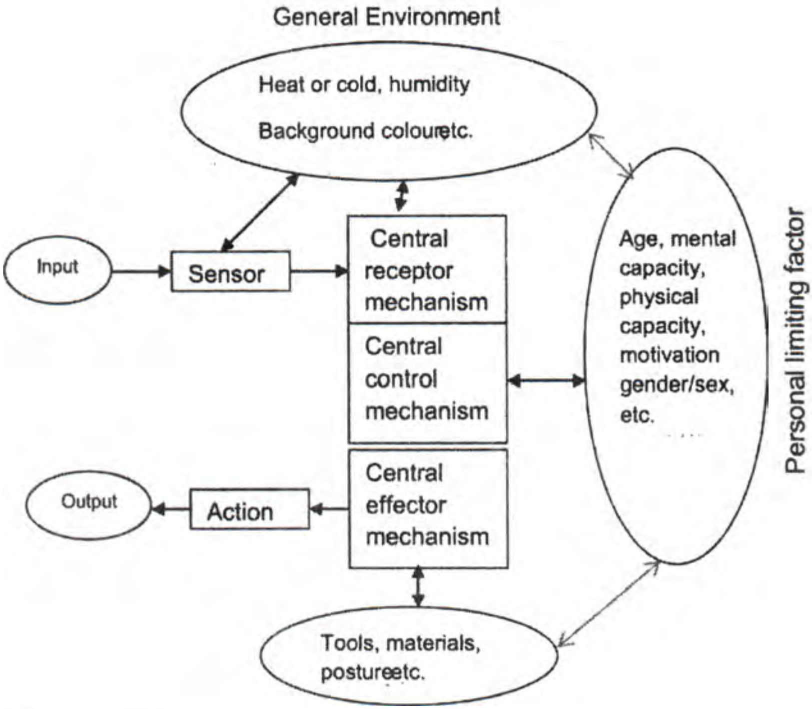

Fig.1: Human interaction with work environment *(source: Charles-Owaba, 2010)*

4.0 Safety and Health Programme for Productivity and National development

The possibilities of integrating safety and productivity are becoming increasing topical interest in occupational safety (Salminen and Saari, 1995). The desire of most productive system be it production or service system is to increase productivity sometimes at the expense of safety of workers. However, rather thanprioritising productivity abovesafety, the two should be seenas goals that can be attainedconcurrently. Karanikas*et al.,* (2018) observed that generally, when workers are pleased with the conditions and environment where they work and also feel secured from any form of injury, they would be more productive.There is therefore a need to consider how ensuring safety and health programme in workplace would eventually lead to productivity improvement.

4.1Safety and Health Programme

In order to have a healthy and safe work system that would lead to increase in productivity, there should be a concerted effort for effective health and safety programme. Avoiding injuries, discomfort and death together with financial pains for employees, their families as well as employers are major concerns of safety and health programme (OSHA, 2016). Ikeogu*et al.,*(2013) identified two approaches to health and safety programme as reactive and proactive approaches. Reactive is responding to injury or illness after occurring with an aim of reducing cost relating to illness and or injury while proactive approaches considers safety and health prior to incidence of any accident. Proactive foresees and make efforts to avoid accidents, it includes all actions directed toward removing accident, procedures used towards managing risks ,analysethe environment for any form of hazard, prevent sickness or diseases and ensure that no worker has zero workday. Maintain. Ikeogu*et al.,*(2013) further stated that reactive is costlier than proactive programmes as it waits for the occurrence of injury or accident before taking any action. This statement of Ikeogu*et al.,*(2013) was corroborated by OSHA (2016) with the submission that proactive method is better than reactive in handling safety and health in workplace as it recognisesthat locating and dealing with hazards before accident occurs is a much more effective approach.

4.1.1 Core Elements of Safety and Health Programme

To implement and have an effective safety program that workers would want to embrace without hindering production and services, OSHA (2016) suggested some practices for an effective safety and health programme. These are described as follows.

Management Leadership: Top management must demonstrate its commitment to continuous improvement in safety and health, communicates that commitment to workers, and sets program expectations and responsibilities. At all levels, safety and health should be made a core organisational value by managers, establish safety and health goals and objectives, provide adequate resources and support for the programme and set a good example.

Participation ofWorker: In setting goals, identifying and reporting hazards, investigating incidents, and tracking progress; workers and their representatives are involved in all aspects. All workers, including contractors and temporary workers, understand their roles and responsibilities under the programme and what they need to do to effectively carry them out. Workers are further encouraged to have means of communicating openly with management and to report safety and health concerns without fear of retaliation. Whatever may serve as barrier to worker participation in the programme should be removed.

Hazard Identification: Safety and health hazards from routine, non-routine, and emergency situations are identified and assessed with procedures put in place to continuously identify workplace hazards and evaluate risks.An initial assessment of existing hazards, exposures, and control measures is followed by periodic inspections and reassessments to identify new hazards. Any incidents are investigated with the goal of identifying the root causes. Identified hazards are prioritised for control.

Hazard Prevention and Control: Employers and employees work together to identify and chooseways for eliminating, preventing, or controlling workplace hazards. Controls are selected based on a hierarchy that uses engineering solutions, safe work practices, administrative controls, and personal protective equipment (PPE) in that order respectively. A plan is developed to ensure that controls are implemented, interim protection is provided, progress is tracked, and the effectiveness of controls is verified.

Training and Education: Everyworker should have understanding about how the programme works and how to perform the responsibilities assigned to them under the programme. Employers, managers, and supervisors receive training on safety concepts and their responsibility for protecting workers' rights and responding to workers' reports and concerns. All workers are trained to recognise workplace hazards and to understand the control measures that have been implemented. Safety knowledge which is basically the levelofworkers' awareness on organisational safety systems, practices, and procedures is determined by the level of education and training that an employee is exposed to (Liu, *et al.*, 2020). It has been found that organisations that increase the knowledge of employee about safety through safety trainingrecord lower rate of accidents and injuries (Tinmannsvik and Hovden, 2003). This stresses the importance of employees acquiring necessary skills through education and training.

Programme Evaluation and Improvement: Control measures are periodically evaluated for effectiveness.Processes are established to monitor program performance, verify programme implementation, and identify programme shortcomings and opportunities for improvement.Necessary actions are taken to improve the programme and overall safety and health performance.

One other important means for safety and health in workplace is to take advantage of digital tools. Safety and productivity can be improved through technology by upgrading old machinery or making use of digital record-keeping tools that track key safety metrics across all locations. Old machinery not only presents a safety risk but also results in productivity loss. Outdated equipment leads to unplanned productivity loss because most of these machines require frequent mechanical work and maintenance. It also puts workforce in danger.

4.2Relating Safety, Healthand Productivity

It is obvious that safety and health compliance activities would impose cost on management of any work system. The question one may want to ask is whether safety compliance really worth it.Several studies have shown that investment in occupational safety and health is very beneficial. For example, Thiede andThiede(2015) stated that Health and safety measures decrease injuries, increase efficiency, and bring income security to workers' families apart from intangible benefits such as trust, motivation and security. Similarly, Riaño-Casallasand Tompa (2018) reported that investment in occupational health and safety per full time

equivalent in medium and large companies in Colombia was statistically significant at 1% level. It was estimated that 4,919 injuries were averted through these investments resulting in the avoidance of $3,949,957 in costs.
Also,Hendrick (1996) stated that good ergonomics or safety and health programme is good economics. This implies that on the long run benefits to be derived would outweigh the cost. Safety should not be an afterthought and it also does not have to be associated with productivity loss. Proper and continuous safety training at all levels within any work system can reduce costly and dangerous mistakes.

Effective management of any method that enhances safety and health such as ergonomics has been linked to accident and incident prevention for decades. Resnick and Zanotti (1997) and Kadefors et al. (1996) noted that a comfortable environment supported operators in performing their job tasks productively, and a safe working environment increased the confidence of personnel, reducing, in turn, the occurrence of injuries. Giving employees with well-designed workstations and training in proper body postures allows them to work more efficiently. On the other hand, poor ergonomics or safety and health practices in workplace have been associated with lower productivity (Clarke,2006; Dianat et al, 2016).

Many work and everyday life situations are hazardous to health. Dul and Weerdmeester (2008) notedthat apart from different type of costs that are associated with poor health and safety programmesacross the globe, illnessesof the musculoskeletaldisorders (majorly lower back pain) and psychological diseases constitute the major causes of absence due to illness and of occupational disability. Some side effects of neglecting or non-compliance with safety principles may not manifest in the body system of the workers immediately but latter at old age. Providing the right working environment can assist in reducing these problems.

5.0Benefits of Safety and Health Compliance

From Hendrick (1996) and OSHA (2016), it canbe deduced that effective implementations of occupational safety and health programmes bring other benefits which are summarised as follows:

i. Reduction in turnover as new employees will likely findergonomically designed tasks that are not beyond their physical capacity.
ii. Compensation costs and other forms of payment such as illness and engaging new employee are reduced.
iii. The self-esteem of workers is enhanced.
iv. Productivity would go up by making tasks easier and creating more conducive environment for employees thereby enhance overall business operations
v. Workplace illnesses are avoided
vi. Compliance with required laws and regulations are improved upon.Enhance their social responsibility goals
vii. Absenteeism is drastically reduced as workers will not likely take off time to recover from soreness of muscles, fatigue and other musculoskeletal disorder related problemsA significant decrease in employees'compensation premiums would be achieved

6.0 Conclusion

Importance of safety and health of man at work has been enumerated as key to productivity increase and national development.It has been highlighted that it is people (workers) who are well, mentally and physically fit that would engage in activities that would lead to national development. When people are hale and hearty to perform their jobs in both public and private sectors, there would be development.

The prominence placed on the importance of health of workers as explained in this chapter agrees with the saying that though health is not everything, but without health, everything is nothing. It appears safe tostate that health and safety arenot everything but with good health and safety there would be room for growth inproductivity and national development. It is concluded that a growing productivity in every ramification will lead to better standard of living of the citizens and thereby national development. Therefore to attain national development, the health, safety and well- being of the workers who are the drivers of development must be guaranteed in any workplace.

7.0 REFERENCES

Charles-Owaba, O.E. (2010).The Men and Machines that change the World. An Inaugural Lecture, University of Ibadan, Nigeria. Ibadan University Press

Charles-Owaba, O.E.(2004). A Theoretical Basis for Industrial Ailment Diagnosis and Remedy, Journal of Pure and Applied Sciences, Vol. 7, No 2, pages 271-284.

Clarke S. (2006). Safety climate in an automobile manufacturing plant: The effects ofwork environment,job communication and safety attitudes on accidents andunsafe behaviour. Personnel Rev Vol 35 pp413-430.

Eurofound (2015). https://www.eurofound.europa.eu/observatories/eurwork/industrial-relations-dictionary/health-and-safety. Accessed on 15 October 2020.

Dianat I, Vahedi A. &Dehnavi S. (2016). Association between objective and subjectiveassessments of environmental ergonomic factors in manufacturing plants. International Journal of Industrial Ergonomics Vol.54 pp26-31.

Dul, J. &Weerdmeester B. (2008). Ergonomics for Beginners, A quick Reference Guide 3rd Edition. CRC Press

Groover, M. P. (2007).Work systems and the Methods, Measurement, and Management of Work. Prentice Hall, Upper Saddle River, NJ 07458

Hendrick, H. W. (1996).Good Ergonomics is good Economics. Proceedings of the Human Factorsand Ergonomics Society, 40th Annual Congress. Human Factors and Ergonomics Society, Santa Monica, CA, 90406-1369

Hughes P.&Ferrett Ed (2011) Introduction to Health and Safety at Work, The handbook for NEBOSH National General Certificate. 5th Edition Elsevier

Ikeogu, D., O., Uwakwe, J., O. and Chidolue I.B. (2013). The Efffect of Health and safety Management in National Development. Mediterranean Journal of Social Sciences Vol. 4 No. 7

Karanikas, N., Melis, D. J., and Kourousis, K. I. (2018). The Balance Between Safety and Productivity and its Relationship with Human Factors and Safety Awareness and Communication in Aircraft Manufacturing. Safety and Health at Work Volume 9.

Krishnan, S., Hizam S. M., Saffian, A. K. M., Baharun, N. S. andAzman, N. (2017) Safety at Workplace Enhance Productivity. Human Resource Management Research Vol 7 No. 1

Liu, S., Kwame Nkrumah, E. N., Akoto, L. S., Gyabeng, E. and Nkruma, E. (2020). The State of Occupational Health and Safety Management Frameworks (OHSMF) and Occupational Injuries and Accidents in the Ghanaian Oil and Gas Industry: Assessing the Mediating Role of Safety Knowledge HindawiBioMed Research International Volume 2020 https://doi.org/10.1155/2020/6354895.

Molamohamadi, Z. and Ismail (2014). The Relationship between Occupational Safety, Health and Environment and Sustainable Development: A Review and Critique. International Journal of Innovation, Management and Technology Vol. 5, No. 3, pp 198-202

Murrell K. F. H. (1965): Ergonomics Man in his working environment. London: Chapman and Hall

OSHA, (2016). Recommended Practices for Safety and Health Programmes. https://www.osha.gov/Publications/OSHA3885.pdf Accessed 15 October, 2020.

Paul, S. V. (2013): Safety Management System and Documentation Training Programme handbook. First Edition, CBS Publishers and Distributor, New Delhi

Prokopenko, J. (1987): Productivity Management.A practical handbook. Geneva, International Labour Office.

Resnick M. andZanotti A. (1997). Using ergonomics to target productivity improvements.Journal of Computer Industrial Engineering Vol 33, pp185-188.

Riaño-Casallas, M. I., and Tompa, E. (2018) Cost-benefitanalysisofinvestmentinoccupationalhealth andsafetyinColombiancompanies. American Journal of Industrial Medicine Vol.61 (11) pp 893-900. DOI: 10.1002/ajim.22911

Salminen, S. and Saari, J. (1995). Measures to improve safety and productivity simultaneously. International Journal of Indutrial Ergonomics. 15 pp 261-269

Thiede, I., and Thiede, M. (2015). Quantifying the costs and benefits of occupational health and safety interventions at a Bangladesh shipbuilding company. International Journal of Environmental Health Vol 21 (2) pp127-136

Tinmannsvik, R. K. and Hovden, J. (2003). Safety diagnosis criteria—development and testing Safety Science, vol. 41, no. 7, pp. 575–590

CHAPTER 14

Garment Sizing System: A Critical Review of the Past, Present and Future

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1.0 Introduction

With the desire to remain competitive and customer driven, companies are fast adopting business models, programs and procedures to meet customer's volatile demand and shortened product lifecycle at efficient cost. Such business model includes mass customization and mass personalisation of products. They are fast becoming effective approach in many manufacturing sectors, such as the automobile, food, textile and garment, cosmetic industry because they offer opportunities for expanding the sphere of influence of a company, widening its customer base and production capacity.

Classically, mass customisation business model is described as the production of goods and services to meet needs of a defined market segment at a cost closer to that of the mass production system. It combines the economies of scale in mass production system with segmentation of market demand. Empowered by the internet, digital devices and social networks, customers are increasingly expressing interest in the design, and development of their product while powerful lever such as flexible computer-aided manufacturing system enable companies to customize or adapt standard products which meet many end users tastes and preference without inventory or purchasing delays. Thus, customers are not only treated as a market segment but as an individual entity. This process of personalizing requirements enhances prosumer's ability to determine their product specification but manufacturers are cumbered with challenges of reducing product life cycle, increased product complexity, and immense pressure from global competition.

The garment production industry is not an exception of such developments. The industry has one of the most complex and diverse products. For example, customers desire unique garment design and style specifications suitable to their unique body proportions, specific need, and personality. A report shows that Levi Straus and Co. offers women customised pants of about 49,000 different sizes in 30styles resulting in about one and a half million options available to consumer. In order to significantly impact and drive consumers' intentions in terms of willingness to repurchase, verbal referrals, commitment and loyalty, garment producers should adopt approach to meet customer's dynamically changing quality requirements without increasing shopping difficulty and confusion. Lamb and Kallal's (1992) proposed the Functional, Expressive, and Aesthetic (*FEA*) *Consumer Needs Model* which provide an overall conceptual framework for designing any type of garment. Consumer's f*unctional requirements include fit*, mobility, comfort, and protection; expressive requirements of a consumer provides an opportunity for the wearer to communicate his or her self-image while the aesthetic requirements are related to appeal of a clothing product in terms of style, colour, appearance, fashionability or attractiveness (Chae, 2017; Kasambala *et al*., 2016). Consumers are most likely attracted to garment items which satisfy all their intended requirements. However, according to various consumer and designer-mediated perspectives, inappropriate sizing and fitting system often result in return of the garment that they have been purchased (Connell, *et al*.,, 2006; Otieno, *et al*.,, 2016; Shin and Damhorst, 2018).

Almost every industrialized nation has home-based garment sizing system for each garment type. For instance, there are Canadian Standards, German sizing system, European, American, Japanese, Korean, Chinese, etc (Gupta, *et al*., 2006; Lee, 2014; McCulloch,*et al*., 1998; Tryfos 1986). Essentially, a sizing system takes garment-related anthropometric data from a sample of individuals in the nation's population as input to produce a number of garment sizes such that each size is for a subset of people who wear the same standard garment size. Thus, instead of dealing with fifty million (50,000,000) sizes for, presumably, fifty million (50,000,000) people in a nation; a tailoring industry may sew only twenty (20) standard sizes, for instance, to adequately cater for the millions (Mpampa, *et al.*, 2010). Each size (a table of garment dimension values), may now have enough demand (2,500,000 potential customers in our case example). The goal of a sizing system is to provide the optimum number ready-to-wear (RTW) garment sizes for a given population with good fit for all individuals (McCulloch, *et al.*, 1998). The literature is however sparse on the existence of garment sizing system for the Nigerian traditional clothing industry. Perhaps, this explains the slackened growth of the industry.

At the moment Nigeria is unable to reap from the afore-mentioned benefits from RTW or mass customisation enterprise because it operates a "bespoke" garment manufacturing system. Tailors produce garment patterns by measuring the body size of individual patrons of the firm, and the fitting process involve physical try-on of garment along some correction steps that reflect wearer's responses to obtain a desired fit. Unlike this production system, online customers do not have the luxury of physically trying-on a cloth and have to rely on the product image and the available size charts to select a product that fits well. As a result, they find it difficult to get garment of excellent fit. When such problem occurs in mass customised or personalised online orders, it can result in more problems than for ready-to-wear garment in mass production. While mass produced garment items can easily be sold to other customers, it may be difficult to sell personalised garment orders because it had been customized to the design, style and size of original orderer (Kim *et al.*, 2019) . This may lead to increase in production costs and inventory management problems. Therefore, research on sizing and fit preferences is very necessary in order to deliver the bespoke customer experiences in the garment mass customisation and personalisation of Nigerian designs, thereby improve customer satisfaction percentage.

2.0 Overview of the Garment Sizing Problem

Garments are primarily worn to provide shelter, warmth against harsh weather change and it is secondarily worn to give beauty and a sense of expression to the wearer. The application of the principles of cutting, sewing with the nitty-gritty of fabrics and skill results in the accomplishment of garment manufacture. There are criteria that cannot be overlooked in designing and making a fabric that would perfectly suit a customer and they include the type of fabric used, colour of the fabric, the style to be sown, accessories/aesthetic used with the fabric and anthropometric measurement of the consumer. Psychological and social factors are also key factors that can be categorized under the significance of a garment. Garment has over time been used as a means of expressing oneself and a way of portraying social importance (Johnson, *et al.*, 2014). According to Festinger (1954), human being get satisfied with the opinions made by other persons which can be consciously or unconsciously; Biolcati (2019) also highlighted that the approval of physical appearance of an individual by other persons most likely yields an increase in their self-esteem. Hence, effect of a garment fit on consumer's appearance and subsequent self-esteem may determine consumers' intent to repurchase a garment size.

Earliest garment sizing systems were dependent on the tailor's very own understanding and first showed up in pattern books before the end of the eighteenth century (Aldrich, 2000). These sizing systems utilized the corresponding scaling technique. The interest for armed force attire brought by wars during the nineteenth and twentieth hundreds of years quickened the production of ready-to-wear (RTW) dress and constrained the improvement in size structure. The proportional scaling technique did not precisely address the issues of the market. During the second half of the twentieth century, sizes started to be created from body estimations utilizing statistical strategies (Aldrich, 2000). From that point forward, anthropometric overviews have been led, and sizing standards have been published in various nations.

A sizing system can be characterized as a lot of pre-decided body sizes assigned in a standard way (Winks, 1997) which highly depends on the body measurements taken on a cross-area of the objective population. Winks (1997) implied that the system comprises of a scope of sizes from the smallest to the biggest with fixed interims between nearby sizes. The production of ready-to-wear garments categorized into various sizes has changed fashion from the era of tailor-fitted garments to mass-produced garments (Burns and Bryant, 2000). There are two major issues relating to garment sizing; the classification and measure of fit. Classification relates to identification of criteria required for distributing the target population into size groups. The classification procedure plays an essential role in assessing when a garment is wearable by a consumer or not. On the other hand, the fit is a measure of how well the consumer fit into the assigned group (Xia and Istook, 2017) . However, the latter remain the most important problem in the garment industry and a recurrent issue in the literature. It has been observed that fit problem is a difficult concept to research and analyse as the relationship between body and clothing is complex and often ambiguous (Loker *et al.*, 2005).

2.1 Techniques for Garment Sizing

There are various approaches reported in literature that have been applied in solving garment sizing problem.

2.1.1 The Earliest Method

The general approach includes individual craftsmen perspective to solving clothing problems i.e. fitting to individual. It is also called 'haute couture" approach. This is common in the early 18th century, when all attire was handmade and fitted to each client. Professional tailors measured the body measurements of each client, and after that drew and cut the patterns for each piece of clothing and each client. After numerous unique designs were collected, tailors found relationships between body measurements, notwithstanding of individual differences. Tailors slowly created these patterns into a framework of attire production to make dress for individuals with comparable figure sorts (Hsu *et al.*, 2007; McCulloch, *et al.*, 1998).

The first sizing system reported in 1941 was based on bivariate classification of about 15000 women according to their hip and bust measurement. This was to ensure sizing uniformity in the garment making industry. Continuation of the work resulted in an empirical sizing system known as the Commercial Standard (CS) 215-58 reported in 1958. This modification of the initial system was based on various manufacturers' experience through trial-and-error. By the year 1970, another empirical sizing system known as the PS 42-70 Standard of the USA was developed using military anthropometrical data and a "trial-and-error" approach. CS215-58 and PS 42-70 sizing systems were based on out-of-date measurements taken at 1941 (Ashdown, 1998). ASTM D5585-94 is another system developed in 1994 by the American Society for Testing and Materials (ASTM) based on the experience of garment designers and available market information. The first national anthropometric study in Europe started in the twentieth century. The Polish cloth sizing table based on anthropometric measurement of about 180000 was first reported in 1982 and later republished in 1997 while that of the Czech Republic was based on anthropometric measurement of about 400000 persons. These serve as an anthropometric data source for many scientific and industrial researches.

However, as the living and medical condition of people begin to improve, there is a significant change in human growth and development in these countries and a significant change in the 21st (twenty-first) century human shape and silhouettes proportion.

2.1.2 Multivariate Statistical Technique

Roebuck (1995) and Beazley(2001) described steps involved in sizing systems to comprise among others, selecting appropriate body anthropometric data, select key dimensions and establish number of each size necessary to outfit the intended users' population. This procedure has been adopted in more contemporary study relating to garment sizing problems.

Perhaps, the first multivariate approach to garment sizing was achieved by Salusso-Deonier (1982) using the principal component analysis (PCA). The principal component analysis is a method used to discov the control variables in research; create a basis for classifying th population after identifying the key body measurements in the undertaken study. This approach is valuable in distinguishing the basic body or the fit affecting measurements that can frame the basis of size chart advancement. Salusso-Deonier (1982) considered anthropometric measurements of adult females over fifty five years old. The data analysis showed that there are two important variables; one represent body laterality such as body girth and width while the second represent body linearity such as heights and lengths. A similar study by Gupta and Gangadha (2004) shows that the bust and the hip measurement are key dimensions for the upper body and the lower body garment out of the twenty-one anthropometric data considered. The developed size charts accommodates 95% of the Indian adult females. The model was validated using aggregate loss of fit index. Also, Veitch, *et al.*,(2007) used PCA to consolidate twelve anthropometric measurements into the two primary central components for laterality (fullness) and linearity (length). The anthropometric data used consist of 54 measurements of 1265 Australia adult females. The classification results in 36 different size groups. This maximizes information pertinent to setting up a size and shape specification for the production of a bodice. Loker *et al.* (2005) applied both statistical and visual analysis methods to improve the garment fit of an existing sizing system of a garment company. In another study by Zakaria *et al.* (2008), multivariate statistical analysis technique was used to explore patterns in anthropometric data and develop a size system. The authors surveyed data of 629 schoolgirls aged between 7 to 12 years belonging to three different ethnic groups, namely, Malays, Chinese, and Indians. Mason *et al.,* (2008) considered sizing by identifying unique body shapes. The analysis of variance (ANOVA) and anthropometric data from female teachers in Africa was used. Esfandarani and Shahrabi (2012) also used principal component analysis to identify variables which partition a heterogeneous population into smaller homogeneous groups. The obtained size chart was evaluated using the aggregate loss of the fitness method. Xia and Istook (2017) considered integration of natural log-transformation, principle component analysis, multivariate linear regression, size range determination, and measurements calculation for developing the sizing system. Both the residual variance analysis and factor analysis are also multivariate techniques similar to the PCA.

According to Salusso-Deonier (1982), the effectiveness of body shape classification technique is highly dependent on the selection of the key body dimensions.

2.1.3 Optimisation Techniques

Generally, optimisation technique is a mathematical expression for the quantity to be maximised or minimised such as minimum number of size groups and maximum fit. The size optimisation method develops the optimum sizing system with the availability of anthropometry data and its framework is based on mathematical model of garment fit.

Gupta *et al.*, (2006) applied three different solution approaches to the linear programming formulation in order to cluster a given population into homogenous body size groups. In the linear programming model, the constraints and the objectives are describeable by relationships which are straight line or linear type. The desired degree of fit is considered a basis for clustering individuals into size groups and exact number of people covered by the system can be determined. Tryfos (1986) in his work recommended the integer programming approach to optimize the number of sizes of a manufacturing clothing company or shoe company so as to maximize anticipated sales or minimize a record of aggregate distress. He partitions the space of body measurements artificially into a set of discrete conceivable sizes and specify a tolerance value for each critical dimension. For example, if a waist tolerance is± 1, a size of 30inches will accommodate customer having a waist girth between 29 and 30 inches. The problem was formulated as a "p median" or "Facility location" problem. Ashdown (1998) and McCulloch *et al.*, (1998) focused on the developing a sizing system better than the ASTM D5585-94. The goodness of the fit experienced by a customer upon wearing a particular size is mathematically captured as a distance between the body measurements of the customer and the dimension of the prescribed size. The larger the variation, the worse the fit of the final garment. A non-linear optimisation technique, "aggregate loss of fit" and the PCSS method was considered as a solution procedure. The non-linear optimization strategies were utilized to infer a set of conceivable measuring systems from anthropometric information. Results appeared that measure assignment as well as the capacity to identify non-accommodated people leads to significant changes in fit over existing measuring frameworks. However, like any other mathematical optimisation problem, increase in the number of constraints may increase model complexity and compromise the performance of these sizing systems.

2.1.4 Data Mining

Increasing use of automatic data collection and storage system necessitates the use of data mining in many areas of science and engineering research domains. Specifically, the clustering methodology for garment sizing problems is a method of organising data based on their relative distances into clusters or natural groups. Clustering is also known as an unsupervised method of mining data which do not depend on any presumption common in statistical strategies.

Hsu *et al.*, (2007) integrated Ward's minimum variance method into the K-Mean technique to cluster eleven anthropometric data of 956 adult females in Taiwan. The Ward's minimum variance method was used for the first hierarchical clustering while the K-Mean was used for the second non-hierarchical clustering. In a similar study by Viktor *et al* .,(2009), the body scanned data was clustered into five clusters. The author stated that clustering technique must account for interrelationship between anthropometric data to obtain good clusters. Opaleye *et al.*, (2019) considered a fuzzy based clustering methodology for sizing adult male trousers. This clustering differs from the hard-clustering method by its nonlinear nature and the flexibility of gathering large data in a disciplined manner. It gives more precise and close-to-nature solutions for partitions and in this suggests more possibility of solutions for decision-making.

Simbolon (2014) deployed the principal component analysis and fuzzy c-means clustering to create a sizing system for Indonesia adults using anthropometric data of 912 adults. Hamad *et al.* (2017) defined an exhaustive methodology to obtain a clustering of human morphology shapes representative of a population and to extract the most significant morphotype of each class. The fuzzy clustering technique is applicable in sizing due to vagueness in classification of body types and imprecision in anthropometric measurement.

2.2 Issue of Garment Fit

The success of any scheme used in the process of sizing is dependent on the extent to which the scheme satisfies the intended function and fit requirements of the item. All consumers want the best fitting clothing item so they select a size close to their anthropometric measures, try it on and purchase or reject the item. A nice design or expensive fabric is of no use when the clothing item do not appropriately fit. In the study by McCulloch *et al.* (1998), the sizing system was formulated for the Misses subpopulation in USA. The researchers noted that the common practise of using one or two key body dimensions does not provide a good fit for populations with large variations in body proportions. Therefore, the non-linear optimization method was formulated as a multivariate sizing system and the fit defined as a measure of the proportional difference of an individual to a prototype (ideal) size. This approach provides a mathematical description of the goodness of fit. Individuals within a defined "cut off" for garment dimensions are automatically assigned into a size group. Ashdown (1998) defined the average of all discrepancies over the given garment dimensions from a specified size as the aggregate loss of fit. This represents how well the sizing system performs in fitting the population. The researchers found that optimized sizing systems better accommodate population with large variation in anthropometric measurement. Gupta *et al.*, (2006) also defined a fit function within which certain proportion of the target population will be accommodated.

Similarly, the concept of grouping based on similarity of parts was adapted by Kolawole (2016). A customer pair-wise fit (CPF) model for quantifying degree of fit was formulated using garment sizing variables customer anthropometric dimensions and customers' tolerance for garment dimension. The fit is considered as a measure of the absolute difference of an individual to an ideal size and tolerance as the numerical value of space that a designer can add or subtract from the value of a particular dimension without hindering the fit of a garment to a set of customers. Given the tolerance, it was found that perfect transitive set of customers will be accommodated in the same size group. The cut-off, fit function and tolerance are synonymous to ease allowance as used in clothing and textile related research. The authors suggest quantitative frameworks for fit estimation; however, none of these researchers provide a clear rationale for quantitative estimation of ease allowance.

3.0 Quantification of Ease

Researchers have established that fit is a function of the interaction between body measurement, design/style parameters with the addition or subtraction of an extra dimension, which is commonly referred to as ease. Traditionally, ease estimation during pattern construction is based on practitioner experience without an explicit communication on how ease may be established, or what contributes to its determination. Without clear information and data on ease estimation, emerging CAD/CAM virtual fitting rooms required for online shopping of ready-to-wear, mass customisation or personalisation of clothing items will be practically impossible.

Theoretical description of ease is based on two definitions of radial ease allowance (REA) and girth ease allowance (GEA). REA is the distance between the body and the cloth surface measured from the same centre while GEA is the additional girth measurements in a garment that were in excess of the basic body dimensions. Ease can also be defined in terms of measured numerical difference between the garment dimension and wearer's anthropometric measurement at all points of their relationship. It accounts for other interdependent factors which in turn affect fit satisfaction. In practice, there are three types of ease; standard ease, dynamic ease and fabric ease. Standard ease is the difference between the maximal and minimal perimeters of the body while sitting or standing. Dynamic ease provide enough space for various body movement such as walking, running and jumping while fabric ease takes into account mechanical properties of the fabric used. As such, optimal quantification of ease is a trade-off between many factors which includes; wearer's body shape, style, fabric used, wearer's motional and aesthetic satisfaction (Y. Chen *et al.*, 2009; Kim *et al.*, 2019). Some research efforts towards the quantification of ease have been made.

Ashdown and DeLong (1995) investigate consumer's threshold of fit based on participant tactile responses to ease variation using sensory evaluation technique. Custom- fitted pants were made for the four participants as the control pant and fourteen other pants varied independently between ± 0.5 and ± 1.0 for the waist, ± 0.5 and ± 1.5 for the hip and ± 0.5 and ± 1.5 crotch were used as the test pants. The test pants were similar in style and fabric material to the control pant except that they were either smaller or larger at one of the identified dimensions. Statistical analysis of the experiment show that all the participants perceived variation at more than one dimension. However, further investigation shows that no consistent interactions exist between the actual and the perceived point of variation. The authors also noticed the operation of kinesthetic after-effects in their perception as participants were unable to recognise the control pants more than 42% of the time. The kinesthetic after-effects may also have effect whenever the difference between the test pants and the control was small. Frackiewicz-Kaczmarek *et al.*, (2015) suggest a similar evaluation approach for tight, regular and loose shirt, jersey, undershirt and interlock undershirt. They used the factorial analysis of variance with Levene's test for homogeneity of variance to determine factors influencing the distribution of the air gap thickness and the contact area in selected garments, such as overall garment fit, garment style, body region, and fabric type. The author noted violation of model underlying assumptions. As a result, the statistical analysis conducted was not reported.

Chen *et al.*, (2006) also propose a method of optimising ease allowance of a garment using a combination of fuzzy logic technique and sensory evaluation. Vertical body measurement and girth body measurement critical to garment design were selected using data sensitivity based criterion. These two features and the participants' sensory evaluations for comfort degree were used as inputs to the fuzzy methodology which permit automatic pattern generation to improve the wearer's fitting perception of a garment. An extension of the work proposed in (Yu Chen *et al.*, 2008) and (Y. Chen *et al.*, 2009) suggest an aggregated ease allowance using an ordered weighted averaging function. The OWA weights are based on garment design and designer's criteria on textile comfort and estimation of the ease allowance was based on some fuzzy rules extracted from the learning data.

Wang *et al.*, (2006) and Kim (2008) proposed ease estimation by measuring difference between garment size and human body size separately at specified segment of the body circumference. Wang *et al.*, (2006) further developed a mathematical model of ease distribution using surface fitting approach in order to predict ease of X-lined jackets at different point of measurements. Petrova and Ashdown (2008) proposed a body-location based estimation method. Garment ease at different dimension points was measured using the 3D scanned data. The authors observed a decrease in ease as body size increases but a statistical relationship was not suggested. Choi and Kim (2004) used a linear distance approach using the GEA for ease estimation in order to compare two different pattern making methods for women clothing. Subjects who have nearly the same body size were selected for the study. In the result of analysing the space between skin and clothing of each pattern by 3D Scanner, there exist significant differences in the chest and bust parts of the pattern considered. A similar method of ease allowance estimation was proposed by Wang *et al.*, 2007; Kin *et al.*, 2011 and Su *et al.*, 2015.

Perhaps the most interesting approach is by Kim *et al.*, (2019). They developed a linear regression model to estimate preferred ease allowance for a popular type of male jacket among male adults in South Korea as of

2014. Six different models were developed for preferred ease allowance on seven different parts measured on the jacket. Ranges of estimated ease allowance were obtained by inputting body size measurements of 62 male customers which showed the highest correlation with the preferred ease allowances. However, the complexity in the relationship between body and garment dimensions renders a straightforward estimation of ease inappropriate. Results of the statistical regression models may be inaccurate, most especially when there are difficulties in verifying distributional assumptions and relationship between the dependent and independent variables is vague.

4.0 Size system validation

Gupta and Zakaria (2014) highlight measures of evaluating a good sizing system which includes; cover factor, aggregate loss and size roll.

The cover factor is the percentage of sample accommodated under each assigned size within a sizing system. The researchers noted that the systems must accommodate between 65%–80%, of the target population. The higher the number accommodated by the system, the better for manufacturers. The aggregate loss is a measure commonly used by researchers for the validation of proposed sizing system (Gupta, and Gangadhar, 2004; McCulloch, *et al.*, 1998). It is the Euclidian distance of the wearer's actual body dimensions to the assigned size. If the size fits the wearer well, then the distance from the assigned size to the actual size is said to be minimized. This an index of the absolute value of fit. According to Gupta and Zakaria (2014), the benchmark for an accurate sizing system is an ideal value of aggregate loss calculated as $2.54n^{1/2}$, (metric in centimetres) where 'n' is the number of key anthropometric dimensions used to segregate the target group. If the actual aggregate loss is less than the ideal, the system is considered good for the target population. The size roll on the other hand is simply the total number of sizes obtained for a sizing system, from the smallest to the largest, with fixed intervals between adjacent sizes. The more the number of sizes, the better the fit but the more customer's confusion in size selection.

Therefore, a trade-off between number of sizes and goodness of fit may be required for optimum size roll. Kolawole and Charles-Owaba (2018) proposed a percentage degree of fit index similar to the aggregate loss of fit. The proposed percentage degree of fit measures the degree (or percentage) to which a certain sizing system "satisfies" the target population. Evaluation of the percentage degree of fit for a sizing system ranges from zero which implies poor fit (no member of the group can wear same size) to 100 which implies perfect fit (all member of the group can wear same size). The measures of fit index enhance the process of individual and group validation of sizing system.

5.0 Conclusion and Future trends

The importance of an effective garment sizing and fitting mechanism to the mass production, mass customisation and personalisation system production systems has been emphasized. Conventional sizing system produce garments in sizes that can accommodate a majority of customers within a set of fixed sizes and it enhances the process of fitting garment to the consumer without which the overall objective of garment production cannot be met. The progressively evolving methods of producing a sizing system impact the efficiency of that sizing system. Methods ranging from simple bivariate classification, statistical techniques, multivariate techniques, mathematical programming techniques, data mining techniques and artificial intelligence techniques have been considered. This was made possible by the experience of more than 70 years of exploring and understanding how to develop sizing systems that are efficient for manufacturers, customers and retailers. Research shows that a good sizing system must be developed based on the knowledge of fit and cater for the actual body sizes and shapes of the target population. Gupta and Zakari (2014) and Kolawole and Charles-Owaba (2018) highlight measures of evaluating a good sizing system which include; cover factor, aggregate loss, size roll and percentage degree of fit.

Given the research discoveries and the weaknesses of different sizing systems, researchers are finding better ways of developing sizing systems and reduce fit problems by adopting advanced data mining, artificial intelligence methods and computer aided design technologies. It is anticipated that newer systems which integrates customers' preferences will produce better sizing systems resulting in a greater goodness of fit for clothing customers. Proper implementation of garment mass customisation and personalisation model will require determination of ease from customer's perceptive. Such model may not be generic as ease allowance is a function of design type and fabric. However, estimation of ease may be determined as a function of customer's willingness to pay for certain garment item with measurements slightly different from their anthropometric measurement of a particular design. An integration of fuzzy concept to account for imprecision in ease estimation and vagueness in body-garment relationship may also be a solution approach. This is very important to garment designers, manufacturers and retailers, as an effective system means that they can produce optimal sizes of garment which satisfy a larger percentage of customers and their fit requirements.

6.0 References

Aldrich, W. (2000). Tailors'cutting manuals and the growing provision of popular clothing 1770–1870: 'Falling apart like a ready-made.' *Textile History*, *31*, 163–201.

Ashdown, S. P. (1998). "An investigation of the structure of sizing systems. *International Journal of Clothing Science and Technology*, *10*(5), 324–341.

Ashdown, S. P., & Delong, M. (1995). *Perception testing of apparel ease variation*. *26*(1), 47–54.

Beazley, A. (2001). Size and fit : Procedures in undertaking a survey of body measurements. *Journal of Fashion Marketing and Management:*, 2(3), 260–284.

Biolcati, R. (2019). Low Self-Esteem and Selfie Posting Among Young Women. *The Open Psychology Journal*, *12*, 155–168.

Burns, L.D., Bryant, N. O. (2000). *The business of fashion: designing, marketing and manufacturing*. Fairchild.

Chae, M. (2017). An innovative teaching approach to product development: creating tennis wear for female baby boomers. *International Journal of Interdisciplinary Research*, *4*(13). https://doi.org/https://doi.org/10.1186/s40691-017-0098-9

Chen, Y., Zeng, X., Happiette, M., Bruniaux, P., Ng, R., & Yu, W. (2009). Optimisation of garment design using fuzzy logic and sensory evaluation techniques. *Engineering Applications of Artificial Intelligence*, *22*, 272–282. https://doi.org/10.1016/j.engappai.2008.05.007

Chen, Yu, Zeng, X., Happiette, M., Bruniaux, P., Ng, R., Yu, W., Chen, Y., Zeng, X., Happiette, M., & Bruniaux, P. (2008). *A new method of ease allowance generation for personalization of garment design*. https://doi.org/10.1108/09556220810865210

Choi, Y. L., Kim, H. E. (2004). A comparison of women's basic pattern using 3D scanner: Between the Bunka and the Secoli pattern. *Fashion and Textile Research Journal*, *6*(6), 749–755.

Connell, L. J., Ulrich, P. V., Brannon, E. L., Alexander, M., Presley, A. B. (2006). Body Shape Assessment Scale: Instrument Development for Analyzing Female Figures. *Clothing and Textile Research Journal*, *24*(2), 80–95.

Esfandarani, M.S., Shahrabi, J. (2012). Developing a new suit sizing system using data optimization techniques. *Int. J. Cloth. Sci. Technol.*, *24*, 27–36.

Festinger, L., Torrey, J., Willerman, B. (1954). Self-Evaluation as a Function of Attraction to the Group. *Human Relations*, *7*(2).

Frackiewicz-Kaczmarek, J., Psikuta, A., Bueno, M. A., Rossi, R. M.

(2015). Effect of garment properties on air gap thickness and the contact area distribution. *Extile Research Journal*, *85*(18), 1907–1918.

Gupta, D., Zakaria, N. (2014). *Anthropometry, apparel sizing and design* (N. Gupta, D., Zakaria (ed.)). Woodhead Publishing.

Gupta, D. and Gangadhar, P. (2004). A statistical model for developing body size charts for garments. *International Journal of Clothing Science and Technology, 16*, 458–469.

Gupta, Deepti, Garg,Naveen,Arora Komal, P. N. (2006). Developing body measurement charts for Garment Manufacture Based on a Linear Programming Approach. *Journal of Textile and Apparel, Technology and Management*, *5*(1), 1–13.

Hamad, M., Thomassey, S., Bruniaux, P., .x. (2017). A new sizing system based on 3D shape descriptor for morphology clustering. *Comput. Ind. Eng.*, *113*, Comput. Ind. Eng.

Hsu, C.-H., Lin, H., & Wang, M. (2007). Developing Female Size Charts • For Facilitating Garment Production By Using Data Mining. *Journal of the Chinese Institute of Industrial Engineers*, *24*(3), 245–251. https://doi.org/10.1080/10170660709509039

Johnson, K., Lennon, S.J., Rudd, N. (2014). Dress, body and self: research in the social psychology of dress. *Fashion and Textiles 1*, *20*(1), 1–24. https://doi.org/https://doi.org/10.1186/s40691-014-0020-7

Kasambala, J., Kempen, E., & Pandarum, R. (2016). Determining female consumers' perceptions of garment fit, personal values and emotions when considering garment sizing. *International Journal of Consumer Studies*, *40*(2), 143–151. https://doi.org/10.1111/ijcs.12236

Kim, I. H., Nam, Y. J., & Han, H. (2019). A quantification of the preferred ease allowance for the men's formal jacket patterns. *Fashion and Textiles*, *6*(1). https://doi.org/10.1186/s40691-018-

0165-x

Kolawole, A. (2016). *Investigation of The Relationship between Fit and Garment Sizing Parameters*. An unpublished PhD Thesis University of Ibadan, Nigeria.

Kolawole A. and O.E. Charles-Owaba. (2018). Customers Pairwise Fit Matrix Approach to Garment Sizing. *Proceedings of the International Conference on Industrial Engineering and Operations Managment*, Pretoria/Johannesburg, South Africa. 1409–1420.

Lamb, J.M., Kallal, M. J. '. (1992). A Conceptual Framework For Apparel Design. *Clothing and Textiles Research Journal*, *10*(2), 42–47.

Lee, Y.-S. (2014). Standards Sizing for Clothing based on Anthropometry Data. *Journal of Ergonomics Society Korea*, *33*(5), 337–354.

Loker, S., Ashdown, S., & Schoenfelder, K. (2005). Size-specific Analysis of Body Scan Data to Improve Apparel Fit. *Journal of Textile and Apparel, Technology and Management*, *4*(3), 1–15.

Mason, A.M., Klerk, H.M., Ashdown, S. (2008). Sizing and fit research at grassroots level: A methodology for the identification of unique body shapes in African developing countries. *Journal Fam. Ecol. Consum. Sci.*, *36*, 9–21.

McCulloch, C.E., Paal, B. and Ashdown, S. P. (1998). An optimization approach to apparel sizing. *Journal of the Operational Research Society*, *49*(5), 492-9.

Mpampa, M. L., Azariadis, P. N., & Sapidis, N. S. (2010). *A new methodology for the development of sizing systems for the mass customization of garments*. *22*(1), 49–68. https://doi.org/10.1108/09556221011008802

Opaleye, A. A., Kolawole, A., & Charles-owaba, O. E. (2019). *Application of Fuzzy Clustering Methodology for Garment Sizing*.

4(1), 24–31. https://doi.org/10.11648/j.ajdmkd.20190401.15

Otieno, A.D., Mehtre, A., Fera O, Lema O., O., Gebeyehu, S. (2016). Developing Standard Size Charts for Ethiopian Men between the Ages of 18-26 through Anthropometric Survey. *Journal of Textile and Apparel, Technology and Management*, *10*(1), 1–10.

Petrova, A., Ashdown, S. P. (2008). Three-dimensional body scan data analysis: body size and shape dependence of ease values for pants' fit. *Clothing & Textiles Research Journal*, *26*(3), 227–252.

Roebuck, J. A. (1995). *Anthropometric methods : designing to fit the human body* (Santa Moni). Human Factors and Ergonomics Society.

Salusso-Deonier, C.J. (1982). *A method for classifying adult female body form variation in relation to the US Standard for apparel sizing*. Doctoral Dissertation, University of Minnesota.

Shin, E., & Damhorst, M. L. (2018). How young consumers think about clothing fit? *International Journal of Fashion Design, Technology and Education*, *11*(3), 352–361. https://doi.org/10.1080/17543266.2018.1448461

Shin E Damhorst M. (2018). How young consumers think about clothing fit? *International Journal of Fashion Design, Technology and Education*, *11*(3), 352–361.

Simbolon, A., Kuo, R.-J., Wijaya, A. (2014). *Developing a novel apparel standard sizing system using fuzzy clustering technique.*

Tryfos, P. (1986). An integer programming approach to the apparel sizing problem. *Journal of the Operational Research Society*, *37*(10), 1001-6.

Veitch, D., Veitch, L., Hennberg, M. (2007). Sizing for the Clothing Industry Using Principal Component Analysis—An Australian Example. *Journal of ASTM Internationa*, *4*(3), 1-12,.

Viktor, H. L. (2009). *Finding Clothing That Fit through Cluster Analysis and Objective Interestingness Measures NRC Publications Archive*

(NPArC) Archives des publications du CNRC (NPArC) Finding Clothing that Fit through Cluster Analysis and Objective Interestingness Measu. August. https://doi.org/10.1007/978-3-642-03730-6

Wang, Z., Newton, E., Ng, R., & Zhang, W. (2006). Ease distribution in relation to the X-line style jacket. Part 1: Development of a mathematical model. *Journal of the Textile Institute*, *97*(3), 247–256. https://doi.org/10.1533/joti.2005.0239

Winks, J. M. (1997). *Clothing sizes International standardization.* The Textile Institute,Redwood Books.

Xia, S., Istook, C. A. (2017). Method to Create Body Sizing Systems. *Cloth. Text. Res. J.*, *35*, 235–248.

Zakaria, N., Mohd, J.S., Taib, N., Tan, Y.Y. and Wah, Y. B. (2008). Using data mining technique to explore anthropometric data towards the development of sizing system. *Int. Symp. Inform. Technol.*, 2, 1–7.

Zeng, X.,Yu,W.,Bruniaux, P. (2006). Estimation of Ease Allowance of a Garment using Fuzzy Logic. *International Conference on Data Science in Business, Finance and Industry*, 367–379.

CHAPTER 15

Comparison of Compromise Constraint Bi-objective LP Method and Three Traditional Weighted Criteria Methods

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1. INTRODUCTION

Engineering and management decision situations with more than one criterion have been encountered with increasing frequency (Adeyeye&Charles-Owaba, 2008; Adeyeye&Oyawale, 2010a; Biswas *et al,* 2020; Zizovic, Miljkovic, &Marinkovic, 2020). In multi-criteria decisions, cases where the criteria conflict with each other are more common. In such situations gain in one criterion leads to loss in one or more of the other criteria. Due to conflict among the criteria, it is impossible to find a point at which all the criteria would assume their optimum values simultaneously. Consequently, there is no common optimal solution. What we have is a compromise solution(s). Since the criteria remain in conflict over the decision space, the analysist often elicits and incorporates the preferences of the Decision Maker (DM) in the model such that the DM gets the best compromise solution.

The criteria are often of varying degree of importance to the DM. Hence preference elicitation is very important in multicriteria optimisation. The preferences of the DM are often expressed as weights to reflect the relative importance of the criteria. The set of weights is often referred to as preference indices or preference structure. The preference structure is very important because the compromise solution obtained often vary from one set of preference structure to another. There are three possible situations in the case of a priori articulation of DM opinion concerning the relative importance of the various criteria. The DM may be satisfied with the compromise solution obtained with his preferencestructure and may not bother himself/herself about other feasible solutions that may exist. In other instance, the DM may have interest in the trade-off options available to him/her. In that case, the problem is solved repeatedly with different preference structures. In this manner, the DM learns about available trade-off options and is able to know how much he/she has to give up in one or more criterion/criteria to gain improvement in one or more of the remaining criteria. He is then able to intelligently select the most preferred solution from the candidate solutions. In some other instances, the DM may want the analyst to present the Pareto optimal solutions to him/her for evaluation after which the most preferred solution is picked. Pareto optimal solutions are often generated using the weights elicited from the DM(Adeyeye&Oyawale, 2010a, b; Adeyeye, Odu& Charles-Owaba, 2015; Zizovic, *et al*, 2020; Navarro, Penades-Pla, Martinez-Munoz, Rempling, &Yepes, 2020; Aiello, *et al,* 2020; Wang, Parhi, Rangaiah, & Jana, 2020).

Many methods have been proposed for solving multicriteria optimisation problems. Among the methods are the linear combination of objective functions or weighted-sum scalarization (WSS) method in which criteria are normalised and combined before performing optimisation of the combined objective (Adeyeye&Oyawale, 2010a;Adeyeye& Charles-Owaba, 2012; Oktal, Yaman, & Kasımbeyli, 2020 & Erozan &Calıskan, 2020). Nonpre-emptiveGoal Programming (NGP) is a distance-function approach which uses a certain target point in the decision space which represents the most desired values for the several criteria as a key element in modelling the problem (Adeyeye& Charles-Owaba, 2008; Adeyeye&Oyawale, 2010b;Bakhtavar, Prabatha, Karunathilake, Sadiq, &Hewage, 2020). Compromise Programming (CP) is another distance-function approach for which the target point is a utopian point usually not feasible which corresponds to the ideal value of each criterion (Adeyeye&Oyawale, 2010b;Adeyeye& Allu, 2017; Salman *et al,* 2020 and Canales,Jurasz, Beluco, &Kies, 2020). Adulbhan andTabucanon, (1977, 1979) and Chen, Wiecek, and Zhang (1998) observed that in multicriteria LP problems, the linear combination of objective functions method is very simplistic and sometimes fail to give the real compromise.

According to Adeyeye and Charles-Owaba (2012), this drawback could be due to the lack of sensitivity of the linear combination of objective functions.The Compromise Constraint Bicriteria LP (CCBLP) method was proposed to overcome the limitation of combination of objective functions method for bicriteria case (Adulbhan&Tabucanon, 1977 & 1979). The CCBLP hasnot gained much popularity apart from few applications probably due to lack of evidence on its efficacy (Adulbhan&Tabucanon, 1979;Adeyeye and Charles-Owaba, 2012). The DMs desire to know the relative merits of these approaches so that under any given decision situations they can be properly guided in making the choice of the method that best meet their needs. Since preference indices are often used to determine the best compromise solution, generate the Pareto optimal solutions and carry out trade-off analysis, the sensitivity of any multicriteria method to changes in weight structure could be a good approach of evaluating the usefulness of the method. In this study, the earlier work of Adeyeye and Charles-Owaba (2012) is extended by comparing the CCBLP method with three commonly used traditional weighted criteria methods, namely; WSS, NGP and CP on their sensitivities to changes in the weight structure for bicriteria LP problem.

2. BRIEF DESCRIPTION OF THE FOUR METHODS

In this section, the Compromise Constraint Bicriteria Linear Programming (CCBLP) and three traditional methods, namely, Weighted-sum Scalarisation, Nonpre-emptive Goal Programming (NGP) and Compromise Programming (CP) are briefly described.

2.1 Weighted-sum Scalarisation (WSS)

Consider a bicriteria problem, with criterion functions $f_1(x) = \sum_{j\in J} c_{1j}x_j$ *and* $f_2(x) = \sum_{j\in J} c_{2j}x_j$, respectively and $g_t(x)$ is the constraint function of t^{th}constraint while b_t is the righthand side of the t^{th} constraint. The elicited weights that reflect the relative importance of criteria are $w_1,\ w_2 > 0\ and\ w_1 + w_2 = 1$. The weighted-sum or linear combination of objective functions is given by;

$$Maximise, F = f_1^N(x) + f_2^N(x)$$

Subject to; (1)

$$g_t \leq, =, \geq b_t, t = 1, 2, \ldots, T$$

Where $f_1^N(x) = \left(w_1 \Big/ \sqrt{\sum_{j \in J} c_{1j}^2} \right) f_1(x)$ and $f_2^N(x) = \left(w_2 \Big/ \sqrt{\sum_{j \in J} c_{2j}^2} \right) f_2(x)$ also the respective coefficients of criteria 1 and 2 are c_{1j}^2 *and* c_{2j}^2.

2.2 Compromise Constraint Bicriteria LP

The CCBLP is a modification of the weighted-sum approach. The objectives are normalised and combined into one. Next, the compromise constraint is derived and added to the structural constraints of the problem. The compromise constraint is expressed as;

$$\left(w_1 \Big/ \sqrt{\sum_{j \in J} c_{1j}^2} \right) (f_1(x) - f_1^*) + \left(w_2 \Big/ \sqrt{\sum_{j \in J} c_{2j}^2} \right) (f_2(x) - f_2^*) = 0 \quad (2)$$

The combined criteria or any of the original criterion may be used as the criterion to be optimised subject to the compromise and structural constraints as shown below.

Maximise (any one of the three criterion

$$f_1(x) = \sum_{j \in J} c_{1j} x_j$$

$$f_2(x) = \sum_{j \in J} c_{2j} x_j,$$

$$F = \left({w_1}\Big/{\sqrt{\sum_{j\in J} c_{1j}^2}} \right) f_1(x) + \left({w_2}\Big/{\sqrt{\sum_{j\in J} c_{2j}^2}} \right) f_2(x)$$

Subject to;
(3)

$$\left({w_1}\Big/{\sqrt{\sum_{j\in J} c_{1j}^2}} \right) (f_1(x) - f_1^*) + \left({w_2}\Big/{\sqrt{\sum_{j\in J} c_{2j}^2}} \right) (f_2(x) - f_2^*) = 0$$

$$g_t \le, =, \ge b_t, t = 1, 2, \ldots, T$$

Where f_1^* and f_2^* are the respective ideal values of criterion 1 and 2 when optimized individually.

2.3 Nonpre-emptive Goal Programming (NGP)

The bicriteria model may be transformed to a GP model by assigning targets to each criterion. In some cases, a priori determination of goal may not be easy. Arbitrary setting of targets may lead to computation dominated or suboptimal solution. Hence, the potentials provided by the objectives are explored by solving them individually and using their optimum values as the target levels. The GP method seeks to minimise the distance between the desired aspiration levels and the compromise solutionobtained according to the preference structure.The general NGP model is given as;

$$Minimise, \qquad a = \sum_i w_i(d_i^+ + d_i^-)$$

Subject to;
(4)

$$f_i(x) + d_i^- - d_i^+ = f_i^*, \quad i = 1, 2, \ldots I$$

$$g_t \le, =, \ge b_t, t = 1, 2, \ldots, T$$

Where $d_i^-, d_i^+ \geq 0$ $and d_i^- \times d_i^+ = 0, \forall i$

2.4 Compromise Programming (CP)

Compromise Programming (CP) has received a lot of attention since it was proposed by Zeleny (1973, 1974). The best compromise solution is identified as the solution that give the shortest distance to a utopian point where all the criteria simultaneously reach their ideal values. The utopian point is not practically attainable but is usually used as a base point. First, the ideal (i.e. the best or anchor) values, (f_i^*) and anti-ideal (worst or nadir) values, (f_i^{**}) are computed for each criterion and are often used for the construction of pay-off matrix. Next, the distance function $(f_i^* - f_i(x))$between the outcome/achievement of each criterion and its ideal/optimum value is defined. This distance gives the degree of closeness of the outcome/achievement of the criterion to its ideal. The distance is usually normalised for dimensional consistency. The normalised distance is given by;

$$D_{ni} = \left(\frac{(f_i^* - f_i(x))}{(f_i^* - f_i^{**})}\right), \forall i \quad (5)$$

The combined distance (D_p) for all the criteria which expresses the closeness of the solution of the problem to the utopia is expressed as;

$$D_p = \left[\sum_{i \in I} \left(w_i \frac{(f_i^* - f_i(x))}{(f_i^* - f_i^{**})}\right)^p\right]^{1/p} \quad (6)$$

Where, p is a metric and real number belonging to the closed interval$[0, \infty]$. The value of$p = 1$, when the distances are of equal concern to the DM and $p = \infty$if only the largest distance is of concern. Observe, that all other solutions fall between the solutions obtained by solving the CP model with $p = 1$ and $p = \infty$. For instance, if the DM weighs the distances in proportion to their magnitude, then, $p = 2$ and the resulting model is solved to obtain the compromise solution. The general CP problem is as presented below;

$$\text{Minimise, } D_p = \left[\sum_{i\in I}\left(w_i \frac{(f_i^{*} - f_i(x))}{(f_i^{*} - f_i^{**})}\right)^p\right]^{1/p}$$

Subject to: (7)

$$g_t \leq, =, \geq b_t, t = 1, 2, \dots, T$$

When only the largest distance(L) counts, then,$p = \infty$,and the problem becomes a min-max problem. The model is stated as;

$$\text{Minimise, } D_\infty = L$$

Subject to:

$$\left(w_i \frac{(f_i^{*} - f_i(x))}{(f_i^{*} - f_i^{**})}\right) \leq L,\ \forall i \qquad (7)$$

$$g_t \leq, =, \geq b_t, t = 1, 2, \dots, T$$

3. EXPERIMENTAL

A bicriteria production planning problem from literature is used (Adeyeye and Charles-Owaba, 2008). The two criteria considered are (i) minimisation of production cost (ii) maximisation of capacity utilisation of production facilities. Cost minimisation criterion was converted to maximising criterion by multiplying by -1. The major production facilities with their respective capacities and cost of processing one unit of materials are presented in Table 1. The model developed by Adeyeye and Charles-Owaba (2008) were used for the experiment see Eq. 8. The problem was solved using the WSS, CCBLP, NGP and CP methods. For WSS method, the normal forms of the criteria were combined into one objective and solved using the existing constraints of the problem. In the case of CCBLP, apart from adding the normal forms of the criteria, the compromise constraint was derived and added to the structural constraints of the problem before solving it. In the case of the NGP and CP, the two criteria were solved individually to determine their ideal and anti-ideal values. For the NGP, the ideal values were set as the target while in the case of CP, the ideal and anti-ideal values were used for the computation of normalised distances.

Various weight structures were used to perform experiment to see the response/sensitivity of the CCBLP and the other three traditional approaches to the changes in the weight structure (see Table 2). The total production costs and capacity utilisation of each production facility was determined. The utilisation of production facilities was computed using the production facilities capacity constraints in Eq. 8. For instance, the respective capacity utilisation of PMV1 and ST3 are $\left(\frac{x_{111}+x_{211}+x_{311}}{9{,}600} \times 100\%\right)$ and $\left(\frac{y_{23}}{20{,}000} \times 100\%\right)$. The utilisation of the remaining facilitieswas computed in similar manner. In this study, the deviations were weighed equally, hence the D_1 distance metric is used to identify the solution that is closest to the utopian and the corresponding preference structure. The D_1 distance metric in its discrete form is mathematically expressed for bicriteria decision situation as $D_1 = w_1 \left|\frac{f_1^{*} - f_1(x)}{f_1^{*} - f_1^{**}}\right| + w_2 \left|\frac{f_2^{*} - f_2(x)}{f_2^{*} - f_2^{**}}\right|$

Table 1: Facilities Capacities and Processing Costs

Stage of Production	Facility Name	Capacity kg/month	Processing cost per unit
Premix	Premix Vessel 1 (PMV1)	9,600	2.00
	Premix Vessel 2 (PMV2)	14,400	1.20
	Premix Vessel 3 (PMV3)	24,000	1.00
Processing	Processing Vessel 1 (PLT1)	25,000	2.00
	Processing Vessel 2 (PLT2)	25,000	1.80
	Processing Vessel 3 (PLT3)	40,000	1.40

	Processing Vessel 4 (PLT4)	30,000	1.60
Storage	Storage 1 (ST1)	80,000	0.30
	Storage 2 (ST2)	45,000	0.45
	Storage 3 (ST3)	20,000	0.20

$$Minimise, Cost$$
$$= 2x_{111} + 2x_{211} + 2x_{311} + 1.2x_{121} + 1.2x_{221} + 1.2x_{321} + x_{131} + x_{231} + x_{331} + 2y_{12} + 2x_{412} + 2x_{512} + 2x_{612} + 2x_{712} + 1.8y_{22} + 1.8x_{422} + 1.8x_{522} + 1.8x_{622} + 1.8x_{722} + 1.4y_{32} + 1.4x_{432} + 1.4x_{532} + 1.4x_{632} + 1.4x_{732} + +1.6y_{42} + 1.6x_{442} + 1.6x_{542} + 1.6x_{642} + 1.6x_{742} + 0.3y_{13} + 0.45y_{23} + 0.20y_{33}$$

Maximise, $Capacity\ Utilisation$

$$= 4.17x_{111} + 4.17x_{211} + 4.17x_{311} + 2.78x_{121} + 2.78x_{221} + 2.78x_{321} + 1.67x_{131} + 1.67x_{231} + 1.67x_{331} + 1.6y_{12} + 1.6x_{412} + 1.6x_{512} + 1.6x_{612} + 1.6x_{712} + 1.6y_{22} + 1.6x_{422} + 1.6x_{522} + 1.6x_{622} + 1.6x_{722} + y_{32} + x_{432} + x_{532} + x_{632} + x_{732} + 1.33y_{42} + 1.33x_{442} + 1.33x_{542} + 1.33x_{642} + 1.33x_{742} + 0.5y_{13} + 0.89y_{23} + 2y_{33}$$

Subject to: (8)

Production facilities capacity constraint

$$x_{111} + x_{211} + x_{311} \leq 9{,}600 \qquad (PMV1)$$

$$x_{121} + x_{221} + x_{321} \leq 14{,}400 \qquad (PMV2)$$

$$x_{131} + x_{231} + x_{331} \leq 24{,}000 \qquad (PMV3)$$

$$y_{12} + x_{412} + x_{512} + x_{612} + x_{712} \leq 25{,}000 \qquad (PLT1)$$

$$y_{22} + x_{422} + x_{522} + x_{622} + x_{722} \leq 25{,}000 \qquad (PLT2)$$

$$y_{32} + x_{432} + x_{532} + x_{632} + x_{732} \leq 40{,}000 \qquad (PLT3)$$

$$y_{32} + x_{432} + x_{532} + x_{632} + x_{732} \leq 30{,}000 \qquad (PLT4)$$

$$y_{13} \leq 80{,}000 \qquad (ST1) y_{23}$$
$$\leq 80{,}000 \qquad (ST2)$$

$$y_{23} \leq 20{,}000 \qquad (ST3)$$

Firm's full capacity constraint

$$x_{111} + x_{211} + x_{311} + x_{121} + x_{221} + x_{321} + x_{131} + x_{231} + x_{331} = 48{,}000$$

Material proportions constraint

$$x_{111} - 0.1x_{311} = 0$$

$$x_{121} - 0.1x_{321} = 0$$

$$x_{131} - 0.1x_{331} = 0$$

$$x_{211} - 1.3x_{311} = 0$$

$$x_{221} - 1.3x_{321} = 0$$

$$x_{231} - 0.1x_{331} = 0$$

$$x_{422} - 0.0625y_{22} = 0$$

$$x_{432} - 0.0625y_{32} = 0$$

$$x_{442} - 0.0625y_{42} = 0$$

$$x_{512} - 0.01042y_{12} = 0$$

$$x_{522} - 0.01042y_{22} = 0$$

$$x_{532} - 0.01042y_{32} = 0$$

$$x_{542} - 0.01042y_{42} = 0$$

$$x_{612} - 0.96y_{12} = 0$$

$$x_{622} - 0.96y_{22} = 0$$

$$x_{632} - 0.96y_{32} = 0$$

$$x_{642} - 0.96y_{42} = 0$$

$$x_{712} - 0.0521y_{12} = 0$$

$$x_{722} - 0.0521y_{22} = 0$$

$$x_{732} - 0.0521y_{32} = 0$$

$$x_{742} - 0.0521y_{42} = 0$$

Material balance constraint

$$x_{111} + x_{211} + x_{311} + x_{121} + x_{221} + x_{321} + x_{131} + x_{231} + x_{331} - y_{12} - y_{22} - y_{32} - y_{42} = 0$$

$$y_{12} + x_{412} + x_{512} + x_{612} + x_{712} + y_{22} + x_{422} + x_{522} + x_{622} + x_{722} + y_{32} + x_{432} + x_{532} + x_{632} + x_{732} + y_{32} + x_{432} + x_{532} + x_{632} + x_{732} - y_{13} - y_{23} - y_{33} = 0$$

Table 2: Relative Importance of Criteria

S/N	Preference Structure
1	$w_1 = 0.25, w_2 = 0.75$
2	$w_1 = w_2 = 0.5$
3	$w_1 = 0.75, w_2 = 0.25$

4. RESULTS AND DISCUSSION

The summary of results of experiments with different preference structures are presented in Table 3 below. All the four methods have been able to assist the DM to determine the utilisation of the production facilities and the associated costs for the different weight structures. However, the usefulness of the various methods as tool for the DM in making intelligent trade-off decisions vary because of the difference in their sensitivity to relaxations in the objectives. The D_1-distanceswere not computed for the WSS, NGP and CP when $w_1 = 0.75$ and$w_2 = 0.25$ because their solutionsare identical to the ideal solution of the minimum cost objective (see Table 3). Their so called "best compromise solutions" could mislead DM because they did not reflect the relaxation provided by the DM. Only the CCBLP responded to the small relaxation in the costminimisation objectives with improved capacity utilisation of production facilities but with a decrease in the achievement of minimum cost objective. The utilisation of the least utilisedfacility improved from 0.18% to 20.32% while production cost increased by 1.8%. The increase in the utilisation of production facilities was achieved at the detriment of production cost because the objectives are in conflict.Also, when $w_1 = 0.25$ and$w_2 = 0.75$, the NGP and CCBLP responded to the relaxation in the capacity utilisation objective while that of WSS and CPare identical to the ideal solution of the maximisation of capacity utilisation objective. It is only in the case where the objectives are of equal importance ($w_1 = w_2 = 0.50$) to the DM that all the four approaches responded to the relaxations in the objectives. In terms of sensitivity of the approaches, WSS and CP were the least sensitive, followed by NGP while CCBLP is the most sensitive. In terms of the D_1-distances, the compromise solution provided by CCBLP is the closest to the utopia and the corresponding preference structure is $w_1 = 0.25$, $w_2 = 0.75$).

Table 3: Results of Simulation with Different Preference Structure

Facility Name	$w_1 = 1$	$w_1 = 0.75, w_2 = 0.25$				$w_1 = w_2 = 0.50,$				$w_1 = 0.25,$ $w_2 = 0.75$				$w_2 = 1$
	Ideal Cost $f_1(x)$	WSS	NGP	CCBLP	CP	WSS	NGP	CCBLP	CP	WSS	NGP	CCBLP	CP	Ideal $f_2(x)$ Capacity utilisation
PM 1	100	100	100	100	100	100	100	100	100	100	100	100	100	100
PM 2	100	100	100	100	100	100	100	100	100	100	100	100	100	100
PM 3	100	100	100	100	100	100	100	100	100	100	100	100	100	100
PP 1	20.32	20.32	20.32	20.32	20.32	20.32	20.32	25.20	20.32	100	100	58.40	100	100
PP 2	100	100	100	100	100	100	100	100	100	100	100	100	100	100

PP 3	100	100	100	100	100	100	100	97	100	50.20	100	76.20	50.20	50.20
PP 4	100	100	100	100	100	100	100	100	100	100	33.60	100	100	100
ST 1	100	100	100	66.80	100	43.90	43.90	43.90	43.90	43.90	43.90	43.90	43.90	43.90
ST 2	0.18	0.18	0.18	59.10	0.18	100	100	100	100	100	100	100	100	100
ST 3	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Cost (₦)	2.48×10^5	2.48×10^5	2.48×10^5	2.52×10^5	2.48×10^5	2.54×10^5	2.54×10^5	2.55×10^5	2.54×10^5	2.67×10^5	2.62×10^5	2.60×10^5	2.67×10^5	2.67×10^5
Distance Metric (L_1)				0.337		0.388	0.388	0.391	0.388		0.366	0.326		
Increase In Cost (%)		0.0	0.0	1.8		2.7	2.7	3.0	2.7	7.5	5.9	5.0	7.5	7.5

The feasible solution space defined by the constraint sets determines the sensitivity of the methods to the changes in the preference structure. In the case of WSS, NGP and CP, the compromise solution is limited to the vertices of the solution space. Such solutions could be misleading because in some cases the real best compromise solution may be in other parts of the solution space other than the vertices. This could be the reason why WSS and CP were giving identical solutions for all the cases studied. The addition of goal constraints to the NGP model changes the feasible solution space of the bicriteria problem by introducing new vertices and eliminating some of the existing vertices. This could be the reason why the solution of the NGP was different from that of WSS and CP for $w_1 = 0.25$ and$w_2 = 0.75$.It is possible that the NGP picks one of the new vertices introduced by the goal constraints. Once the goal constraints are added to the structural constraints, the feasible region for the problem has been defined and does not change with relaxations in the criteria and the solutions are limited to the vertices. In the case of CCBLP, the preference indices are used to derive the compromise constraint which is added to the original constraint set and it forces the criteria to settle on a common point on any part of the boundary of the solution space. The CCBLP is able to identify the real compromise solution because it is not limited to the vertices of the constraint set. Although the CCBLP approach is the most sensitive to changes in preference structure, its application is limited to bicriteria case whereas WSS, NGP and CP can handle more than two objectives. The CP approach has a means of incorporating the concerns of the DM over the deviations through the use of the topological metric, $p$which is a real number belonging to the closed interval $[0, \infty]$. The choice of which of the approaches the DM should use in a given situation depends on the number of criteria, sensitivity to relaxations in the criteria and the concerns of the DM on the deviation from utopian solution among others.

5. CONCLUSION

Simulation with different preference structures showed that CCBLP is the most sensitive to the changes in the preference structures and gives the real compromise solution. It is able to identify the real compromise anywhere on the boundary of the feasible region either on the vertices on not. The CCBLP is limited to bicriteria while WSS, NGP and CP can handle more than two criteria. This provide a guide for Decision Maker on the choice of method to use for his decision problem.

REFERENCES

Adeyeye A. D. And Allu A. (2017). *Compromise Programming Approach to Welding Flux Performance Optimization.* Proceedings of The International Conference on Industrial Engineering and Operations Management Bogota, Colombia, October 25-26 :53-63

Adeyeye, A. D. & Charles-Owaba, O.E. (2008). Goal programming model for production planning in a toothpaste factory. *South African Journal of Industrial Engineering, 19(2),* 197-209

Adeyeye, A. D. & Charles-Owaba, O.E. (2012).Application and comparison of three multiobjective linear programming methods. *Proceedings of NIIE 2012 Conference, 254-267*

Adeyeye, A. D.&Oyawale F. A. (2010a).Multi-objective methods for welding flux performance optimization. *RMZ – Materials and Geoenvironment, 57(2),* 251–270.

Adeyeye, A. D.&Oyawale, F. A. (2010b). Optimisation of weld-metal chemical composition from welding flux ingredients: A non-pre-emptive goal programming approach. *Maejo International Journal of Science and Technology, 4(2),* 347-359.

Adulbhan, P.&Tabucanon (1977). Bicriterion linear programming. *Computers & Operations Research, 4(2),* 147-153

Adulbhan, P. &Tabucanon, M. T. (1979). A biobjective model for production planning in a cement factory. *Computers & Industrial Engineering, 3(1),* 41-51

Aiello, G., Benitez, J., Carpitella, S., Certa, A., Enea, M., Izquierdo, J. and La Cascia, M. (2020). A decision support system to assure high-performance maintenance service. *Journal of Quality in Maintenance Engineering*, Vol. ahead-of-print No. ahead-of-print. doi:10.1108/JQME-11-2019-0107

Bakhtavar, E., Prabatha, T., Karunathilake, H., Sadiq, R. &Hewage, K. (2020). Assessment of renewable energy-based strategies for net-zero energy communities: A planning model using multi-objective goal programming. *Journal of Cleaner Production, 272* 122886

Biswas, S. (2020). Measuring performance of healthcare supply chains in India: A comparative analysis of multi-criteria decision making methods. *Decision Making: Applications in Management and Engineering*, *3*(2), 162-189. Retrieved from https://dmame.rabek.org/index.php/dmame/article/view/133

Canales, F. A., Jurasz, J., Beluco, A., Kies, A. (2020). Assessing temporal complementarity between three variable energy sources through correlation and compromise programming. EnergyVolume 192, doi: 10.1016/j.energy.2019.116637

Chen, W., Wiecek, M.M. and Zhang, J. (1998). Quality utility – a compromise programming approach to robust design. [Online] Available: www.uic.edu/labs/idel/pdf/Chen_Wiecek.pdf

Erozan, I. &Calıskan, E. (2020). A multi-objective genetic algorithm for a special type of 2D orthogonal packing problems. *Applied Mathematical Modelling, 77(1),* 66-81

Navarro, I. J., Penades-Pla, V., Martinez-Munoz, D., Rempling, R., &Yepes, V. (2020). Life cycle sustainability assessment for multi-criteria decision making in bridge design: a review. *Journal of Civil Engineering and Management*, *26*(7), 690-704. https://doi.org/10.3846/jcem.2020.13599

Oktal, H.,Yaman, K. &Kasımbeyli, R. (2020). A Mathematical Programming Approach to Optimum Airspace Sectorisation Problem. *The Journal of Navigation, 73(3),* 599-612

Salman, S. A., Shahid, S., Ismail, T., Al-Abadi, A. M., Xiao-jun Wang&Chung, E. (2019). Selection of gridded precipitation data for Iraq using compromise programming. *Measurement, 132,* 87-9

Wang, Z., Parhi, S. S., Rangaiah, G. P. & Jana, A. K. (2020). Analysis of Weighting and Selection Methods for Pareto-Optimal Solutions of Multiobjective Optimization in Chemical Engineering Applications. *Ind. Eng. Chem. Res., 59(33)*, 14850–14867

Zeleny, M. (Ed.). (1973). *Compromise programming, multiple-criteria decision making*. South Carolina, 262–301, University of South Carolina Press, Columbia.

Zeleny, M. (1974): A Concept of Compromise Solution and the Method of the Displaced Ideal, *Computer & Operations Research, 1*, 479–496.

Zizovic, M., Miljkovic, B., &Marinkovic, D. (2020). Objective methods for determining criteria weight coefficients: A modification of the CRITIC method. *Decision Making: Applications in Management and Engineering*, *3*(2), 149-161.

CHAPTER 16

Preventive Maintenance Interval Prediction: Application of a Cost-Based Approach with Lost Earnings Consideration in a Manufacturing Firm

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Abstract

In this work, the pertinent maintenance parameters in manufacturing firms were identified and used to develop a cost function for machine maintenance. In the cost function, the lost earnings due to corrective maintenance and preventive maintenance were considered alongside machine reliability to determine an optimal interval for preventive maintenance. Thereafter, the model was evaluated by applying it to a cash crop processing company in Nigeria.The model application considered the two lost earnings cost parameters that were identified in the determination of the preventive maintenance interval and their influence on the total maintenance cost. Numerical examples were presented to demonstrate the solution techniques and the results were presented accordingly.

1. Introduction

Preventive maintenance is central to addressing the availability and useful life of machines. According to Dhillon (2006), maintenance can be defined as the combination of appropriate actions for retaining and/or restoring components/equipment/part to its designated functions.Every action directed towards keeping equipment or facility in a proper working condition is regarded as maintenance (Sobamowo*et al.,* 2012). This includes both technical and administrative efforts to ensure the functioning of a system (Reason, 2000; Swanson, 2001).In preventive maintenance, there is a set of organized activities which are performed on machinery to achieve its best operational condition. More specifically, the activities are targetted towards the preservation of equipment conditions, prevention of equipment failure, and repair of broken equipment(Jardine& Tsang, 2013). Through adequate maintenance of facilities, production loss, downtime, environmental hazards have been greatly reduced in manufacturing firms.

Maintenance actions not only have a direct effect on machine availability but also influence the profit-making of the manufacturing firms. That is, when the machine meant for manufacturing activities are in a good working condition, it promotes the organizationalgoals. Also, issues bothering on the machine downtime, defective products, production loss, personnel injuries and accidents which could arise from a poor machine condition can all be avoided. Inlight of this, maintenance actions have become very important and strategic part of anymanufacturing business.

However, executing preventive maintenance actions always come at an inevitable cost and, directly competewith the savings of the manufacturing firms.For example, costs of failure and the cost incurred as a result of the time spent to execute the maintenance actions affect the useful production time.While the maintenance actions resulting in these costs have become inexorable, it increases the cost of business of the manufacturers. And so, manufacturershave decisions to make onwhen to execute themaintenance actionsat a minimal cost while achieving machineavailability.

In this study, we present a model for the determination of the preventive maintenance interval in a manufacturing firm and specifically considered the influence of lost earning duringmaintenance actions.

2.Review of Maintenance Studies

Maintenance in the past has been viewed as a necessary evil by manufacturing companies (Paz & Leigh, 1994). However, this has changed from being a necessary evil to an integrated part of manufacturing and business in general (Adebimpe, 2014). The recent consideration of maintenance as an important aspect of the business has been spurred by the increased requirements in machine performance, environment and safety for businesses to gain competitive advantages in the manufacturing market.

Maintenance can be classified into two: Corrective Maintenance (CM) and Preventive Maintenance (PM) (Alaswad& Xiang, 2017).The corrective maintenance allows the machine to operate until it finally breaks down. This type of maintenance activity is also referred to as breakdown maintenance or failure based maintenance. In this type of maintenance, no work is performed on the machine until the machine fails. Though this maintenance policy wasconsidered to be feasible in cases where profit margins are large (Sharma *et al.,* 2005), the strategy could lead toan unpleasant circumstance for the business. It could cause serious damage to machine, environment, personnel as well as production downtimeand machine unavailability (Basri*et al.,* 2017).

On the other hand, preventive maintenance is planned and aimed at optimal machine availability. Preventive maintenance refers to every action executed on a machine before it fails. These are activities which are directed towards the reduction of the rate of machine degradation and consequently to extend the useful life while the machine is still functional. One main objective of preventive maintenance is to reduce the rate at which a machine fails (Vilarinho*et al.,* 2017).According to Angius*et al.* (2016), preventive maintenance has shown a great contribution to the quality of product or service delivery, environmental and personnel safety. However, the time spent for PM actions often affects the useful production hours of a manufacturing firm and as a result, affects the production target.

The two main classifications of maintenance techniques are presented in Figure 1 alongside a further classification of preventive maintenance as described by(Avontuur, 2017).

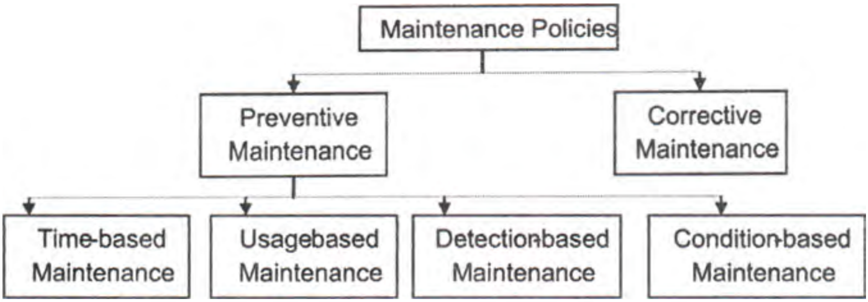

Figure 1: Types of Maintenance Techniques
Source: Peters, 2018.

2.1 Preventive Maintenance

Though maintenance has been part of human life since inception, the understanding of the importance of preventive maintenance (PM) policies can be dated back to the early 1950s (Murthy *et al.,* 2002). In the past, corrective maintenance was popular. However, the current stringent business policies, competitive market, change in focus of business executives and decision-makers as well as the furtherance of improved methodologies to enhance the effectiveness of manufacturing systemshas led to the adoption of preventive maintenance.

In PM, maintenance tasks are predetermined and are derived from the equipment or machines component lifetimes and basic operations. For that reason, certain actions are planned to replace some parts before they eventually fail to function. In Simoes*et al.* (2011), PM was viewed from both the managerial perspective and the operational perspective. In a managerial perspective, issues bothering on decision making and support received towards the analysis of maintenance data are considered. This includes inputs such as objectives of preventive maintenance, maintenance planning, systems performance and the adopted problem-solving techniques. Thus, the viewpoint is referred to as the outer process because historical data and analysis are used for the execution of PM actions and decisions.

Meanwhile, the operational perspective is viewed as the maintenance action which is executed for sustaining a system (Bjorklund*et al.*, 2010). Consequently, it is referred to as the inner process because it considers the technical aspect of PM based on inputs. However, these two viewpoints are considered to be very important towards achieving effectiveness and efficiency of a manufacturing system. The roles of the two viewpoints are crucial to attaining efficient and effective manufacturing systems.

2.2 Overview of Preventive Maintenance Models

Numerous approaches have been applied in maintenance studies, especially to predict preventive maintenance. For instance, Sim and Endrenyi (1988) developed preventive maintenance model which was aimed at minimization of machine unavailability as a result of frequent breakdown while Bottazi *et al.* (1992) analysed the preventive and corrective maintenance strategies of a collection of buses for a range of five years.A Monte Carlo simulation approach was applied to evaluate the maintenance policies using a developed updatable database.

In Chareonsuk*et al.* (1997), a multi-criteria approach was applied to determine optimal preventivemaintenance interval considering age-based failure rate of components, cost and reliability of the components. Meanwhile, Percy *et al.* (1998) developed models to address preventive maintenance schedules in complex systems. Also, Kardon and Fredendall (2002), Chen *et al.* (2003), Juang and Anderson (2004), Das *et al.* (2007) applied mathematical principle and modeling to solve the problems of preventive maintenance interval.

Similarly, in predicting the preventive maintenance intervals, authors such as Zequeira and Be´ren-guer (2006), Wangand Pham (2006), Das *et al.* (2007), Taboada*et al.* (2008), Castro, (2009)have applied cost-basedapproach with the reliability of the machines under consideration. However, the cost function has not captured lost earnings during maintenance activities. Thus, Ojeih (2011) and Adebimpe*et al.*(2014) considered the lost earnings and developed a cost-based model to predict an optimal preventive maintenance interval in a manufacturing firm. Also, Adebimpe*et al.* (2015), included the cost of inventory of the required spare parts for the preventive maintenance as part of the cost function. They applied the model and establish its applicability in manufacturing firm.

However, there is a need to further demonstrate the application and, the impact of lost earning as an important cost parameter in the totalmaintenance cost. Thus, we considered the lost earnings during corrective maintenance and preventive maintenance as a factor in the cost-based approach.

3. The Model

The model developed by Adebimpe*et al.* (2015) was adapted for this study and the development process is presented.The developed model is a cost-based model which considers related cost involved in carrying out preventive maintenance in a manufacturing company and the lost earning that results from carrying out the maintenance activities. The basic cost parameters that wereidentified in this model are; the preparation cost for the preventive maintenance activities, cost of executing the preventive maintenance, cost of executing corrective maintenance and lost earnings while executingcorrective maintenance and preventive maintenance.

3.1 Model Notations

The following describes the representation and the meanings of the notations used in the model development;

1. t_{PM}: preventive maintenance interval (Hours).
2. TC: total maintenance cost for a planning horizon.
3. C_o: cost of executing a planned preventive maintenance (Cost/Maintenance).
4. C_{PM}: average cost of preventive maintenance (Cost/Maintenance).
5. C_F: average cost of corrective maintenance during the interval t_{PM}.

6. C_{BM}: cost of executing corrective maintenance.
7. LE_{BM}: lost earnings resulting from corrective maintenance.
8. LE_{BM}: lost earnings due to planned preventive maintenance.
9. D_M: average duration for corrective maintenance.
10. P_L: estimated profit per hour.
11. D_T: average duration for planned preventive maintenance.
12. $\beta$and$\propto$: shape and scale parameters of Weibull distribution for the machine.

3.2 Model Assumptions

The following are the assumptions made for the model development;

1. The machine failure is characterized by Weibull distribution.
2. The cost of carrying out preventive maintenance is known.
3. The preparation cost of performing preventive maintenance is known.
4. The average number of machine failure within a PM interval is known.
5. The average cost of executing corrective maintenance is known.
6. The minimum acceptable reliability of the machine is known.
7. The average time taken for corrective maintenance and preventive maintenance is known.
8. The labours used for the maintenance are the employees of the company (i.e. operators).

3.3Cost Functionand Reliability

Adapting from Adebimpe*et al.* (2015), the cost function is described as follows;

$$\begin{gathered} Total\ Maintenance\ Cost = \\ \{Preparation\ Cost\ of\ Preventive\ Maintenance + \\ Cost\ of\ Executing\ Preventive\ Maintenance + \\ Cost\ of\ Executing\ Corrective\ Maintenance + \\ Lost\ Earnings\ During\ Corective\ Maintenance + \\ Lost\ Earnings\ During\ Preventive\ Maintenance\} \end{gathered} \tag{1}$$

The mathematical expression for the cost components that makes up the $Total\ Maintenance\ Cost$ as described in equation 1 is now described.

i. Preparation Cost for the Preventive Maintenance C_o: this describes all the costs associated with the mobilization of all resources and set-up.

ii. Cost of Executing Preventive Maintenance C_{PM}: this describeslabour cost (which is a percentage of employees' salary) of maintenance personnel, material and tools used in preventive maintenance.

iii. Cost of Executing CorrectiveMaintenance C_{BM}: this describes the cost of tools, labour and materials used for corrective maintenance within a preventive maintenance interval (t_{PM}). This is further expressed as shown in equation 2;

$$C_{BM} = C_F(\frac{t_{PM}}{\alpha})^{\beta} \tag{2}$$

iv. Lost Earnings during Corrective Maintenance LE_{BM}: this accounts for the money lost as a result of downtime caused by sudden machine failure. Thus we expressed this in equation 3 as the average number of failures that occur within an interval of preventive and the average duration of failure before the machine is restored to its normal working condition;

$$LE_{BM} = D_M P_L(\frac{t_{PM}}{\alpha})^{\beta} \tag{3}$$

v. Lost Earnings during Preventive Maintenance LE_{PM}: this accounts for the money lost as a result of planned downtime as a result of preventive maintenance. It is expressed as equation 4 below;

$$LE_{PM} = D_T P_L \tag{4}$$

Thus, by aggregating equations 1-4 we have the total cost *TC* as described in equation 5 and 6

$$TC = C_o + C_{PM} + C_{BM} + LE_{BM} + LE_{PM} \tag{5}$$

$$TC = C_o + C_{PM} + C_F(\frac{t_{PM}}{\propto})^{\beta} + D_M P_L(\frac{t_{PM}}{\propto})^{\beta} + D_T P_L \tag{6}$$

Now that the objective function has been demonstrated, the cost function is subject to the reliability of the machine under consideration. Therefore, we expressed the reliability function of the machine as expressed in Das *et al.* (2006) using the cumulative probability function of Weibull when the upper bound for the failure probability is set by the firm;

$$F(t_{PM}) = 1 - e^{-\left(\frac{t_{PM}}{\alpha}\right)^{\beta}}; \text{ where } t_{PM}, \alpha, \beta > 0 \tag{7}$$

And by manipulating equation 7,$t_{PM}$is made the subject of the equation and we have equation 8 as;

$$t_{PM} \leq \alpha\left\{\ln\left\{\frac{1}{1-F(t_{PM})}\right\}\right\}^{1/\beta} \tag{8}$$

$$F(t_{PM}) \leq Upperbound \tag{9}$$

Equation 10 describes the cycle of preventive maintenance in a year given a specific preventive maintenance interval. To predict the cycle of preventive maintenance$n$ activities in a year, we considered the time lag between the start of the preventive maintenance and the completion of the activityD_T. Thus, we expressed $n$in equation 10 as;

$$n = \left\lfloor\frac{T}{D_T + t_{PM}}\right\rfloor, \text{ is an integer} \tag{10}$$

Thus after aggregating equations 1 to 10we have;

Optimal Interval

$$Min \quad TC(T) = n\left[C_o + C_{PM} + C_F \left(\frac{t_{PM}}{\propto}\right)^{\beta} \right] + n\left[D_M P_L \left(\frac{t_{PM}}{\propto}\right)^{\beta} + (D_T P_L)\right] \quad (11)$$

Subject to

$$t_{PM} \leq \propto \{In\left[{}^{1}/_{1} - F(t_{PM})\right]^{1/\beta}\} \quad (12)$$

$$F(\,t_{PM}) \leq Upper\ Bound \quad (13)$$

3.4Algorithm

Step 1: Input $C_o, C_{PM}, C_F, P_L, D_M, D_T, Upper\ Bound.$

Step 2: Compute the t_{PM} using the reliability function in equation 7.

Step 3: Substitute the t_{PM} in the objective function to estimate the total cost TC in the model at minimum reliability and the computed preventive interval t_{PM}.

Step 4: Repeat steps 1 to 3 for a range of reliability and checks for the t_{PM} value at minimum cost. Then, end the procedure.

4. Model Application

In this section, the model was applied using the data that was collected from a manufacturing firm. The model application considered the influence of the two parameters of lost earnings in the numerical example and the subsequent analysis. The first numerical example considered the lost earnings due tocorrective maintenance and the second considered lost earning as a result of corrective and preventive maintenance todemonstrate the solution technique.

4.1 Manufacturing Firm Data

Table 1 represents the data of a critical machine in a cash crop processing company. The company under consideration is located in South-Western Nigeria and has one of the biggest beverage companies whose products are widely consumed in Nigeria and all neighbouring country as its major customer. That is, the company under consideration has a high volume of demand and is engaged in a competitive market and as a resultof these, an optimal interval for planned preventive maintenance is required.

Table 1: Data from the Manufacturing Company

Parameters	Values
β	1.21
$\propto$	199.61
C_o	1400 Naira
C_{PM}	2560 Naira
C_F	15190 Naira
P_L	4500 Naira
D_T	8 Hours (9.13 x 10^{-4} year)
D_M	2.5 Hours
T	8760 Hours (1 Year)

4.2 Numerical Example 1

The example demonstrates the prediction of the preventive maintenance interval using the presented model and algorithm. In the example, only the lost earning during corrective maintenancewithin preventive maintenance interval was considered. The approach applied the data in Table 1, with the Upper Bound of $F(t_{PM})$ being set at 0.25,

$$t_{PM} \leq 199.61\{In\left[{}^{1}/_{(1-0.25)}\right]^{1/1.21}\}$$

$$t_{PM} \leq 199.61\{In\left[{}^{1}/_{(0.75)}\right]^{1/1.21}\}$$

$$t_{PM} \leq 199.61\ X\ 0.3573$$

$$t_{PM} \leq 70.66\ Hours$$

Thereafter, we estimate $n = \left\lfloor \frac{T}{D_T + t_{PM}} \right\rfloor$ and substitutes $t_{PM} = 70.66\ Hours$ with the inputted parameters into the cost equation as described below;

$$n = \left\lfloor \frac{8760}{8 + 70.66} \right\rfloor$$

$$n \approx 112$$

$$Min \quad TC(T) = n\left[C_o + C_{PM} + C_F \left(\frac{t_{PM}}{\propto}\right)^{\beta} + D_M P_L \left(\frac{t_{PM}}{\propto}\right)^{\beta} \right]$$

$$TC(T) = 112\left[1400 + 2560 + 15190\left(\frac{70.66}{199.61}\right)^{1.21} + 2.5\ X\ 4500\left(\frac{70.66}{199.61}\right)^{1.21}\right]$$

$$TC(T) = 112[3960 + 15190(0.2846) + 11250(0.2846)]$$

$$TC(T) = 112[3960 + 4323.66 + 3201.75]$$

$$TC(T) = 112[11485.41]$$

$$TC(T) = 1{,}286{,}365.92\ Naira$$

Table 2: Result of Preventive Maintenance Interval and Total Cost

Upper Bound	Preventive Maintenance Interval $(D_T + t_{PM})$	Cycle of Preventive Maintenance (n)	Total Cost of Maintenance $TC(T)$

0.25	78.66	112	1;286,365.92
0.27	84.84	104	1,278,073.38
0.29	90.6	97	1,265,896.39
0.31	96.11	92	1,268,613.05
0.33	101.5	87	1,263,364.83
0.35	107.75	82	1,261,288.06
0.37	113.81	77	1,249,435.14
0.39	119.61	74	1,261,303.04
0.41	125.18	70	1,248,719.77
0.43	131.58	67	1,257,003.27
0.45	138.69	64	1,267,057.50
0.47	145.46	59	1,268,544.95
0.49	151.91	58	1,261,868.33
0.51	158.94	56	1,277,561.22
0.53	166.45	53	1,269,588.36
0.55	173.58	51	1,277,460.42
0.57	181.83	49	1,289,982.76
0.59	189.63	47	1,294,671.06
0.61	193.7	46	1,296,611.34
0.63	206.66	43	1,300,656.06
0.65	215.78	41	1,300,315.45
0.67	225.36	39	1,297,562.65
0.69	235.43	38	1,327,029.63
0.71	246.08	36	1,320,649.00
0.73	257.38	35	1,350,066.70
0.75	269.42	33	1,339,982.01
0.77	282.35	31	1,369,916.73
0.79	296.3	30	1,356,382.46
0.81	311.49	29	1,387,855.17
0.83	328.18	27	1,371,457.23
0.85	346.75	26	1,406,631.53
0.87	367.72	24	1,389,144.25
0.89	391.89	23	1,432,790.87
0.91	420.49	21	1;419,479.83
0.93	455.74	20	1484639.654

0.95	502.05	18	1,496,153.05
0.97	570.67	16	1,545,768.54
0.99	715.47	13	1,640,505.77

4.3 Numerical Example 2

In this example, we predict the preventive maintenance interval with consideration for lost earning due to both corrective and preventive maintenance. The approach illustrated the model and algorithm using the data in Table 1, with the Upper Bound of $F(t_{PM})$ being set at 0.25;

$$t_{PM} \leq 199.61\{In\left[{}^{1}/_{(1-0.25)}\right]^{1/1.21}\}$$

$$t_{PM} \leq 199.61\{In\left[{}^{1}/_{(0.75)}\right]^{1/1.21}\}$$

$$t_{PM} \leq 199.61\, X\, 0.3573$$

$$t_{PM} \leq 70.66\ Hours$$

Thereafter, we estimate $n = \left\lfloor \frac{T}{D_T + t_{PM}} \right\rfloor$ and substitutes $t_{PM} = 70.66\ Hours$ with the inputted parameters into the cost equation as described below;

$$n = \left\lfloor \frac{8760}{8 + 70.66} \right\rfloor$$

$$n \approx 112$$

$$Min \quad TC(T) = n\left[C_o + C_{PM} + C_F\left(\frac{t_{PM}}{\propto}\right)^{\beta}\right] + n\left[D_M P_L\left(\frac{t_{PM}}{\propto}\right)^{\beta} + (D_T P_L)\right]$$

$$TC(T) = 112\left[1400 + 2560 + 15190\left(\frac{70.66}{199.61}\right)^{1.21}\right] + 112\left[2.5\,X\,4500\left(\frac{70.66}{199.61}\right)^{1.21} + 4500\,X\,8\right]$$

$$TC(T) = 112[3960 + 15190(0.2846) + 11250(0.2846) + 36000]$$

$$TC(T) = 112[3960 + 4323.66 + 3201.75 + 36000]$$

$$TC(T) = 112[47485.41]$$

$$TC(T) = 5{,}318{,}365.92\ Naira$$

Table 3: Result of Preventive Maintenance Interval and Total Cost of Maintenance with Lost Earnings Due to Corrective Maintenance and Preventive Maintenance

Upper Bound	Preventive Maintenance Interval $(D_T + t_{PM})$	Total Cost of Maintenance $TC(T)$
0.25	78.66	5,318,386.80
0.27	84.84	5,022,073.38
0.29	90.6	4,757,896.39
0.31	96.11	4,580,613.05
0.33	101.5	4,395,364.83
0.35	107.75	4,213,288.06
0.37	113.81	4,021,435.14
0.39	119.61	3,925,303.04
0.41	125.18	3,768,719.77
0.43	131.58	3,669,003.27
0.45	138.69	3,571,057.50

0.47	145.46	3,464,544.95
0.49	151.91	3,349,868.33
0.51	158.94	3,293,561.22
0.53	166.45	3,177,588.36
0.55	173.58	3,113,460.42
0.57	181.83	3,053,982.78
0.59	189.63	2,986,671.08
0.61	193.7	2,952,611.34
0.63	206.66	2,848,656.06
0.65	215.78	2,776,315.45
0.67	225.36	2,701,562.65
0.69	235.43	2,695,029.63
0.71	246.08	2,616,649.00
0.73	257.38	2,610,066.70
0.75	269.42	2,527,982.01
0.77	282.35	2,521,916.73
0.79	296.3	2,436,382.46
0.81	311.49	2,431,855.17
0.83	328.18	2,343,457.23
0.85	346.75	2,342,631.53
0.87	367.72	2,253,144.25
0.89	391.89	2,260,790.87
0.91	420.49	2,175,479.83
0.93	455.74	2,204,639.65
0.95	502.05	2,144,153.05
0.97	570.67	2,121,768.54
0.99	715.47	2,108,505.77

Table 4:Lost Earnings due to Breakdown Maintenance and Preventive Maintenance

Upper Bound	Preventive Maintenance Interval ($D_T + t_{PM}$)	Lost Earnings During CM (Naira)	Lost Earnings During PM (Naira)
0.25	78.66	3,201.75	4,032,000
0.27	84.84	3,543.99	3,744,000
0.29	90.6	3,867.92	3,492,000
0.31	96.11	4,182.27	3,312,000
0.33	101.5	4,493.80	3,132,000
0.35	107.75	4,859.78	2,952,000
0.37	113.81	5,219.26	2,772,000
0.39	119.61	5,567.40	2,664,000
0.41	125.18	5,905.34	2,520,000
0.43	131.58	6,297.81	2,412,000
0.45	138.69	6,738.84	2,304,000
0.47	145.46	7,163.50	2,196,000
0.49	151.91	7,572.20	2,088,000
0.51	158.94	8,022.05	2,016,000
0.53	166.45	8,507.49	1,908,000
0.55	173.58	8,972.87	1,836,000
0.57	181.83	9,516.62	1,764,000
0.59	189.63	10,035.73	1,692,000
0.61	193.7	10,308.47	1,656,000
0.63	206.66	11,185.25	1,548,000
0.65	215.78	11,809.53	1,476,000
0.67	225.36	12,471.52	1,404,000
0.69	235.43	13,174.00	1,368,000
0.71	246.08	13,924.09	1,296,000
0.73	257.38	14,727.69	1,260,000
0.75	269.42	15,592.36	1,188,000
0.77	282.35	16,530.31	1,152,000

0.79	296.3	17,552.70	1,080,000
0.81	311.49	18,677.84	1,044,000
0.83	328.18	19,927.78	972,000
0.85	346.75	21,334.67	936,000
0.87	367.72	22,942.94	864,000
0.89	391.89	24,821.17	828,000
0.91	420.49	27,075.86	756,000
0.93	455.74	29,900.14	720,000
0.95	502.05	33,681.76	648,000
0.97	570.67	39,422.03	576,000
0.99	715.47	52,009.02	468,000

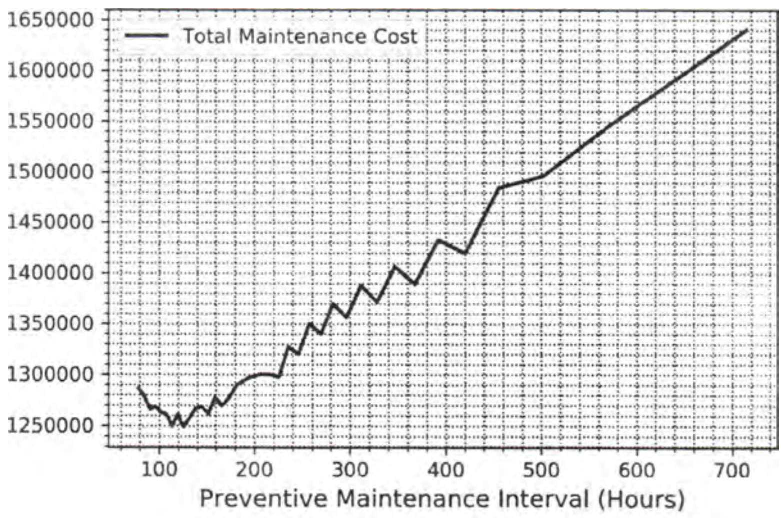

Fig 1: Graph showing the relationship between Total Maintenance Cost and Preventive Maintenance Interval with CM Lost Earning Consideration.

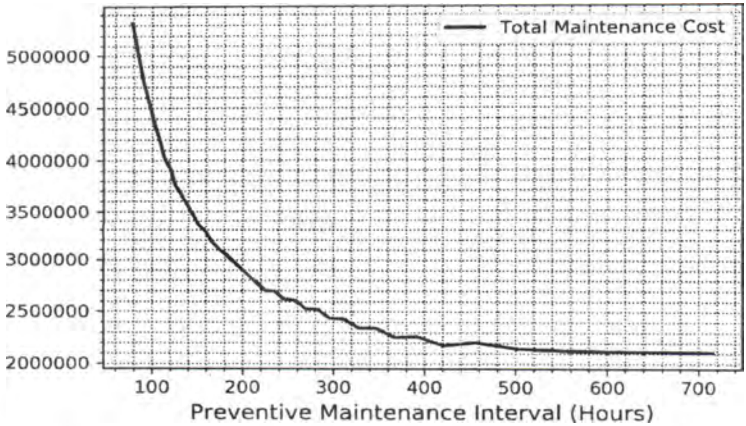

Fig 2: Graph showing the relationship between Total Maintenance Cost and Preventive Maintenance Interval with CM and PM Lost Earning Consideration.

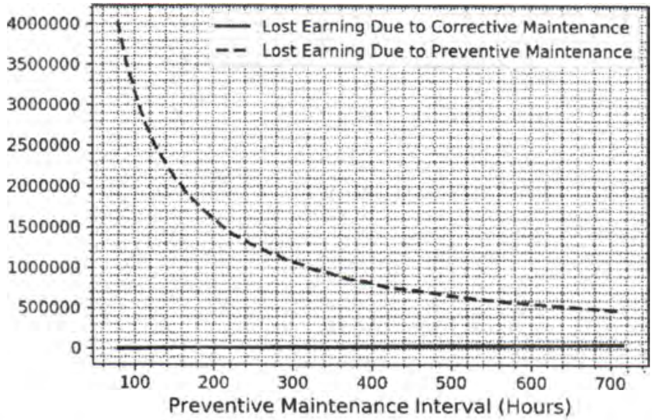

Fig 3: Graph showing the relationship between Lost Earnings During CM and PM and Preventive Maintenance Interval.

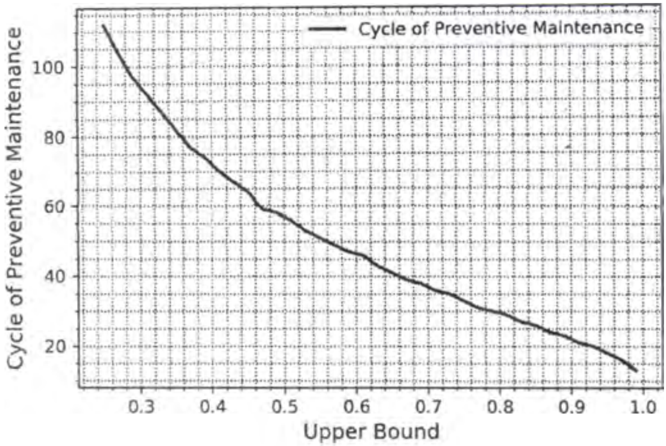

Fig 4: Graph showing the relationship between the Cycle of Preventive Maintenance in a Planning Horizon with the Upper Bound

5. Discussion

The numerical examples 1 and 2 showcase the step to step approach of the algorithm.In example one, the preventive maintenance interval t_{PM} is computed as$70.66\,Hours$. However, when the average time for executing the preventive maintenance activities is considered, then $D_T + t_{PM}$is $78.66\,Hours$. The corresponding total cost of maintenance in a year with the predicted preventive maintenance interval is $1{,}286{,}365.92\,Naira$.

In the case of the numerical example two, the computed preventive maintenance interval t_{PM} appears to be the same preventive maintenance activities is considered, and then$D_T + t_{PM}$is $78.66\,Hours$. The corresponding total cost of maintenance in a year with the predicted preventive maintenance interval is $5{,}318{,}365.92\,Naira$ while the machine will undergo preventive maintenance during the planning horizon for $n = 112$ times. This result shows that lost earnings due to preventive maintenance increase the cost incurred by manufacturing firms.

The resultsfrom the subsequent analysis with the Upper Bound of $F(t_{PM})$ being set at 0.27 and above are presented in Tables 1-3 and Figures 1-4.In Table 2, the work first considered the lost earnings due to corrective maintenance among other cost factors. The results show a minimum Total Maintenance Cost *TC* of 1,248,719.77 Naira at which preventive maintenance can be performed. The optimum preventive maintenance interval at this minimum cost is 125.18 Hours. Considering the estimated optimal preventive maintenance in Table 2, the cycle of preventive maintenance within the planning horizon of a year is 70.

Table 3 and Figure 2shows the result for lost earning during preventive maintenance alongside the lost earning during corrective maintenance. As presented, it was observed that there is an increase in preventive maintenance interval when the Total Maintenance Cost (TC) decreases. That is, an inverse relationship exists between the preventive maintenance interval and the Total Maintenance Cost when the lost earnings due to preventive maintenance actions were considered. While, the manufacturing firm losses a specific amount of money during the period of the preventive maintenance, the result suggests that lost earning during the period of executing preventive maintenance should be considered as a planned loss. However, if the decision-maker tries to save the preventive maintenance hours for production, the result shows that the machine reliability will be affected. The machine failure rate would increase as seen in Table 3 and could reduce the useful life of the machine.

Comparing the cost incurred due to corrective and preventive maintenance as presented in Table 4 and Figure 3, we observed an increasing lost earning as a result of corrective maintenance. Meanwhile, when the preventive maintenance interval increases, the lost earning due to preventive maintenance decreases. This implies that the wider the preventive maintenance interval, the more the lost earning that could be incurred as a result of the loss of production time. Although there is a notable decrease in lost earning due to preventive maintenance while the lost earning due to corrective maintenance increases, the result didn't justify economic savingsif the PM is ignored. This is because a decrease in lost earning during preventive maintenance shows an increase in failure probability and thus making the machine reliability to be very low.

6. Conclusion

The application of a cost-based approach to predict the preventive maintenance interval in a manufacturing firm has been demonstrated and this has revealed the applicability of the model. The identification of some cost factors including the lost earning due to corrective maintenance and preventive maintenance in determining the total maintenance cost for a production cycle has helped to capture the necessary costs that are incurred during maintenance. Also, we have been able to demonstrate the impact lost earnings could have on the determination of the optimal preventive maintenance interval and how each lost earning factors influences. Thus, this showsthe real-life situation and can serve as a quality decision support system for the maintenance team.

7. References

Adebimpe, O.A (2014). Spare Parts Inventory and Lost Earning Based Preventive Maintenance Interval Predicting Model. *MSc project, Unpublished, Department of Industrial and Production Engineering, University of Ibadan, Nigeria.*

Adebimpe, O.A., Oladokun, V.O. & Charles-Owaba, O.E. (2015). Preventive Maintenance Interval Prediction: a Spare Parts Inventory Cost and Lost Earning Based Model. *Engineering, Technology & Applied Science Research, 5(3):* 811-817.

Alaswad, S. & Xiang, Y. (2017). A review on condition-based maintenance optimization models for stochastically deteriorating system. *Reliability Engineering & System Safety, 157*, 54-63.

Angius, A., Colledani, M., Silipo, L., &Yemane, A. (2016).Impact of preventive maintenance on the service level of multi-stage manufacturing systems with degrading machines. *IFAC-PapersOnLine*, *49*(12), 568-573.

Avontuur, T. (2017) Maintenance optimization of process rolls with an application to electrolytic tinning lines. PhD thesis, University of Technology Eindhoven, Netherland.

Basri, E. I., Razak, I. H. A., Ab-Samat, H., &Kamaruddin, S. (2017). Preventive maintenance (PM) planning: a review. *Journal of Quality in Maintenance Engineering*.

Bjorklund, S., Pribytkova, M. &Karaulova, T. (2010).Development the maintenance plan: maintenance activities on operational level, *7th International DAAAM Baltic Conference, Industrial Engineering, Tallinn*, 22-24 April

Bottazzi, A., Dubi, A., Gandini, A., Goldfeld, A., Righini, R. & Simonot, H. (1992). Improving the preventive maintenanceof a bus yard by a Monte Carlo simulation method. *Safety and Reliability*, 883-895.

Castro, I.T. (2009). A model of imperfect preventive maintenance with dependent failure modes, *European Journal of Operational Research Vol. 196, No. 1*, 217–224.

Chareonsuk C., Nagarur N. & Tabucanon M.T. (1997). A multicriteria approach to the selection of preventive maintenance interval. *International Journal of Production Economics*.

Das, K., Lashkari, R.S. &Sengupta, S. (2007). Machine reliability and preventive maintenance planning for cellular manufacturing systems.*European Journal of Operations Research Vol. 183,* No. 1, pp. 162-180.

Dhillon, B. S. (2006). *Maintainability, maintenance, and reliability for engineers.*CRC press.

Jardine, A. & Tsang, A. (2013) Maintenance, replacement and reliability: Theory and Applications. Second. London: Taylor & Francis Group; doi:10.1017/CBO9781107415324.004.

Murthy, D.N.P., Atrens, A. &Eccleston, J.A. (2002).Strategic maintenance management, *Journal of Quality in Maintenance Engineering*, Vol. 8 No. 4, pp. 287-305.

Ojeih, G.V. (2012) Development of a combined opportunity cost and reliability model for preventive maintenance interval determination, *MSc project, unpublished, Department of Industrial and Production Engineering, University of Ibadan, Nigeria.*

Paz, N.M & Leigh, W. (1994) Maintenance scheduling: issues, results and research needs. *International Journal of Operations and Production Management*, 14:47.

Percy, D.F., Kobbacy, K.A.H. & Ascher, H.E. (1998). Using proportional intensities models to schedule preventive maintenance intervals. *IMA Journal of Mathematics Applied in Business and Industry Vol 9*, 289-302.

Peters, R.A.M (2018). Increasing availability byoptimizing maintenance.Department of Industrial Engineering & Innovation SciencesOperation Management & Logistics,University of Technology Eindhoven, Netherland.

Reason, J. (2000), Cognitive Engineering in Aviation Domain, Lawrence Erlbaum Associates, Mahwah, NJ.

Sharma, R.K., Kumar, D. & Kumar, P. (2005). FLM to select suitable maintenance strategy in process industries using MISO model. *International Journal of Quality in Maintenance.*

Sim, S.H. & Endrenyi, J. (1988). Optimal preventive maintenance with repair. In *IEEE Transactions on reliability Vol 37*, 92-96.

Simões, J.M., Gomes, C.F. &Yasin, M.M. (2011).A literature review of maintenance performance measurement: a conceptual framework and directions for future research, *Journal of Quality in Maintenance Engineering*, Vol. 17 No. 2, pp. 116-137.

Sobamowo, M.G., Ismail, S.O., Ojolo, S.J. & Adebayo, A.A. (2012). Optimal Preventive Maintenance Models for Steam Turbines: A Case Study of Egbin Thermal Station, Lagos, Nigeria. *International Journal of Mechanical Computational and Manufacturing Research, Volume I pp* 6-11.

Swanson, L. (2001). Linking maintenance strategies to performance, *International Journal of Production Economics*, Vol. 70 No. 3, pp. 237-244

Taboada, H.A., Espiritu, J.F. & Coit, D.W. (2008). MOMS-GA: A multi-objective multi-state genetic algorithm for system reliability optimization design problems. *IEEE Transactions on reliability*, Vol 57.

Vilarinho, S., Lopes, I., & Oliveira, J.A. (2017). Preventive maintenance decisions through maintenance optimization models: a case study. *Procedia Manufacturing*, *11*, 1170-1177.

Kardon, B. &Fredendall, L.D.(2002).Incorporating overall probability of system failure into a preventive maintenance model for a serialsystem.*Journal of Quality in Maintenance Engineering 8 (4),* 331–345.

Wang, H. & Pham, H. (2006). Availability and Maintenance of Series Systems Subject to Imperfect Repair and Correlated Failure and Repair. *European Journal of Operational Research, 174*, 1706-1722.

Zequeira, R.I.&Bérenguer, C. (2006).Optimal scheduling of non-perfect inspections. *IMA Journal of Management Mathematics*, *17*(2), 187-207.

CHAPTER 17

Supply Chain Modelling: A Discrete Event Approach

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Abstract

The present world direction in automating everything has effect on barely every sectors including the logistic section of an industry. However, many company are still lacking behind with the use of low level description in regards to their global Supply Chain Network (SCN). In this work, an agent-based model is developed for modelling supply chain risk management (SCM) with focus on price and demand variation are the considered emerging properties of all the agents interaction. Agent-based Modelling (ABM) has been used extensively as a promising computational tool that depicts entities with autonomy and dynamic behaviour. The supply chain network consists of different agents e.g. manufacturers, inventory policy, retailers, transporters, etc. Réseau.py, built in Python modelling environment was used for the computational development. Based on the agent's autonomy and their respective objectives, simulations of supply chain network were carried out to investigate price variation effect among the agents. The results show that fluctuation in price is an established factor to be consider among agent's interaction in the SCN.

Keywords: Supply Chain Network, Supply Chain Management, Agent-based Modelling, Python.

1.0 Introduction

A supply chain can be defined as a network of autonomous or semiautonomous business entities collectively responsible for moving a product or service from supplier to customer (Swaminathan et al., 1998). In order to achieve a reliable logistic network, a number of researchers have developed different models to describe units and activities of a supply chain (Ran et al., 2009). The present world direction in automating everything has effect on barely every sectors including the logistic section of an industry. However, many companies are still lagging behind in the use of low level description (Cohen & Lee, 2020) with regards to their global Supply Chain Network (SCN). Supply chain modelling methods that have been used for several periods are likely to be increasing company cost of operations, as they could be missing out on different opportunities. Missing out on different opportunities is likely due to unreliable model being used by the organisation.

Supply chain reliability means the likelihood of performing supply chain activities in accordance with plans and expectations. Preparation for demand adequately, reducing inventory, and increasing reliability top supply chain professionals agenda. There have been several approaches to model supply chain reliability by researchers; for example, control theory approach is based on operational research, and differential equations approach, which depends on algorithms and optimization theories (Yildiz, 2013). However there are few or no works on modelling the reliability of supply chain using discrete event simulation. In particular, the use of an agent-based modelling approach is limited. Based on the gaps highlighted, there are still many research opportunities that can be pursue in the complex adaptive system of interactions of the individual agents within supply chain network.

Agent-based Modelling (ABM) has been used extensively as a promising computational tool (Borshchev & Filippov, 2004a, 2004b) to model supply chain reliability with features like uncertainty, partial information sharing, and dynamics (Long & Zhang, 2014). ABM, an agent-oriented approach to model and simulate complex adaptive systems, depicts a new development in supply chain area of research that has been regarded adequate for studying supply chain management (Chen et al., 2013). In order to bridge the research gap in literature, this work focuses on the use of ABM for modelling supply chain reliability in order to unravel the complexity of supply chain system. We analyse supply chain complex adaptive attributes considering energy flows, materials, and the related demand-supply match for each output products (by-products, useful waste and finished goods) and also simulate the effect of supply and demand, and price variations to depict how ABM is a promising tool in modelling supply chain reliability.

The remainder of this work is structured as follows. Section 2 presents works related to modelling supply chain management as well as the gaps that exists in this research area. Section 3 to 4 is.an overview of the modelling method (ABM) as well as how it can benefit supply chain management and the model description. Section 5 gives a numerical example to the problem and Section 6 gives the conclusion.

2.0 Literature Review

Increasingly, companies are viewing reliability problems as part of their organization goal to improve their daily operations. Most industries continues to reduce lead time, attain Just-in-Time delivery and lower inventories. An insightful research such can be found in (Bernstein &

Federgruen, 2005; Lee & Billington, 1993; Perakis & Roels, 2007) showing current direction supply chain management practices.

Moving beyond that and toward high performance level, is not possible without reliable equipment, processes, and people. All the elements (people, equipment, tasks etc.) must be reliable to give higher percentage of reliable supply-chain process. From a supply chain management view, the goal is to improve lead-time each step of the supply chain tasks. Just as this is important is also to know the ability of how products will last long, while the aim is to achieve maximum return on investment (ROI) from management perspective.

Recently, researchers have carried different studies on the complexity of supply chain management using couple of evolutionary approaches. Some of these works can be found in (Isik, 2011; Perona & Miragliotta, 2004; Wilding, 1998) to mention few of these papers.

Agent-based modelling (ABM) has been used extensively as a promising computational tool that depicts entities with autonomy and dynamic behaviour (Kuhn et al., 2010). ABM is being used in science, social science, and other fields like engineering. It involves simulating the interaction the behaviour of many autonomous agents or entities over time (Ghali et al., 2017). ABM is also known as bottom-up (Albino et al., 2016) approach method.

ABM look promising and useful tool that can be use to model large scale system (Kogler & Rauch, 2020), by incorporating the system with corresponding rules with assumptions that is most relevant within the supply chain network, the interaction among the agents, and possible emerging behaviour from the agents' interactions.

(Tah, 2005) used ABM to simulate the emergence of industrial network focusing on modelling and simulation platform, which provide a risk-free environment and low cost for organisations to experiment with emerging SCM practices prior to implementation. In addition to their work, a prototype system was developed to explore the possibility of modelling and simulation of project procurement using multi-agent. They were able to conclude that multi-agent approach in modelling SCM is adequate for the simulation of supply chain network construction. Kim *et al.*(2012) developed an ABM method for end product exchange network between sellers and buyers in an industrial network. Their proposed solution method has limitations because setting off was not investigated. Yazan *et al.*(2016) approach modelling industrial networks with the aid of enterprise input-output for the design and simulation of a reliable supply chain network. However, their results were static and therefore not reflecting real life situation. (Abideen & Mohamad, 2020) work focus on dynamic quantification and visualization of the future state of a warehouse supply chain value stream map using discrete event simulation (DES) technique. The DES simulation was able to mimic the future state lead time reductions successfully.

In this work, the focus is on using a descriptive event approach called agent-based model to model supply chain risk management (SCRM) reliability with focus on price and demand variation. We analyse supply chain complex adaptive attributes considering energy flows, materials, and the related demand-supply match for each output products (by-products, useful waste and finished goods) and also simulate the effect of supply and demand, and price variations to depict how ABM is a promising tool in modelling supply chain reliability.

3.0 Réseau-SCM Agent-Based Model

There are many approaches of simulating a complex system and one of the applicable methods is through agent-based modelling (ABM). ABM is extensively used within complexity theory and springs from object-oriented programming and distributed artificial intelligence. The agent formulations used in this work extend on the basic formulation by (Ajisegiri, 2019). The model was named Réseau, which means a network. The Overview, Design Concepts and Details (ODD) protocol proposed by (Grimm et al., 2010) is used for its description. It was designed so that ABM publications would be more complete, quick and easy to understand, and organized in a manner that allows for presenting information in a consistent order (Grimm et al., 2010). The details of ODD adaptation in Réseau can be found in the extra supplement information (ESI) section. The model is an integrated agent-based model and input-output approach and was developed using Python platform, which is a general-purpose programming language.

Simulation Flow

The logic flow of Réseau agent-based model for the problem identified above is described below. The logic flow is divided into four distinct heading and the high level of how the mode runs is explained below for each of the header.

System logic flow

- Initialised agents
- Load all agent parameters from external file

Begin trading

Step 1

- Randomise all agents in the list
- Agents produce
- Agents predict requirements

Step 2

- Randomise all buyers
- Each buyer checks all sellers and complete transaction

Step 3

- Randomise all sellers
- Each seller checks all buyers and complete transaction

Step 4

- The histories are collated and stored

Step 5

- Each agent records its transaction in an external file

Seller logic flow
Step 1 – Production

- The production quantity for each product is assumed equivalent to the production quantity.

Step 2 - Predict requirement

For each product:

- Product sales quantity SQ_i is asummed to follow Gaussian distribution with mean, μ and sigma, σ.

For each product

- Check history and get average price in the market over 10 periods
- If condition is random: product price p_i is asummed to follow Gaussian distribution with mean, μ and sigma, σ.
    - If condition is risk based and average price equal zero: delta p equal p_i
    - If condition is risk based: get product price

Step 3 – Sell product

- Create an empty list to append buyers
- For each product, if the storage capacity is less than sales quantity
    - Randomize all the buyers
    - For buyer in buyers list: make deal for each product
    - If deal is valid
    - Append buyer in the list of deals
    - Sort the deal based on highest price: Initiaiize the count n = 0
    - While the sales quantity is greater than storage capacity and n is Less than length of the deals list: execute trading and increase n by 1

Buyer logic flow
Step 1 - Production

For each raw material: If list of raw material equal empty then raw material quantity equal zero

Step 2 - Predict requirement

- The raw material demand Di is asummed to follow Gaussian distribution with mean, μ and sigma, σ.

Step 3 – Buy raw material

- Create an empty list to append sellers
- For each raw material, randomize all the sellers
- For seller in sellers list, make deal for each raw material. If deal is valid, append seller in the list of deals and then sort the deal based on lowest price
- Initialize the count n = 0. While raw material demand is greater than zero and n is less than length of the deals list then execute trading and increase n by 1

Factory logic flow
Step 1 - Production

- For each raw material obtain

$$PC = minimum(\frac{RMQ}{RMU}, RMC) \quad (2)$$

- For each raw material obtain

$$RMQ_i = RMQ_i - PC \times RMU_i \quad (3)$$

- For each raw material

$$SQ_i = SQ_i + PC \times PU_i \quad (4)$$

$$PQ = SQ \quad (5)$$

Step 2 - Predict requirement

Total capacity C is asummed to follow Gaussian distribution with mean (μ) and sigma (σ).

- For each product sales quantity

$$SQ_i = SQ_i + C \times PU_i \quad (7)$$

- For each raw material demand

$$RD_i = C \times RMU_i \times SQ_i - RMQ_i \quad (8)$$

- For each product
  - Check history and get average price in the market over 10 periods
  - If condition is random
    - Product price p_i is assumed to follow Gaussian distribution with mean, μ and sigma, σ.
    - If condition is risk based and average price equal zero
    - Delta p equal p_i
  - If condition is risk based
    - Get product price

Step 3 – Buy raw material

- Create an empty list to append sellers
- For each raw material, randomize all the sellers.
- For seller in sellers list: make deal for each raw material
- If deal is valid, append seller in the list of deals and sort the deal based on lowest price.
- Initialize the count n = 0. While raw material demand is greater than zero and n is less than length of the deals list then execute trading and increase n by 1

Where PC is production capacity, RMQ is all raw material quantity, RMU is all raw material usage, RMC is all raw material capacity, RMQ_i is each raw material quantity, RMU_i is each raw material usage, RD_i is each raw material demand, SQ_i is each sales quantity, PU is product usage, PQ all product quantity and SQ all sales quantity.

4.0 Numerical example

To demonstrate the effectiveness of the proposed methodology and gain some managerial insights a case study is conducted for only one input-output factory type. We believe that if a single input-output system works perfect for the model, it will surely represent a multiple input multiple output system which is a representation of a real problem. Sensitivity analysis is further conducted to provide deep understanding of the proposed hypothetical SCM system. The proposed structure of the SCM system studied in this work is shown in Figure 1.

The factories consist of three combined heat and power plant (CHP) differentiated by their unique identifier, CHP1, CHP2, CHP3. The CHP's main raw material input is biogas apart from other input which are not included in this simulation. This demonstration is strictly for single input-output scenario. The CHP's main output is electricity. The other made up industries/factories are, anaerobic digester (AD), that is, AD1, AD2 and AD3. The anaerobic digester uses electricity as its main raw material input to generate biogas. The SCM system is made up of six different industries/factories with the possibility of transacting business among themselves. Each of the industries/factories can also make possible connection with external environment if external agent supplier's price is favourable compare to any of the factory agents. Apart from the factories, the SCM also contains three infinite sink agents (market buyers B1, B2 and B3) that willing to buy from the source agents at a considerable price and also infinite sink agents (market sellers, S1, S2 and S3). The infinite market agent either buys or sells directly from/to the factory agents.

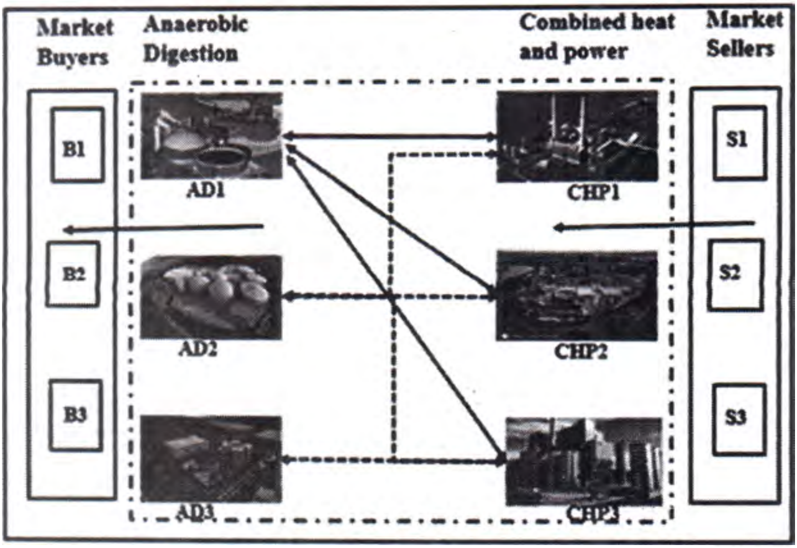

Figure 1: Hypothetical supply chain management (SCM) of energy based system.

The initial data for the anaerobic digestion and combined heat and power plants were obtained from (Gonela & Zhang, 2014). The three CHP plants separately have demand capacity for biogas (methane) ranging from 80,000 – 500,000 cubic meter per month while the AD plants utilizes food and bio-solid wastes in the range of 0.3 million tons and required energy within 30 – 65 megawatt.

Simulation results and discussion

Based on the numerical example described above, a single simulation run was carried out and the results is as shown in Figure 2 – 3. The supply and demand evolution of the three CHP's are shown in Figure 2. It should be noted that a time period of one month stand for one simulation cycle. This was found to be enough to give a stable final configuration. It can be seen that CHP2 has a higher demand evolution with average value around 480,000 cubic meter per month. CHP3 demand for biogas is the lowest. CHP1 has a demand in between the value of CHP2 and CHP3. This is understandable based on the demand capacity of each of the three combined heat and power plant. However, Figure 3 shows the electricity demand on monthly basis by the AD plants. AD2 has the highest demand on monthly basis. AD1 has the lowest. The demand by each plant is based on their demand capacity. From these results, it can be established that price variation over a period of time is a determinant that need to be consider in modelling of supply chain risk management.

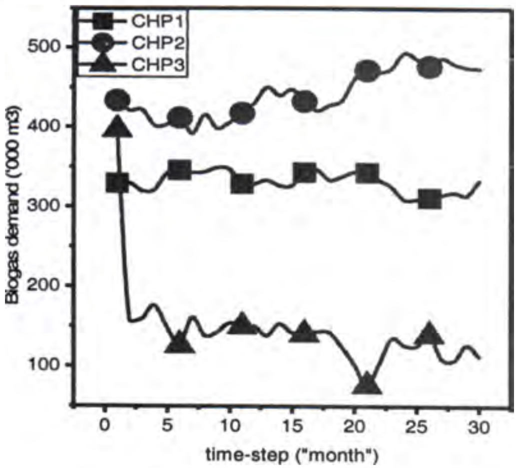

Figure 2: Biogas demand/month for CHP plants.

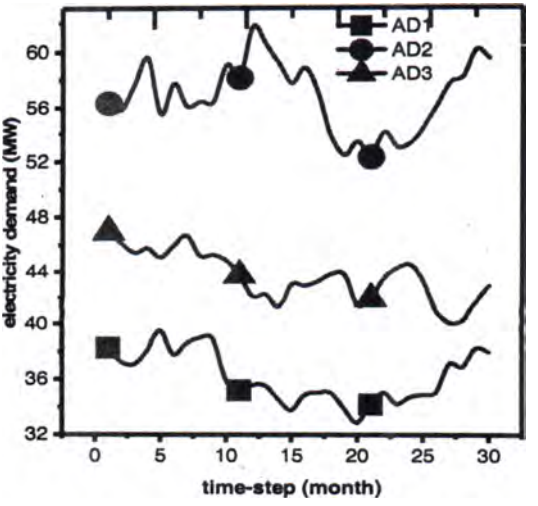

Figure 3: Electricity Demand/month for AD plants.

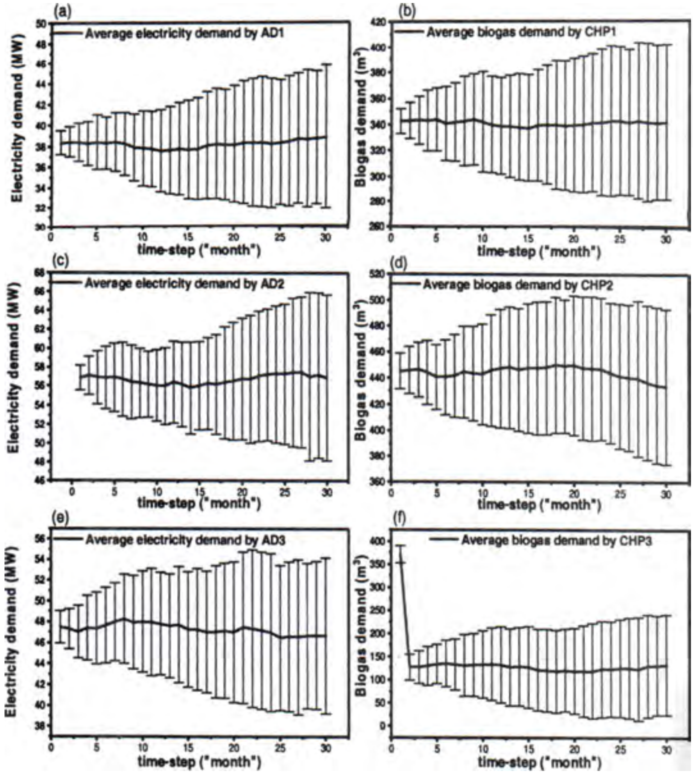

Figure 4: Average demand and mean error over 30 time-steps.

Figure 4 (b), (d) and (f) show the average biogas demand. It can be seen that the demand for biogas by CHP1 with a mean of 340,000 cubic meter and standard deviation (SD) of 40. CHP2 has an average demand of 440,000 cubic meter and SD of 50 while CHP3 has an average demand of 120,000 cubic meter and SD of 60 cubic meter.

A single run simulation for the evolution of price are as shown in Figure 5– 6. The price of electricity sales per month for each CHP plant is as shown in Figure 5. It can be seen in the figure that the CHP with lowest average price per step is CHP2 and its price dominate the other two CHP's. On the part of the AD factories, Figure 6 indicate that the sales price of biogas per month. In the same vein, AD2 has the best price and that dictates why it dominates the transaction in the SCM. From these results, it can be established that price variation over a period of time is a determinant that needs to be considered in the modelling of supply chain risk management.

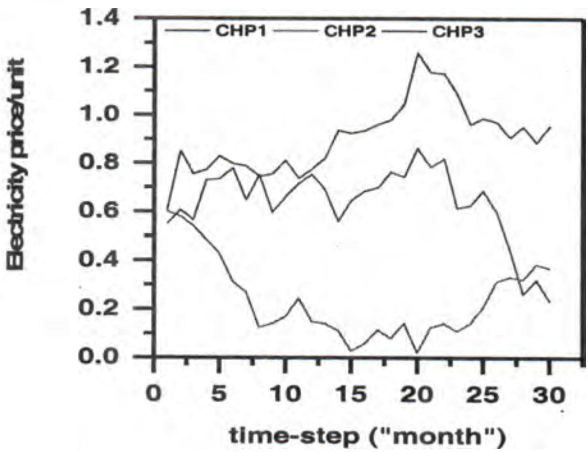

Figure 5: Price/Unit of Electricity

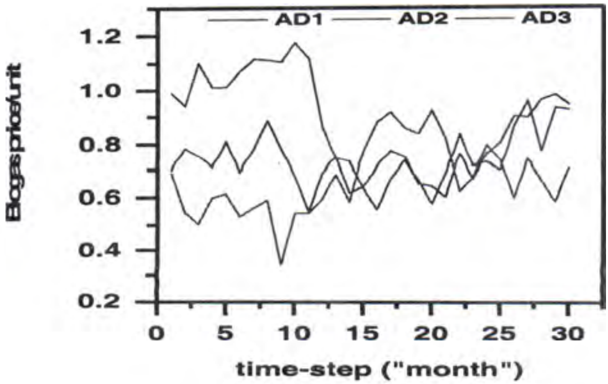

Figure 6: Price/Unit of Electricity.

5.0 Conclusion

In this work, supply chain risk management reliability with focus on price and demand variation are the considered emerging properties of all the agents' interaction. A hypothetical SCM of six different process plants acting as market sellers and buyers were developed. The source agents sell to the sink agent based on the lowest price at any period. Results revealed that ABM is a promising computational tool for modelling and simulating periodic supply and demand. It was determined that variation in price is one of the deciding elements in modelling reliability of supply chain risk management. Future research needs to investigate the effect of setting price by each agent and their sum effect on the entire network.

References

Abideen, A., & Mohamad, F. B. (2020). Improving the performance of a Malaysian pharmaceutical warehouse supply chain by integrating value stream mapping and discrete event simulation. *Journal of*

Modelling in Management. https://doi.org/10.1108/JM2-07-2019-0159

Ajisegiri, G. O. (2019). *Application of an Agent Based Model to Study the Resource Exchanges within Eco-industrial Parks* (Issue 680843) [PhD Thesis, University of Leeds, United Kingdom]. https://doi.org/10.5220/0006836300830090

Albino, V., Fraccascia, L., & Giannoccaro, I. (2016). Exploring the role of contracts to support the emergence of self-organized industrial symbiosis networks: an agent-based simulation study. *Journal of Cleaner Production*, *112*, 4353–4366.

Bernstein, F., & Federgruen, A. (2005). Decentralized supply chains with competing retailers under demand uncertainty. *Management Science*. https://doi.org/10.1287/mnsc.1040.0218

Borshchev, A., & Filippov, A. (2004a). From System Dynamics to Agent Based Modeling. *Simulation*, *66*(11), 25–29. http://www.econ.iastate.edu/tesfatsi/systemdyndiscreteeventabmcompared.borshchevfilippov04.pdf

Borshchev, A., & Filippov, A. (2004b). From system dynamics and discrete event to practical agent based modeling: reasons, techniques, tools. *Proceedings of the 22nd International Conference of the System Dynamics Society*, 22.

Chen, X., Ong, Y. S., Tan, P. S., Zhang, N. S., & Li, Z. (2013). Agent-based modeling and simulation for supply chain risk management - A survey of the state-ofthe- Art. *Proceedings - 2013 IEEE International Conference on Systems, Man, and Cybernetics, SMC 2013*. https://doi.org/10.1109/SMC.2013.224

Cohen, M. A., & Lee, H. L. (2020). Designing the right global supply chain network. *Manufacturing and Service Operations Management*. https://doi.org/10.1287/msom.2019.0839

Ghali, M. R., Frayret, J.-M., & Ahabchane, C. (2017). *Agent-Based Model of Self-Organized Industrial Symbiosis*. internal-pdf://176.250.215.114/1-s2.0-S0959652617310685-main.pdf

Gonela, V., & Zhang, J. (2014). Design of the optimal industrial symbiosis system to improve bioethanol production. *Journal of Cleaner Production*, *64*, 513–534. https://doi.org/10.1016/j.jclepro.2013.07.059

Grimm, V., Berger, U., DeAngelis, D. L., Polhill, J. G., Giske, J., & Railsback, S. F. (2010). The ODD protocol: A review and first update. *Ecological Modelling*, *221*(23), 2760–2768. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2010.08.019

Isik, F. (2011). Complexity in Supply Chains: A New Approachto Quantitative Measurement of the Supply-Chain-Complexity. In *Supply Chain Management*. https://doi.org/10.5772/15005

Kim, H., Ryu, J., & Lee, I.-B. (2012). Development of an agent-based modeling methodology for an industrial byproduct exchange network design. *Industrial & Engineering Chemistry Research*, *51*(33), 10860–10868.

Kogler, C., & Rauch, P. (2020). Contingency plans for thewood supply chain based on bottleneck and queuing time analyses of a discrete event simulation. *Forests*. https://doi.org/10.3390/F11040396

Kuhn, J. R., Courtney, J. F., Morris, B., & Tatara, E. R. (2010). Agent-based analysis and simulation of the consumer airline market share for Frontier Airlines. *Knowledge-Based Systems*, *23*(8), 875–882.

Lee, H. L., & Billington, C. (1993). Material management in decentralized supply chains. *Operations Research*. https://doi.org/10.1287/opre.41.5.835

Long, Q., & Zhang, W. (2014). An integrated framework for agent based inventory-production-transportation modeling and distributed simulation of supply chains. *Information Sciences*. https://doi.org/10.1016/j.ins.2014.02.147

Perakis, G., & Roels, G. (2007). The price of anarchy in supply chains:

Quantifying the efficiency of price-only contracts. *Management Science*. https://doi.org/10.1287/mnsc.1060.0656

Perona, M., & Miragliotta, G. (2004). Complexity management and supply chain performance assessment. A field study and a conceptual framework. *International Journal of Production Economics*. https://doi.org/10.1016/S0925-5273(02)00482-6

Ran, L., Jia, X., & Tian, R. (2009). Modeling and analyzing supply chain reliability by different effects of failure nodes. *2009 International Conference on Information Management, Innovation Management and Industrial Engineering, ICIII 2009*. https://doi.org/10.1109/ICIII.2009.555

Swaminathan, J. M., Smith, S. F., & Sadeh, N. M. (1998). Modeling Supply Chain Dynamics: A Multiagent Approach. *Decision Sciences*, *29*(3), 607–632. https://doi.org/10.1111/j.1540-5915.1998.tb01356.x

Tah, J. H. M. (2005). Towards an agent-based construction supply network modelling and simulation platform. *Automation in Construction*. https://doi.org/10.1016/j.autcon.2004.08.003

Wilding, R. (1998). The supply chain complexity triangle: Uncertainty generation in the supply chain. *International Journal of Physical Distribution & Logistics Management*. https://doi.org/10.1108/09600039810247524

Yazan, D. M., Romano, V. A., & Albino, V. (2016). The design of industrial symbiosis: an input–output approach. *Journal of Cleaner Production*, *129*, 537–547. https://doi.org/https://doi.org/10.1016/j.jclepro.2016.03.160

Yildiz, A. R. (2013). A new hybrid differential evolution algorithm for the selection of optimal machining parameters in milling operations. *Applied Soft Computing Journal*. https://doi.org/10.1016/j.asoc.2011.12.016

CHAPTER 18

Evaluation Of Mechanical Strain Resulting From Working With Two Locally Fabricated Engine Powered Stationary Grain Thresher

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Abstract

In place of the combine harvesters, stationary grain threshers are the most common among the farmers in the developing countries, many are being produced locally to meet up with the local demands by the farmers which they find to be relatively cheap and affordable. To ascertain the level of their user friendliness, two threshers of heights 92 cm (M1) and 161.5 cm (M2) with capacities 3000kg/hr. and 6500kg/hr. respectively were selected for evaluation to determine the possible biomechanical strain that may result from working with these locally fabricated threshers. Questionnaire and physical measurements were employed for data collection of thirteen randomly selected operators, with ages ranged in-between 20 and 35 years. The results of machine performance tests showed that quantity threshed on average ± SD per minute are 12.59kg ± 2.41 (M1) and 20.38kg ± 3.84 (M2),corresponded to the mean (SD) of weight per lift of 1.75kg (0.44) and 2.06 (0.22), and mean; SD of frequency of lift/minute of 7lift/min;1.59 and 10lift/min;1.81. The body kinematics analysis showed flexion, extension, lateral deviation and abduction with respective highest mean values of 167.750 at kneel (M1), 111.500 at ankle (M1), 24.750 at neck (M2) and 72.000 at shoulder (M2) at the end of lift. Regression analysis of biomechanical parameters, and frequency of lift and weight per lift gave F-value of 425.987 (R2 =0.974), which shows no relationship at $\alpha = 0.01$. Subjects' indications of body parts discomforts showed highest percentages of 78.3%; 84.6% and 72.9%; 80.8% for M1; M2 at shoulder and lower back respectively. Conclusively, the overall result showed that the two machines need to be ergonomically modified to prevent the users from the risk of musculoskeletal disorder (MD).

Keywords: biomechanical strain, developing countries, ergonomics, local demands, operators, stationary grain thresher

1.0 Introduction

The industrialization of agriculture has introduced new equipment with little attention paid to ergonomic design. Most machinery turned out in the developing nations to meet the need of the farmers are products from artisans with little or no consideration to operators but the operations of the machinery. As many technological approaches in solving associated problem with manual operations in agriculture are on the increase, the need for application of ergonomics/ human factors in machinery development become indispensable. There are diverse forms of occupations carried out by men and women; hence, the risk of musculoskeletal injuries as a result of occupational vulnerabilities may vary by sex (Messing *et al.,* 2009). An ample of occupational risk factors existing in the course of working life are regarded to be detrimental to musculoskeletal health that resulted to various forms of musculoskeletal disorder diagnosis and eventually damages the physical functioning of workers in their latter lives (Prakash *et al.,* 2017)

The aim of this study is to evaluate the level of ergonomic factor consideration in the design and fabrication of locally manufactured agro-processing machinery and to determine biomechanical strains that may result through the performance evaluation of the selected grain threshers.

2.0 REVIEW OF LITERATURE

In contempt of the existing information on the corresponded work-related disorders in musculoskeletal systems, a profound number of occupations are still linked to poor working postures and awkward body movements in association with a heavy physical work load (Karla *et al.,* 2012). Competition and increased work demands have also increased farmer's exposure to risk factors through increased work pace and/or duration. In American, Mazza *et al.* (1997) recorded that of the thirteen most common agricultural health related problems reported by rural health care providers, heavy lifting was the most common exposure of patients, while repetitive motions was fourth.

External loads are given rise to in the physical work environment and are communicated through the biomechanical forces of the body, specifically the limbs and trunk, to produce intramural loads on tissues and bodily structures. Biomechanical variables include posture of the body, bodily strain, intensities and movements, as well as individual factors such as age, strength, agility and dexterity, and additional components that mediate in the transferal of outer loads to inside loads on bodily structures. Tissue injury may transpire when the applied load transcends the inner forbearance of the tissue and resulted to tissue irritation and pain, impairment or disability. As with most biomechanical systems, loading is influenced greatly by the external moment imposed on the system. However, because of biomechanical disadvantage at which the torso muscles operate relative to the trunk fulcrum during lifting, very large loads can be generated by the muscles and imposed on the spine (Marras, 2006).

In occupational setting human anatomy can be affected by traumas that lead to musculoskeletal disorders, these are; acute trauma (this can transpire when a single application of a force is so huge that it transcends the endurance limits of the body structure during occupational task) and cumulative trauma (this refers to repeated application of force to a structure that tends to wear down the structure, thus, lowering its tolerance to the point where it is exceeded through a reduction of this tolerance limit). The latter type of the trauma may of necessity common in the threshing of grain with stationary thresher, in that the process of manual loading of un-threshed grain into the threshing machine is more of repetitiveness. The repetitive application of force can affect either the tendons or the muscles of the body, the process which results in terrible joint discomfort and a chain of musculoskeletal reactions such as decrease strength, lower tendon movement, and decrease mobility. A disorder, as presented by musculoskeletal disorders, has a slow start as juxtaposed to an acute injury, which is as a result of a single distinguishable occurrence. A disorder is essentially arbitrated by some pathogen or pre-pathological progression (Kurmar, 2001).

Kasey *et al.* (2014) reported that musculoskeletal disorders are non-harmful soft tissue disorders, which may resulted from and/or heightened by workplace exertions. Sergey *et al.* (2017) presented that diverse forms of damage to the bones and soft tissues of the elbow joint are corresponded with particular postures of flexion and turning of the forearm on the elbow during injury. Mechanical degradation of tissue may occur due to exposure over time from mechanical stresses that are repetitive, prolonged or forceful. The expression "load" is habitually used to relate the physical stresses at work on the body and structures inside the body. These stresses comprise kinetic (force), kinematic (motion), oscillatory (vibration), and thermal (temperature) energy sources (Radwin *et al.,* 2001). Repetitive tendon motion is thought to promote shear damage at the tendon sub-synovial connective tissue (SSCT) interface, which is supported by the finding that fibrosis is exacerbated in SSCT layers adjacent to flexor tendon (Aaron *et al.,* 2014). Loads can originate from the external environment or result from action of the individual.

3.0 MATERIALS AND METHOD

Thirteen physically active subjects (11 males, 2 females, age = 24.8 ± 3.2 years, height = 173.91 ± 5.96 cm, weight = 63.38 ± 7.86 kg) volunteered as subjects. Individuals with self-reported health problems related to head injury in the recent past were excluded from the study. All subjects completed 3 iterative testing operations on the selected machine, during which sagittal-plane kinematics and lifting distances were recorded while they performed the threshing from the origin of the lift to the end of the lift, also, individual body temperature was taking before and after the

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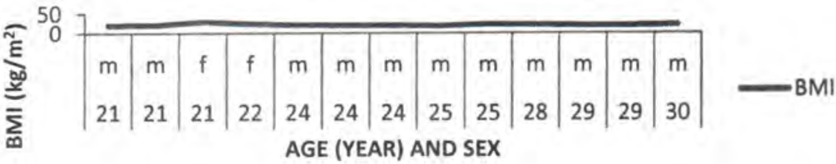

Fig. 1: age, sex and respective body mass indexes (BMI) of the subjects

4.2 Occupational Lifestyles of the Subjects

The occupational lifestyles of the subjects are; Farming, Mechanical work, Driving, Hawking, and Schooling. The percentages distribution are 23%, 15%, 8%, 15%, and 39% respectively as shown in figure 2. It can be deduced that energy requirements for this group of works ranges from 10KJ/min to more than 30KJ / min, from student through to farming (Rowett, 2008).

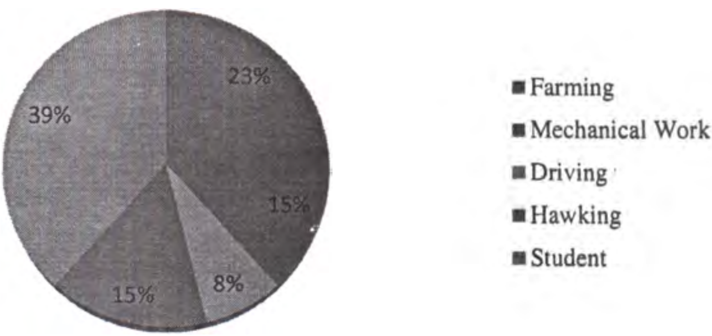

Fig 2: percentage of occupational description of the subjects

4.3 Relative Anthropometry Measurements for the Study

Table 1 shows the parameters that are essential in the process of threshing by stationary grain thresher. Mean (SD) of height/stature is 173.91 (5.96), and the subjects' weight ranged from 53kg to 78kg. Arm reaches can explain the degree of flexion and extension of the different parts of the body and it ranged from 69.5cm to 83.5cm; hand length and hand width explain gripping effect with mean ±standard deviations of .19.75cm ± 1.13 and 9.19cm ± 0.46; ankle height ranges from 8.3cm to 9.2cm with mean ±standard deviations of 0.31cm ± 8.71, these are indispensable as all joints play important roles in operations that involves dynamic movement of the body parts.

Table 1: Anthropometric data of the Subjects (cm)

Parameters Value	Mean	S.D	Min. Value	Max.
Height	173.91	5.96	165	186
Weight*	63.38	7.86	53	78
Arm Reach (Front)	77.04	4.14	69.5	83.5
Overhead Reach	203.88	21.09	139	223
Shoulder Height	142	12.9	106	159.5
Hand Length	19.75	1.13	18	21.2
Hand Width	9.19	0.46	8.7	10
Elbow Height	108.92	5.07	101	118
Shoulder Width	44.07	2.09	40.2	47
Leg Length	100.62	4.47	90	107
Lower Leg Length	50.42	4.29	43.5	58.5
Lower Arm Length	34.23	2.49	30.5	39
Arm Reach (From Floor)	73.85	3.92	68.5	80.5
Ankle Height	8.71	0.31	8.3	9.2

SD = standard deviation *kg

4.4 Determination of Frequency of Lift, Weight per Lift as Corresponded to Quantity Threshed on M1 And M2

The frequency of lift per minute and weight per lift together with quantity threshed per minute are as shown in the Table 2 in terms of their mean and standard deviations. Statistical analysis indicated that on the average, frequency of lift per minute (7 lift/ min ± 1.59 SD) while working with machine 1 is lesser compare to machine 2 which is 10lift/min ± 1.81 SD. In the same way, weight per lift and quantity threshed are 1.75kg ± 0.44 SD and 12.59kg ± 2.41 SD for M1, and 2.06kg ± 0.22 SD and 20.38kg ± 3.84 SD for M2. These results attested to the machines capacities and efficiencies (Table 2).

Table 2: Frequency of Lift per Minute, Weight per Lift, and Quantity

Parameters		Machine 1	Machine 2
Frequency of lift	Mean	7.00	10.00
per minute (lift/min)	S D	1.59	1.81
Weight per lift (Kg/Lift)	Mean	1.75	2.06
	S D	0.44	0.22
Quantity Threshed	Mean	12.59	20.38
per minute (Kg/min)	S D	2.41	3.84

Shelled Per Minute

S D = standard deviations N = 13

Replication = 3

4.5 Indication of Body Discomforts before and after Operations on M1 and M2 by the Subjects

Table 3 gives details about the expressed opinions of the subjects regarding body parts discomforts experienced before and as a result of threshing grain with stationary threshers. Before evaluation it was discovered that 61.5% of the subjects has no body discomforts, 15.4% has shoulder and neck pains with lowest percentage of 7.7% for low-back and wrist as shown in Table 3.

The two machines were said to have produced some level of discomforts by all subjects. When interviewed about the severity of the pain, the subjects commented on how the pain was moderate before commencing shelling and more severe afterwards. Comparing all types of body discomforts, working with machine 2 (M2) proved to be more unfit ergonomically in that it has greater percentages except on wrist where percentages for M1 is 31.2 and 30.8 for M2. Shoulder strain has lesser percentage of body discomfort for M1, 78.3% compare to 84.6% for M2, while upper leg and ankle have the least percentage of 6.0% and 7.7% respectively for M1 and M2 (Table 3).

4.6 Analysis of the Degree of Variations from Neutral Position while working with M1 and M2

The posture adopted to operate the M1 and M2 may have resulted in pain or discomfort over much of the body since they involved considerable spinal flexion (Table 4). This was particularly observed with the subjects at initiation of lift in stooping posture and the termination of lift. Results from the measured angles of variation from the neutral position during the evaluation of M1 and M2 suggested that this subsequently resulted in an increase in the incidence of pain or discomfort in most body parts.

Table 3: Subjects' Indication of Body Parts Discomfort

S/N	Body Discomforts	Percentage of Subjects Affected		
			After Evaluation (%)	
		Before Evaluation (%)	M1	M2
1	Lower Back	7.7	72.9	80.8
2	Shoulder	15.4	78.3	84.6
3	Wrist	7.7	31.2	30.8
4	Forearm	nill	14.1	15.4
5	Neck	15.4	9.8	11.5
6	Upper Leg	nill	6.0	7.7
7	Ankle	nill	6.0	7.7
8	None	61.5	nill	nill

A stooping posture, as adopted during threshing operation, is generally considered to be undesirable, with spinal flexion causing deformation of the intervertebral disc and exerting a risk of the nucleus being extruded (Pheasant, 1991). Any mechanical advantage from the weight of the body through a tilted trunk will thus be offset by the risk of cumulative musculoskeletal damage or overexertion from such a posture. Repetitive lifting of load involves asymmetrical movement that further increases the risk of musculoskeletal damage. With spinal rotation there will be an increase in the loading on the spine, causing further deformation of the discs (Pheasant, 1991).

Table 4: Results of Different Degrees of Variation from Neutral Position

	Stooping		Standing M1		Standing M2	
	Mean	S D	Mean	S D	Mean	S D
Lumb-osacral	102.25*	7.72	28.75*	15.22	22.5**	3.7
Knee	129.25*	33.05	167.75*	3.86	164.25*	6.45
Neck	101.50*	28.10	16.00*	11.43	24.75[d]	7.27
Ankle	17.57*	98.00	111.50**	8.27	84.00*	27.65
Elbow	139.75*	24.66	115.00*	14.14	136.25*	23.53
Wrist	54.41*	133.5	145.50*	8.43	145.75*	23.81
Shoulder	70.50*	16.9	84.50*	9.15	72.00[a]	9.09

S D = standard deviation N = 13 * flexion ** extension

d= lateral deviation a = abduction

shelled (Table 5).

Considering the impact of each predictor variable, on the criterion variable (Weight per lift and frequency per lift), the following findings were deduced. The weight per lift, and frequency of lift per individual subject was negatively related to quantity shelled per individual and was significant at 1% level respectively (Table 5). This indicates that the factors are significant to the study and have significant effect on the quantity shelled per individual on the two machines.

This suggested that the oxygen consumption is somewhat higher in the evaluation of the two machines than would be expected for the weight lifted at the observed frequencies

Table 5: Result from Regression Analysis for Biomechanical Parameters

Model	Unstandardized Coefficient		Standardized Coefficient		
	B	Standard Error	Beta	t	Sig.
Constant	-15.986	1.16		-3.784	0
Frequency of Lift	1.956	0.082	0.811	23.95	0
Weight Per Lift	8.141	0.456	0.604	17.845	0
F	425.987				
R^2	0.974				

Dependent variable: quantity shelled per individual N = 13

5.0 CONCLUSIONS AND RECOMMENDATION

This study has brought to the limelight how agricultural machinery developed for use in a developing country can be improved by employing human factors/ergonomics approach to design. The so called technological interventions in agriculture have revealed how would be users are exposed to hazards through ergonomics evaluation. By incorporating ergonomics into the design process, drudgery associated with the machine will be reduced and productivity, user comfort and satisfaction will be increased. Improving the posture and manual handling to be adopted to operate the machine will result in a significant reduction in physical strain and incidence of body-part discomfort and can be expected to reduce the risk of musculoskeletal damage.

5.1 Conclusions

The study had shown that biomechanical strain resulted through the performance evaluation results. On this premise, the following conclusions were drawn:

1) Machines capacities and heights, hopper shapes and orientation and concave sizes as well as personal limiting factors of individual subjects may be the determinant for frequency of lift and weight per lift as they varied across the machines.

2) Lifting process in repetitive manner by the operators has shown some significant deviations from neutral position, the accumulation of which could result in musculoskeletal injury, therefore make the use of the types of the evaluated machines ergonomically unfit and hazardous to human.

5.2 Recommendation

Based on the results from the evaluation, the following recommendations are hereby suggested in order to correct and improve on the existing locally developed stationary threshers and to prevent likely work related musculoskeletal disorder (WRMSD).

1. Incorporation of adjustable plat-form on which the unshelled crops will be put to check stooping posture involved in the initiation of lift.
2. Design and development of stationary grain thresher involving height adjustable mechanism, capable of accommodating 5th to 95th percentile of the operators' population to check repetitive variations from neutral positions.
3. The importance of ergonomic/human factors intervention in the design and fabrication of agricultural machinery produced locally.

REFERENCES

Aaron M. Kociolek, Jimmy Tat, Peter J. Keir (2014) Biomechanical Risk Factors and Flexor- Tendon Frictional Work in the Cadaveric Carpal Tunnel *Journal of Biomechanics, pp 449-456.* Elsevier Ltd. http://dx.doi.org/10.1016/j.jbiomech.2014.12.029 0021-9290/& 2014.

Karla G. G., Gabriel I., and Juan L. H. (2012) Biomechanical Analysis of a Manual Material Handling Tasks in a Local Manufacturing Company, *Proceedings of the 1st Annual Conference of the Society for*

Industrial and Systems Engineering, Washington, D.C, USA September 16- 18.

Kasey C., Ashish D. N., Xiaopeng N. and Majid J. (2014) A Biomechanical Strain Index to Evaluate Shoulder Stress *Proceedings of the 2014 Industrial and Systems Engineering Research Conference Y. Guan and H. Liao, eds.*

Kumar S. (2001) Theories of Musculoskeletal Injury, *Ergonomics. 44(1), 17-47.*

Marras W.S. (2006) *Basic Biomechanics and Workstation Design (*Handbook of Human Factors and Ergonomics (ed. Salvendy, G.), John Wiley and Sons.

Mazza J. J., Lee B. C., Gunderson P.D., and Stueland D.T. (1997) Rural Health Care Providers' Educational Needs Related to Agricultural Exposures, *Journal of Agricultural Health and Safety. 3(4), 1997, 207-215.*

Messing K., Stock S.R. and Tissot F. (2009) Should Studies of risk Factors for Musculoskeletal Disorders Be Stratified by Gender? Lessons from the 1998 Québec Health and Social Survey. *Scand J Work Environ Health.* 35(2):96–112.

Pheasant S. (1991) *Ergonomics, work and health*, (Macmillan, London)

Prakash K. C., Subas N., Päivi L., Mikaela B. von Bonsdorff, Taina R., Monika E. von Bonsdorff, Jorma S., Juhani I. and Clas-Håkan N. (2017) Work-Related Biomechanical Exposure and Job Strain as Separate and Joint Predictors of Musculoskeletal Diseases: A 28-Year Prospective Follow-up Study. *American Journal of Epidemiology Vol. 186, No. 11DOI: 10.1093/aje/kwx189 Advance Access publication: June 2, 2017*

Radwin R.G., Marras W.S. and Lavendar S.A. (2001) *Biomechanical Aspects of Work-Related Musculoskeletal Disorders* (Theoretical Issues in Ergonomics Science. 2(2),153-217.

Rowett Research Institute (2008) "Energy Expenditure."http://www.rowett.ac.uk/edu-web/sec-pup/energy-expenditure.

Sergey S., Ievgen L., Vasily M. and Jan A. (2017) Comparative Biomechanical Analysis of Stress–Strain State of the Elbow Joint After Displaced Radial Head Fractures. *Journal of Medical Biology Engineering (2018)38:618-624*

CHAPTER 19

Team-based Material Selection for a DC Machine Armature Design Using Compromise Programming Optimization

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Abstract:
Concurrent engineering design which emphasizes team decisions has created new challenges. The process of selecting a single material type from many varieties to best satisfy all product specifications and stakeholders' requirements is one such challenge in team design. The literature is sparse on team decision-support instrument to enable Design engineers reach consensus on such contentious design issues. This study was designed to develop a compromise programming optimization model of a team-based material selection for a DC machine Armature design. A team-compromised instrument (TCI) for computing criteria weights that collates inputs from individual rankings was developed, and combined with material selection optimization function and solved as multi-criteria compromise programming (MCP) algorithm. This was applied to select materials for the design of a DC machine armature Core, armature shaft and armature windings and the results were compared to those of a popular non-team based Existing Algorithm (EA) known as Technique of Ranking preference by Similarity to Ideal Solution (TOPSIS). The results obtained show that both algorithms selected the same materials when the team-compromise instrument was used with associated compromise gain, such as Carbon Steel SAE 1090 (59.34%), Oxygen-free electronic copper UNS C10100 (59.81%) for DC armature shaft and armature windings respectively. However, for the armature core, the MCP selected JG-core Grain-oriented electrical steel (59.01%) while EA selected AK steel DI-Max HF-10

non-oriented electrical steel (51.25%).The model can therefore be used conveniently for making design decisions and reduce the possible conflicts that may arise from the design team and design requirements.
Keywords: Team-compromise instrument, Material selection, Multi-criteria optimization, Compromise programming, Design criteria.

1. Introduction:

Material selection is one of the foremost functions of effective engineering design as it determines the reliability of the design in terms of industrial and economic aspects. A good design may fail if unable to find the most appropriate material combinations. Therefore, it is crucial to ascertain the best materials that would be suited for a particular design. Hence, material selectionis the act of choosing the material best suited to achieve the desire requirements of a given application. It is also regarded as the foundation of all engineering applications and design. Though many factors are involved into determining the selection requirements, such as mechanical properties, chemical properties, electrical properties, ability to manufacture and cost, but the selection process can be described with respect to application requirements, possible materials, physical principles and selection method. This task is compounded by several material types from which a single material has to be selected for a particular design.

However, apart from the numerous existing material types that are available today, there are a large number of design specification related material characteristics which have to be simultaneously satisfied in the process of design (Al-Ogla, et al. 2015). These design characteristics is yet another major challenges in material selection equation because selecting material to meet a single property requirement is known as single criterion material selection problem. A solution based on a single criterion may provide worst solution value for other criteria, for example, the selection of material with minimum density may not provide for the desired ductility and hardness; another with maximum toughness may not counter for the electricity conductivity and cost requirements. So, a situation may arise where several combinations of these opposed requirements which render the one-criterion solution approach unsuitable. Therefore, for several properties to be simultaneously satisfied, there exists a multi-criteria optimization problem.

Apart from the material criteria requirements problem, there is also disagreement arising from team of designer as stakeholders in taking decisionssuch that each individual of the design team may have a certain preference of a certain criteria over the others. The behaviour of team members in an organization is crucial to its performance because each individual should be capable of doing his/her job and perform team roles in a way that will moves the entire team towards achieving their objectives (Nestsiarovich and Pon, 2020; Megan, et al. 2015).Hence, the roles that members take can affect the team outcomes due to conflicts that may exist among them.Therefore, teamwork is very important due to the fact it has the will to compromise and work jointly with others and with the intention of reaching a common goal and purpose (Odu and Charles-Owaba, 2017).

Within the design team, role expectations must be determined to allow members to work effectively and reduce delays due role conflicts (Terpstra, 1989).Design team interactions requires planning as always applied to nominal group technique. Such techniques as meeting agendas and decision-making procedures can make team projects more effective. However, with careful planning, team interactions may lead to interpersonal conflicts. Members must find a way to share their professional expertise and beliefs (Xuan and Du, 2003), and also willing to compromise on issues to settle conflicts procedures for handling compromises and unresolved conflicts may need to be determined.

This view can be expressed with the concept of design for assembly, design for safety, design for cost, design of manufacture, etc., (Thankachan et al., 2010), where each team members wants their point of view be noticed. In Engineering design, there is always a high risk of possible failure due to the wrong choice of material selection which may have huge costs in product design, building construction, automobiles, and other engineering products (Dev et al., 2020). One possible reason a lot of engineering design may face the risk of failure is the fact that availability of so many alternatives has often led to poor material selection, therefore, there is need for scientific approach to the material selection process. Besides, new materials are continually being developed due to pressures from domestic and foreign competition, increased demand for quality and serviceability, or negative customer feedback and changes in prices. Moreover, decision-making by an individual judgment in the choice of material has always been biased most times, and this has led to improper material use. However, whenever this individual member comes together as a group, conflicts arises because their opinions are different. There is the need to develop a mathematical model that will compromise their individual decision and eventually eliminate the conflicts among the stakeholders so that consensus on issues can be reached. Therefore, this book chapter focuses on the development of a compromise programming optimization model for multiple criteria material selection using team-based approach for a DC machine armature component. However, the objectives of the study include: (1) develop a team-based compromise instrument for effective collation of DC machine input data from different design professionals, (2) develop a compromise programming optimization model for team-based multi-criteria material selection, and (3) formulate a model for comparing the quality of multi-criteria optimization material selection procedures.

In the past one or more years, majority of the traditional materials that were used for engineering product design for some time now are being restored with newly found materials so as to make weight reduction possible and improve their outcomes (Rao, 2008). The variation of materials available exist in abundance (Roth et al., 2002, Ashby, 2010).It is estimated that the number of materials available to the designers for consideration is vast, over 120,000 are at his or her disposal. This comprises of metallic and its alloy, and non-metallic materials for example, plastics, composite materials, ceramics, semi-conductors, and glasses. This numerousnumbers of materials, along with the complex relationships between the different selection parameters, frequently makes the selection of a material for a given component a difficult task.

2. Materials and Method

2.1 Selection Methods

Material selection includes three stages: Initial screening, determining the relative importance of material property, and determination of best solution (Ashby, 2010; Balanli et al., 2019). The initial screening of materials and processes can be very tedious task if performed manually from handbooks and supplier catalogs. This difficulty has prompted the introduction of several computer-based systems for materials and/or process selection (Farag, 2006). One of the important characteristics needed for initial screening of materials is the critical requirements of each part which defines the performance requirements of the material. First, start with all materials available and narrow down the choices on the basis of the rigid properties. Having specified the performance requirements of different parts, the required material properties can be established for each of them. These properties may be quantitative or qualitative, desirable or non-desirable. The desirable material properties should be maximized, while the non-desirable properties that should be minimized. All these properties should be achieved at a reasonable cost. In such cases, alternatives must be made possible through redesign, compromise of requirements, or development of new materials.

2.2 Criteria weights Determination

The second stage of the material selection process involvesdetermination of relative importance of material property/criterion.It is required of the designer to find a suitable method of computing the relative importance of material property. In this study, a modified nominal group technique will be adopted such that selected material reflect the concept of design for assembly, design for manufacturing, design for maintenance, design for safety, design for cost, etc. This is more reason why a team-based material selection model is developed to minimized conflicts that may arise within the design team. Though, the proposed model will not only specify the weights, but will at the same time evaluate the criteria weights through a mathematical function referred to as team-compromise instrument. The model itself is very adequate because of its robustness, flexibility, accountability and simplicity.

2.2.1Team-Compromise Instrument Development

Team-based approach to design has been the usual practice in an integrated product development in response to customer satisfaction. This approach is sometimes referred to as concurrent engineering. However, in the recent times, there has been few challenges, especially in the area where different team members of experts or professionals in a team has find a common ground on some contentious issues that relates to design requirements is one of such problem. And due to these challenges, conflicts seem to emanate from the following: Lack of information or input data on the product requirements to enable the stakeholders make the right decision; adoption of 'traditional' practice of design in decision-making process; trust issues between individual team members and team leaders in the design decision process; and individual stakeholders with strong professional learning.

In order to develop a team-based compromise instrument that is well structured, it is important that instrument allow individuals to acquaint themselves with the following:

1) A comprehensive data of material related design requirement will be sent to each team members. Also, information on the inputs resulting from each of the component in terms of operation,

aesthetics, process manufacturing, component's specifications and operating environment etc., are documented. The above information is independently studied without interference.

2) Individual team members are to rank the criteria independently with ordinal scale of first, second, third, etc., without having the same outcome.

Now, a mathematical functioncapable of receiving the inputs from all the stakeholders in (2) above is developed; and a set of criteria preferences is generated. The team-compromise instrument is developed as follows:

And for the purpose of promoting team-spirit, it is very important to add that the following conditions must be satisfied:

(1) Enter the data for criteria weights w_j computation, received from each of the team member, where w_j, is the value of team preference index for criterion j,

(2) $\sum_{j=1}^{n} w_j = 1$

(3) $w_j > 0 \forall j$

In order to satisfied the above conditions, the theoretical aspect of group decision-making approaches, such as Brain writing, Brain storming, Delphi, Analytical hierarchy process (AHP), and Nominal group technique (NGT)) reported in the literature (Al-Ogla&Salit, 2017; Abdullah and Rafikul, 2011; MacPhail 2013) was critically investigated. However, the structure of the NGT decision-making looks more acceptable for the mathematical modeling of team-compromise instrument and hence, satisfying simultaneously the three conditions earlier stated.

The followingnominal group technique beneficial properties will be considered for the purpose of this study.

(1) The possible number of criteria should be known (N)

(2) Agreement on team size cannot be changed and minimum required number is seven (7) members;

(3) Individual team member is allowed some time toindependently evaluate the information provided on the criteria and the ranking procedure;

(4) The ranking of criteria is carried out by individual team member without interference;

(5) Team members are to rank the criteria using ordinal scale of first, second, third, etc., without having the same outcome, and zero rank is not allowed.

(6) The ordinal scale ranked in (5) are changed to relative scores so that criterion having the highest score becomes first, N; and 2nd position criterion takes $N-1$, 3rd position takes $N-2$, etc.;

(7) Decision made from all team membersare recorded according to a peculiar ranking pattern, such that the individual values form Arithmetic Sequence of$(1, 2, 3, \ldots, N-2, N-1, N)$.

(8) Accumulated scores for a certain criterion are the addition of scores from all theteam members.Note thatcombination of scores with values between 1 and N is most likely to depend on independent ideas of members;

(9) The overallscoresgotten fromthe combination of all team members, Z with the use of ordinal scale to rank the set of N criteria is given by the expression in equation (1).

$$SC = N(1+2+3+\ldots\ldots\ldots+N) = ZN(N+1)/2 \qquad (1)$$

Therefore, the use of nominal group techniquecharacteristics are utilized in deriving a mathematical model which will meet the initial mentioned properties of criteria weightsw_j.Let R_{kj} be the associated score andψ_{kj} be the relative rank assigned by team member i to criterion j. Hence, the maximum possible score on any criterion is N and the minimum score by an individual is given as 1.Thus, the relationship between R_{kj} and ψ_{ij} is given in equation (2).

$$R_{kj} = N - \psi_{kj} + 1 \qquad (2)$$

By assigning ordinal ranking asfirst, or second, or third, etc., in equation (2) it indicates that higher the rank, the same goes for the scoretoo. The system of ranking by individuals gives room for each team member to have better decision according to the laid down rules.

Note that, making use of an ordinal scale of 1st, 2nd, 3rd, etc., without having the same outcome,it is difficult for just a member to arrive with a score of more than 2 criteria that has the same value.As a result of these,the scores of any member aligns with the following arithmetic sequence.

$$R_{kj} = \{1, 2, 3, ..., N\text{-}2, N\text{-}1, N\} \qquad (3)$$

It is mandatory for all members to rank a criterion by making use of the rank indicator (TS_j), then the sum of the scores of criterion j, $TS_j$by all participants in the team is given in equation (4)

$$TS_j = \sum_{k=1}^{Z} R_{kj} \qquad (4)$$

Note that the set of scores received from all team members on a particular criterion must not always be arithmetic sequence in nature as illustrated in item (8) of the nominal group technique property. Since equation (4) represents the team ranking of criterion j. then, a team preference index of criterion j, w_j, will be a function of TS_j. This can be expressed as follows:

$$w_j = \frac{TS_j}{\sum_{k=1}^{Z}\sum_{j=1}^{n} R_{kj}} = \frac{\sum_{k=1}^{Z} R_{kj}}{\sum_{k=1}^{Z}\sum_{j=1}^{n} R_{kj}} \qquad (5)$$

where the sum of all the scores from Z team members can be expressed as:

$$\sum_{k=1}^{Z}\sum_{j=1}^{N} R_{kj} = ZN(N+1)/2 \qquad (6)$$

Substituting into (5), gives

$$w_j = \frac{\sum_{k=1}^{Z} R_{kj}}{ZN(N+1)/2} \qquad (7)$$

In terms of the ranking variable (ψ_{kj}) in expression (2),

$$w_j = \frac{\sum_{k=1}^{Z} (N - \psi_{kj} + 1)}{ZN(N+1)/2} \qquad (8)$$

Expressions (7) and (8) are referred to as team preference index assigned to criterion *j*, and are used to determine the common values of the criteria weights w_j, thereby avoiding possible team conflicts. This is achieved by giving each team member ample time to independently go through the information as regards to the components that required material selection. Note that in this case, team members do not meet face-to-face.

2.2.2 Team-based Compromise Criteria Weight Assigning Instrument

In view of the above team-compromise instrument analysis, the following procedure is taken to assist the team of designers to come up with appropriate decision on the set of criteria weights for the components under consideration.

Item 1: The leader of the design team should document all necessary information on the DC machine requirements, including information regarding the design process, component function, process manufacturing. Also, stating clearly the ranking system procedure.

Item 2:Once item (1) is completed; the team leader sent the prepared document to individual team member asking them to rank and return the set of data$\{\psi_{kj}\}$ back on a specific timeline for collation.

Item3: Using equation (8) above, the set of criteria weights w_j are then computed for N design criteria

Hence, the material selection problem may be expressed by combining the team compromise instrument (TCI) preference indices and the mathematical programming compromise (trade-off) to form a multi-criteria compromise programming (MCP) model as follows:

$$Min\ F_i = \left\{ \sum_{j=1}^{n} \frac{\sum_{k=1}^{z} (n - \psi_{kj} + 1)}{\frac{z}{2}[n(n+1)]} [f_{ij}]^2 \right\}^{\frac{1}{2}}$$; (for minimization problem) (9)

$$Max\ F_i = \left\{ \sum_{j=1}^{n} \frac{\sum_{k=1}^{z} (n - \psi_{kj} + 1)}{\frac{z}{2}[n(n+1)]} [f_{ij}]^2 \right\}^{\frac{1}{2}}$$; (for maximization problem) (10)

$i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n;\ k = 1, 2, \ldots, z$

2.3 Selecting the Optimum Solution

The selection of an optimum solution is the third stage of material selection process. It involves various mathematical programming and operation research principles. Various mathematical programming and optimization principles were utilized to develop the process of material selection (Jahan, et al., 2011).Optimization is an engineering discipline where extreme values of design criteria are sought. However, quite often there are multiple conflicting criteria that need to be handled. Satisfying one of these criteria comes at the expense of another.Generally, multi-criteria optimization deals with this type of conflicting objectives, and It provides a certain level of mathematical structure for an optimal solution to be reached so as to accommodates the various objectives required by the application.The process of optimization involves choosing the best solution from a pool of potential candidate solutions such that the chosen solution is better than the rest in certain aspects (Odu and Charles-Owaba, 2013). In the case of a single objective problem, we are maximizing or minimizing a single output and/or constraining a set of outputs to stay within a certain range (Van der and Koch, 2010).In the present-day situation, multi-criteria optimization is no doubt a very popular topic for both researchers and engineers. But still there are many open questions in this area. In fact, there is no globally acceptable definition of 'optimum' as regards to single criteria optimization, it is more difficult in trying to compare solutions of one method to another, since in reality the decision about the best option is similar to that of the decision-maker. (Ashish and Satchidananda, 2004).

Over the past few years, several researchers have applied different multi-criteria optimization methodsfor solving material selection problems in various engineering applications. Amongst those methods are: Technique for Order Preference by Similarity to Ideal Solution, (TOPSIS) –(Shanian &Savadogo, 2006;Shanian &Savadogo, 2009; Jahan et al., 2012; Kumar et al., 2014;andBabanli et al., 2019); Multicriteria Optimization and Compromise Solution (VIKOR) - (Rao, 2008; Chatterjee et al., 2010; Cavallini et al., 2013); Elimination and Choice Expressing the Reality (ELECTRE) – (Chatterjee et al., 2009; Peng at al., 2015); PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation - (Caliskanet al., 2013; Peng & Xiao, 2013); Complex Proportional Assessment (COPRAS) – (Ayrim et al., 2018; Sahin, 2019); and Preference Selection Index (PSI) Method – (Kahraman and Otay 2019; Maniya and Bhatt, 2010; and Madic et al., 2017). In this book chapter, a compromise programming optimization model will be developed and utilized to develop the process of selecting the best material incorporating the team-compromise instrument detailed in section (2.2.1); and compared to one of the most popular and existing algorithms (TOPSIS) in selecting material for a DC machine armature design. Material candidates with the highest performance indices canbe used to develop a detail design.

2.4 Development of objective function for material selection performance measure for a compromise programming model

Let y_{ij}^{-} and y_{ij}^{+} be the performance index or actual value for minimization and maximization criteria of material *i* in a particular property *j* desired for engineering design property for non-beneficial and beneficial criteria respectively. And let y_j^{min} and y_j^{max} to be the ideal value based on the fact that single criterion is used in solving minimization and maximization problem respectively.Also, let F_i be such a performance measure that may need to be optimized and F_i^{Norm} is anaggregate function capable of combining different material properties into single function.

If $\in_i = \{y_{i1}, y_{i2}, y_{i3},...., y_{ij},...., y_{in}\}$ be the set of performance index of n distinct number of desired properties for material i,then it is desirable to express F_i as a combination of $\in_i$. To do this F_i^{Norm} has to be normalized by converting each element of $\in_i$ has to be converted into a dimensionless quantity.

But because we want to simultaneously satisfy two or more criteria with one material, it is difficult to adopt a single optimization; therefore, there is need to compromise in order to satisfy all the criteria/objectives at the same time by deviating from the ideal value. This implies that the deviation or distance from the ideal is the loss due to compromise. For minimization problem, the deviation or distance (d_{min}) from ideal value is expressed as:

$d_{min} = y_{ij}^{-} - y_j^{min}$ (for minimization problem)

(11)

Hence, normalized distance, d_{min}^N from ideal is given as:

$$d_{min}^N = \frac{y_{ij}^{-} - y_j^{min}}{y_j^{max} - y_j^{min}}$$

(12)

The degree of closeness (dC_L^-) to the ideal value may be expressed as 1–Normalized deviation or 100% - Normalized deviation.

Mathematically,

$$dC_L^- = 1 - \frac{y_{ij}^{-} - y_j^{min}}{y_j^{max} - y_j^{min}}$$

(13)

This can be simplified further to

$$dC_L{}^{-} = \frac{y_j^{max} - y_{ij}^{-}}{y_j^{max} - y_j^{min}}$$
(14)

The expression in equation (14) shows how close the actual value is to the ideal.

Similarly, for maximization problem, the deviation from ideal value is expressed as:

$$d_{max} = y_j^{max} - y_{ij}^{+}$$
(15)

Then, the normalized deviation from ideal is

$$d_{max}^{N} = \frac{y_j^{max} - y_{ij}^{+}}{y_j^{max} - y_j^{min}}$$
(16)

Hence, the degree of closeness, dC_L^{++} to the ideal is given by $1 - d_{max}^{N}$, and is expressed as

$$dC_L^{++} = 1 - \frac{y_j^{max} - y_{ij}^{+}}{y_j^{max} - y_j^{min}}$$
(17)

By simplifying equation (4.7), we have

$$dC_L{}^{++} = \frac{y_{ij}^{+} - y_j^{min}}{y_j^{max} - y_j^{min}}$$
(18)

where

$y_j^{max} = \max_i imum\{y_{ij}\}$, is the maximum value of material property j and $y_j^{min} = \min_i imum\{y_{ij}\}$ is the minimum value of material property j

Therefore, the equation in (14) and (18) may be expressed in terms of the following objective functions such that they are dimensionless in order to form a mathematical programming compromise or trade-off.

For minimization problem,

$$f_{ij} = \frac{y_j^{\max} - y_{ij}^{-}}{y_j^{\max} - y_j^{\min}}; \quad i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots, n \qquad (19)$$

For maximization problem,

$$f_{ij} = \frac{y_{ij}^{+} - y_j^{min}}{y_j^{max} - y_j^{min}}; \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \qquad (20)$$

where f_{ij} is the normalized objective function of the material i for property j; Therefore,

$$F_i^T = f_{i1} + f_{i2} + f_{i3} + \ldots + f_{ij} + \ldots + f_{in} \qquad (21)$$

Usually, in almost all multi-objective optimization problems including compromise programming requires information regarding criteria preference of each criterion to bring about desirable properties. In order to establish and satisfy a multiple measure of performance across all the criteria selected, thus providing a basis for identifying the best or preferred options. Therefore, in this case, the normal approach of compromise programming model is to introduce criteria preference index, w_j according to how important each is regarded in relation to each other obtained from the stakeholders.

Thus, the compromise programming model can be expressed by introducing w_j into equation (21), we have

$$F_i^{Tw} = w_1 f_{i1} + w_2 f_{i2} + w_3 f_{i3} + \ldots + w_j f_{ij} + \ldots + w_n f_{in}$$

(22)

Hence, combining all the properties, we have,

$$F_i^{TW} = \sum_{j=1}^{n} w_j f_{ij}$$

(23)

The model determines the best compromise solution formulation by solving:

For minimization problem,

$$Min\ F_i = \left\{ \sum_{j=1}^{n} w_j \left[\frac{y_j^{max} - y_{ij}^{-}}{y_j^{max} - y_j^{min}} \right]^2 \right\}^{\frac{1}{2}}$$

(24)

For maximization problem,

$$Max\ F_i = \left\{ \sum_{j=1}^{n} w_j \left[\frac{y_{ij}^{+} - y_j^{min}}{y_j^{max} - y_j^{min}} \right]^2 \right\}^{\frac{1}{2}}$$

(25)

2.5Compromise Gain (CG)

Inmulti-criteria optimization, the normalized objective function may differ for differentalgorithms because different algorithms may adopt different normalization process.For instance, two different algorithms may select the same material for a particular problem situation, but with different optimal values of objective functions. This makes it difficultto compare qualityof solutions from optimal value of objective function perspective. Thiscalls for the use of a different concept which may allow quality of different solutions tobe compared. One such rational is the concept of compromise gain/loss. Notice that f_{ij} is the value of the normalized algorithm solution as defined in expression (21) and (22), and $f_{ij}^{\max}$ is the ideal value (for maximization problem) or $f_{ij}^{\min}$ (for minimization problem). The closer f_{ij} gets to ideal value, $f_{ij}^{\max}$ or $f_{ij}^{\min}$ the greater the gain the algorithm has achieved with respect to criteria *j* for material *i*. Hence, the goal of any solution procedure is to drive f_{ij} to the ideal for all criteria for a given material. Whenever f_{ij} is equal to $f_{ij}^{\max}$ or $f_{ij}^{\min}$ it implies that the algorithm solution is 100 percent gain. Unfortunately, there is a limiting criteria value for every material. For material *i*, for instance, if its value for property *j* is f_{ij}^{l}, then f_{ij} cannot be greater than f_{ij}^{l}. In a case where f_{ij}^{l} is also less than the ideal, $f_{ij}^{\max}$ then there is a compromise loss to this solution. In terms of distance, this may be expressed as follows:

$$Compromise\ \ loss = f_{ij}^{\max} - f_{ij}$$

While the corresponding compromise gain is f_{ij}.

To illustrate this concept, consider the diagram in Figures 1 and 2.

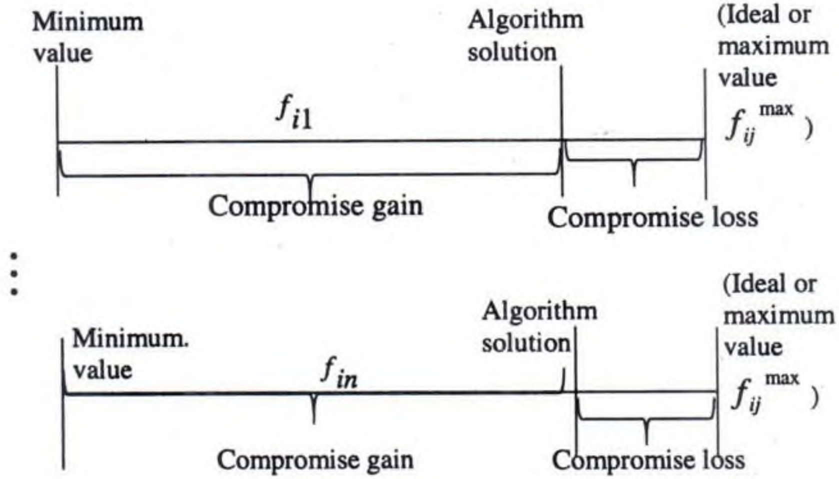

Fig. 1 Compromise gain/loss for maximization problem (beneficial criteria)

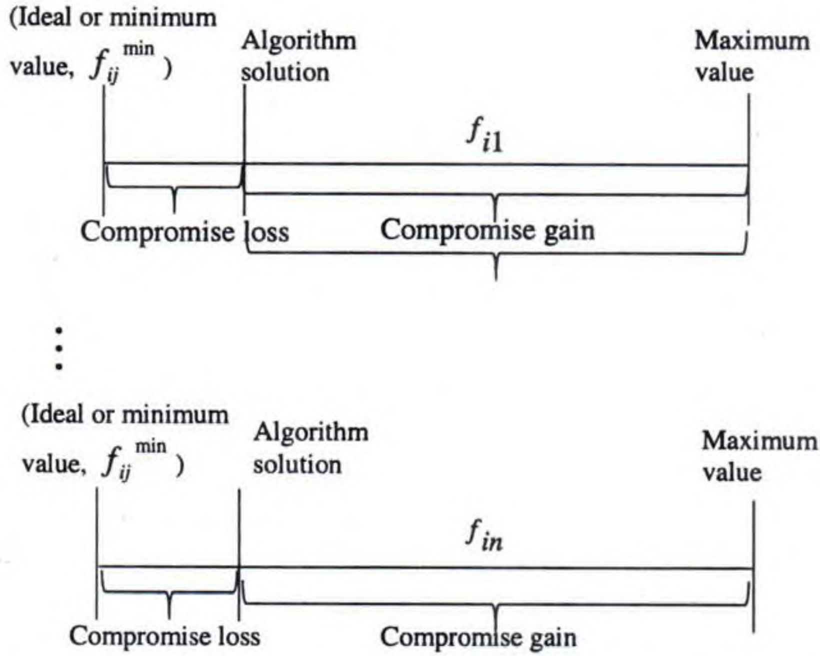

Fig. 2. Compromise gain/loss for minimization problem (non-beneficial criteria)

Observe that if f_{ij}^{l} were equal to the ideal value, $f_{ij}^{\max}$ or $f_{ij}^{\min}$ then the compromise gainis maximum while compromise loss is zero. From this point of view, the quality of solution maybe measured as the amount of compromise gain/loss attained by the solution procedure (algorithm). In terms of degree of closeness to the ideal, compromise gain may be defined as follows:

Definition 1: Degree of Compromise Gain (CG)

Degree of Compromise gain of a known solution is the ratio (percentage) of the sum of all the elements in the set, $\{ f_{ij} \}$,to the sum of the ideal values, $\sum_{j=1}^{n} f_{ij}^{\max}$

That is

$$CG(solution) = \frac{\sum_{j=1}^{n} f_{ij}}{\sum_{j=1}^{n} f_{ij}^{\max}} \times 100$$

(26)

where

$$f_{ij}^{\max} = \frac{y_j^{\max} - y_j^{\min}}{y_j^{\max} - y_j^{\min}}; \quad j = 1, 2, \ldots, n;$$

Substituting $f_{ij}^{\max}$ into the expression in (26), we have

$$CG(solution) = \frac{\sum_{j=1}^{n} f_{ij}}{n} \times 100 \tag{27}$$

Similarly, for minimization problems, the same expression (27) for computing degree of compromise gain holds.

3. Results and Discussion

3.1 Possible Materials and their properties for a DC machine Armature Design

Each of the DC machine components have a specific product requirement where the upper/lower limits of each property for the design specifications of three armature DC machine components are identified and materials are sourcedfrom the web (Matweb) as shown in Table 1, 2, and 3 for the DC armature core, armature shaft and armature windings respectively.

Table 1: List of Candidate Materials and their Properties for Material Selection of Armature Core of a DC machine.

Alt. Mat.	D g/cm^3	UT MPa	YS MPa	DU (%)	H Vickers	ER ($\Omega.m$ x 10^{-8})	ML W/kg	C ($/kg)
AC1	7.65	370	340	14	195	4.8	0.83	20.15
AC2	7.65	490	359	23	130	5.0	1.20	35.10
AC3	7.68	565	450	25	215	5.2	3.05	40.00
AC4	7.75	400	265	34	137	3.2	4.50	25.25
AC5	7.65	352	331	9	153	5.1	0.56	15.50
AC6	7.70	483	345	32	114	4.3	3.42	25.50
AC7	7.60	369	302	35	188	4.8	1.45	23.50
AC8	7.65	359	345	11	159	5.0	0.87	27.50
AC9	7.65	450	350	20	144	5.4	0.50	20.55

Alternative Materials

H 085-27 Grain oriented electrical steel – AC1

AK Steel DI-MAX M-15 Non-oriented electrical steel – AC2

ASTM A677 (36F155) Non-oriented electrical steel – AC3

JN-CORE (50JN600) Non-oriented Electrical steel - AC4

AK Steel CARLITE M-4 Grain oriented electrical steel – AC5

AK Steel DI-MAX M-43 Non-oriented electrical steel – AC6

JG-CORE Grain-oriented electrical steel – AC7

H-1Carlite DR Grain-oriented electrical steel - AC8

AK steel DI-Max HF-10 Non-oriented Electrical steel - AC9

Table 2: List of Candidate Materials and their Properties for Material Selection of Armature Shaft of a DC machine.

Alt. Mat.	UT MPa	YS MPa	EM GPa	DU (%)	H Vickers	D g/cm^3	TC W/m.K	TD (x10^{-5})	TE (20^{0}Cx10^{-6})	C ($/kg)
AF1	330	285	206	20	98	7.87	64.9	1.71	12.6	15.90
AF2	475	400	210	12	143	7.85	49.8	1.32	11.5	17.08
AF3	365	301	200	20	107	7.87	51.9	1.35	12.6	17.59
AF4	525	440	200	12	150	7.85	48.7	1.27	11.7	15.94
AF5	696	540	202	10	195	7.85	49.8	1.32	11.5	14.57
AF6	710	605	200	10	200	7.87	51.2	1.33	11.5	24.05
AF7	420	350	186	15	126	7.87	51.9	1.35	11.7	20.60
AF8	640	420	205	26	176	7.85	44.6	1.38	12.0	25.50
AF9	440	370	205	15	131	7.75	51.9	1.37	12.0	24.60
AF10	420	350	186	15	126	7.85	47.7	1.26	11.7	25.06

Alternative Materials	
1	Carbon Steel SAE 1006 – AF1
2	Carbon Steel SAE 1117 – AF2
3	Carbon Steel SAE 1010 – AF3
4	Carbon Steel SAE 1030 - AF4
5	Carbon Steel SAE 1090 – AF5
6	Carbon Steel SAE 1547 – AF6
7	AISI 1020 low Carbon Steel – AF7

8	Alloy Steel SAE 4027 – AF8
9	AISI 1080 Steel - AF9
10	AISI 1040 Carbon Steel – AF10

Table 3: List of Candidate Materials and their Properties for Material Selection of Armature Windings of a DC machine.

Alt. Mat.	D (g/cm^3)	UT MPa	YM GPa	DU (%)	SM GPa	TC W/m.K	TD (x10^{-5})	MP (^{0}C)	ER ($\Omega.m$ x 10^{-8})	MA (%)	C ($/kg)
AW1	8.94	380	115	1.5	44	388	11.30	1083	1.72	20	27.70
AW2	8.94	260	115	25	44	388	11.27	1083	1.72	20	26.70
AW3	8.94	310	115	20	44	386	11.21	1083	1.74	20	26.80
AW4	8.89	240	115	35	44	388	11.30	1080	1.72	20	28.75
AW5	8.89	240	115	45	44	234	11.30	1050	2.44	20	25.50
AW6	8.89	455	115	55	44	391	11.20	1083	1.71	20	29.55
AW7	8.89	525	129	1.5	40	367	10.72	980	1.86	20	25.45
AW8	2.80	290	73.1	20	28	134	5.44	507	5.15	20	25.70
AW9	2.81	400	71.7	19	27	154	6.23	521	4.32	30	25.25
AW10	2.70	140	68.2	7.3	25.9	200	8.23	632	3.30	20	23.45

Alternative Materials	**Code**
Oxygen-free Silver bearing Copper (Temper wire) UNS C10500, H04	AW1

Oxygen-free Silver bearing Copper (Temper wire) UNS C10700, H01	AW2
Oxygen-free extra-low phosphorus Copper, UNS C10700 H80	AW3
Silver-bearing tough pitch Copper, UNS C11300	AW4
Silver-bearing tough pitch Copper, UNS C11600, H08	AW5
Oxygen-free electronic Copper UNS C 10100	AW6
Zirconium Copper (Amzirc Brand Copper) wire UNS C 15000	AW7
Aluminium 2014-T4, 2014-T451	AW8
Aluminium 2025-T6	AW9
Aluminium 5005-H12	AW10

3.2 Criteria Preferences for the Design Product Specifications
Table 4, 5, and 6 shows thepossiblecandidate materials data with the achievement level for the Armature core, Armature shaft, and Armature windings design.The criteria preferences resulting fromthe team-compromise instrument indicates that electrical resistivity and magnetic core loss are the most ranked properties/criteria with a value of 18.0 and 16.4 percent respectively for the DC Armature core as shown in Table 4. A low value of electrical resistivity is required and it indicates a material that readily allows movement of electric charge and is measures the material ability to conduct an electric current, while on the other hand, for magnetic core, a soft magnetic material is needed to provide an easy path for flux in order to facilitate flux linkage between two or more magnetic elements. Also, in the design of a D.C armature shaft, the criteria preferencesare shown in Table 5, and the result shows that yield strength (14.4%), ultimate strength (14.4%) and hardness (11.6%) has the highest

ranked criteria preferences. It is seen from the results that these three properties/criteria are very important in the design of armature shaft. The shaft must able to withstand an appreciable load and should have the ability to resist denting and wear.
And in terms of the armature windings, it is obvious that electrical resistivity and thermal conductivity were mostly ranked with a weight value of 14.4 and 13.3 percent respectively. Thermal conductivity is an important factor when designing and exploring any electromagnetic device due to heat generation and dissipation in the windings.

Table 4 Material Selection Data for Armature Core with Criteria Preferences

Criteria	Criteria type	Aspiration Level	Veto threshold	Criteria Weight (%)
Yield strength (YS) – (MPa)	Beneficial	450	265	10.4
Hardness (H) - (Vickers);	Beneficial	215	114	12.2
Ductility (DU) – (%)	Beneficial	35	9.0	9.6
Ultimate tensile strength (UT) – (MPa)	Beneficial	565	352	11.2
Density (D)- (g/cm^3);	Non-beneficial	7.60	7.75	10.0
Magnetic core loss (ML) (W/kg @ magnetic field 1.50	Non-beneficial	0.5	4.5	16.4
Electrical resistivity (ER)- (Ω.m);	Non-beneficial	3.2	5.4	18.0
Cost of base material (C) - (\$/kg)	Non-beneficial	15.5	40.0	12.2

Table 5. Material Selection Data for Armature Shaft with Criteria Preferences

Criteria	Criteria type	Aspiration Level	Veto threshold	Criteria Weight (%)
Ultimate tensile strength (UT) – (MPa)	Beneficial	710	330	14.4
Yield strength (YS) – (MPa)	Beneficial	605	285	14.4
Elastic modulus (GPa)	Beneficial	210	186	11.0
Ductility (DU) – (%)	Beneficial	26	10	8.4
Hardness (H) - (Vickers)	Beneficial	200	98	11.6
Density (kg/m^3)	Non-beneficial	7.75	7.87	6.2
Thermal conductivity (W/m-k)	Beneficial	64.9	44.6	9.2
Thermal diffusivity ($m^2/s \times 10^{-5}$)	Non-beneficial	1.26	1.71	6.7
Thermal expansion ($°C^{-1} x 10^{-6}$)	Non-beneficial	11.5	12.6	8.8
Cost of base material (C) - ($/kg)	Non-beneficial	14.57	25.50	9.3

Table 6: Material Selection Data for Armature Windings with Criteria Preferences

Criteria	Criteria type	Aspiration Level	Veto threshold	Criteria Weight (%)
Density (kg/m^3)	Non-Beneficial	2.7	8.94	8.0
Ultimate tensile strength (UT) (MPa)	Beneficial	525	140	8.1
Young modulus (GPa)	Beneficial	129	68.2	7.4
Ductility (DU) – (%)	Beneficial	55	1.5	9.1
Shear modulus (GPa)	Beneficial	44	25.9	5.7
Thermal conductivity (W/m-k)	Beneficial	391	134	13.3
Thermal diffusivity ($m^2/s \times 10^{-5}$)	Beneficial	11.3	5.44	9.7
Melting point ($^{\circ}C$)	Non-Beneficial	507	1083	8.2
Electrical resistivity($\Omega.m \times 10^{-8}$)	Non-beneficial	1.71	5.15	14.4
Machinability (%)	Beneficial	30	20	6.9
Cost of base material (C) - ($/kg)	Non-beneficial	23.45	29.55	9.2

3.3Selection of Optimum Material for the DC Components

The developed compromise programming model to select material for the DC armature core, armature shaft, and armature windings. The result shows that the model selectedJG-CORE Grain-oriented electrical steel; Carbon Steel SAE 1090; and Oxygen-free electronic Copper UNS C 10100as the bestmaterial with highest performance index of 65.61, 78.35, and 72.33

percentfor the D.C. armature core, shaft and winding respectively as shown in Table 7, 8 and 9.

Table 7.Performance index value (%) for a D.C. Armature Core for the Compromise Programming Algorithm

Mat. Code	Material Identity	Performance Index (%)	Rank
AC 1	H 085-27 Grain oriented electrical steel	61.31	3rd
AC 2	AK Steel DI-MAX M-15 Non-oriented electrical steel	52.12	7th
AC 3	ASTM A677 (36F155) Non-oriented electrical steel	64.74	2nd
AC 4	JN-CORE (50JN600) Non-oriented Electrical steel	57.01	6th
AC 5	AK Steel CARLITE M-4 Grain oriented electrical steel	60.03	4th
AC 6	AK Steel DI-MAX M-43 Non-oriented electrical steel	49.77	9th
AC 7	JG-CORE Grain-oriented electrical steel	65.61	1st
AC 8	H-1Carlite DR Grain-oriented electrical steel	51.14	8st
AC 9	AK steel DI-Max HF-10 Non-oriented Electrical steel	59.91	5th

Table 8. Performance index value (%) for a D.C. Armature Shaftfor the Compromise Programming Algorithm

Mat. Code	Material Identity	Performance Index (%)	Rank
AF1	Carbon Steel SAE 1006	52.24	6th
AF2	Carbon Steel SAE 1117	61.28	4th
AF3	Carbon Steel SAE 1010	42.05	8th
AF4	Carbon Steel SAE 1030	58.41	5th
AF5	Carbon Steel SAE 1090	78.65	1st
AF6	Carbon Steel SAE 1547	76.76	2nd
AF7	AISI 1020 low Carbon Steel	40.49	9th
AF8	Alloy Steel SAE 4027	63.77	3rd
AF9	AISI 1080 Steel	50.10	7th
AF10	AISI 1040 Carbon Steel	40.24	10th

Table 9. Performance index value (%) for a D.C. Armature Windingsfor the Compromise Programming Algorithm

Mat. Code	Material Identity	Performance Index (%)	Rank
AW1	Oxygen-free Silver bearing Copper (Temper wire) UNS C10500, H04	64.33	6th
AW2	Oxygen-free Silver bearing Copper (Temper wire) UNS C10700, H01	64.76	3rd
AW3	Oxygen-free extra-low phosphorus Copper, UNS C10700 H80	64.47	5th
AW4	Silver-bearing tough pitch Copper, UNS C11300	64.55	4th
AW5	Silver-bearing tough pitch Copper, UNS C11600, H08	56.29	9th
AW6	Oxygen-free electronic Copper UNS C 10100	72.33	1st
AW7	Zirconium Copper (Amzirc Brand Copper) wire UNS C 15000	68.98	2nd
AW8	Aluminium 2014-T4, 2014-T451	56.35	8th
AW9	Aluminium 2025-T6	63.16	7th
AW10	Aluminium 5005-H12	54.81	10th

3.4 Solution Quality Assessment

The quality of solutions of the model's procedure was tested, where the compromise gain was computed for the material selection solutions as presented in Table 10, Table 11, and Table 12. This indicates that the compromise gain for the best material is the same as that of the material selected by the proposed model for armature core, armature shaft, and armature windings respectively. In comparing the model's solution procedure to know which model is better in terms of performance, analysis was carried out based on three different weighting methods. First, with equal attribute preference, secondly, using the instrument attribute preference by adopting the modified nominal group technique, and lastly, with the existing attribute preference method. In each of the category, the DC machine components were used to test the performance of the models' procedure comprising: Compromise programming model, and Existing Algorithm (TOPSIS).However, with the use of the team-based compromised instrument, the compromise programming algorithm selected the same material types as the use of equal criteria weights. The selected material types areJG-Core Grain-oriented electrical steel, Carbon steel SAE 1090, and Oxygen-free electronic copper UNS C10100 with compromise gain values of 59.01, 59.34, and 59.81 percent for armature-core, armature-shaft, and armature-winding respectively. While with the existing attribute generated preferences, the proposed model selected different material type (ASTM A677 Non-oriented electrical steel) with a lower compromise gain of 56.69 percentcompared to the equal weights, andinstrument attribute preferences for the DC armature core.

Table 10: Compromise gain (%) associated with each material for the DC Armature Core

Code	Material Identity	Compromise Gain (%)
AC1	H 085-27 Grain oriented electrical steel	51.89
AC2	AK Steel DI-MAX M-15 Non-oriented electrical steel	46.58
AC3	ASTM A677 (36F155) Non-oriented electrical steel	56.69

AC4	JN-CORE (50JN600) Non-oriented Electrical steel	37.71
AC5	AK Steel CARLITE M-4 Grain oriented electrical steel	44.13
AC6	AK Steel DI-MAX M-43 Non-oriented electrical steel	45.34
AC7	JG-CORE Grain-oriented electrical steel	59.01
AC8	H-1Carlite DR Grain-oriented electrical steel	40.67
AC9	AK steel DI-Max HF-10 Non-oriented Electrical steel	51.25

Table 11: Compromise gain (%) associated with each material for the DC Armature Shaft

Code	Material Identity	Compromise Gain (%)
AS1	Carbon Steel SAE 1006	43.37
AS2	Carbon Steel SAE 1117	46.34
AS3	Carbon Steel SAE 1010	27.22
AS4	Carbon Steel SAE 1030	42.99
AS5	Carbon Steel SAE 1090	59.34
AS6	Carbon Steel SAE 1547	51.97
AS7	AISI 1020 low Carbon Steel	28.53
AS8	Alloy Steel SAE 4027	47.73
AS9	AISI 1080 Steel	42.15
AS10	AISI 1040 Carbon Steel	22.05

Table 12: Compromise gain (%) associated with each material for the DC ArmatureWindings

Code	Material Identity	Compromise Gain (%)
AW1	Oxygen-free Silver bearing Copper (Temper wire) UNS C10500, H04	51.65
AW2	Oxygen-free Silver bearing Copper (Temper wire) UNS C10700, H01	54.26
AW3	Oxygen-free extra-low phosphorus Copper, UNS C10700 H80	45.08
AW4	Silver-bearing tough pitch Copper, UNS C11300	52.59
AW5	Silver-bearing tough pitch Copper, UNS C11600, H08	52.26
AW6	Oxygen-free electronic Copper UNS C10100	59.81
AW7	Zirconium Copper (Amzirc Brand Copper) wire UNS C15000	58.20
AW8	Aluminium 2014-T4, 2014-T451	32.25
AW9	Aluminium 2025-T6	47.62
AW10	Aluminium 5005-H12	37.84

On the other hand, the TOPSIS (Existing) algorithm selected different material types: JG-core Grain-oriented electrical steel, Alloy steel SAE 4027, and Oxygen-free electronic copper UNS C10100 with corresponding compromise gain of 59.01, 47.73, and 59.81 percent respectively when equal criteria weights was applied. Moreover, with the use of team compromise instrument and existing attribute generated preferences, the existing algorithm selected material types: AK steel DI-Max HF-10 Non-oriented Electrical steel, Carbon steel SAE 1090, and Oxygen-free electronic copper UNS C10100 with corresponding compromise gain of 51.25, 59.34, and 59.81 percent respectively. The results also show that with the use of the compromise programing performs better than the TOPSIS algorithm when the equal criteria weights, TCI, and TOPSIS generated preferences were applied for the DC armature core, DC armature shaft, and Dc armature windings as indicated with the compromise gain of 59.01, 59.34, and 59.81 percent compared to 59.01, 47.73, and 59.81 percent respectively. Also, from the result it was observed that for the design of DC armature core adopting the team-compromise instrument preferences, a lower compromise gain of 51.25 percent is obtained when the existing algorithm (TOPSIS) is applied compared to the compromise gain of 59.01 percent for the compromise programming. This suggest that the compromise programming algorithm has a higher gain than the existing algorithm (TOPSIS), which makes it better.

The results obtained when Existing criteria preferences was applied to the three components shows that a lower compromise gain of 59.01, 47.43, and 37.84 percent as compared to the compromise gain of 56.69, 59.34, and 59.81 percent for the proposed model (compromise programming algorithm). This also confirms that the proposed model is better in terms of performance. Therefore, the quality value of 59.34% and 59.81% of the ideal value is better when compared to 47.73% and 37.84% of the ideal value for the design criteria for DC armature shaft and DC armature windings respectively because of the higher gain.

Table 13. Summary of Materials selected and their corresponding Compromise Gainon the Product/Components

Weighting Method	Components	Models			
		Multi-criteria Compromise Programming (MCP) Model		Existing Algorithm (EA) (TOPSIS)	
		Material Selected	Compromise Gain (%)	Material Selected	Compromise Gain (%)
Equal Attribute Preference	DC Armature Core	JG-CORE Grain-oriented electrical steel	59.01	JG-CORE Grain-oriented electrical steel	59.01
	DC Armature Shaft	Carbon Steel SAE 1090	59.34	Alloy Steel SAE 4027	47.73
	DC Armature Windings	Oxygen-free electronic Copper UNS C10100	59.81	Oxygen-free electronic Copper UNS C10100	59.81
Instrument Attribute preference	DC Armature Core	JG-CORE Grain-oriented electrical steel	59.01	AK steel DI-Max HF-10 Non-oriented Electrical steel	51.25
	DC Armature Shaft	Carbon Steel SAE 1090	59.34	Carbon Steel SAE 1090	59.34
	DC Armature Windings	Oxygen-free electronic Copper UNS C10100	59.81	Oxygen-free electronic Copper UNS C10100	59.81
Existing Attribute generated preferences	DC Armature Core	ASTM A677 (36F155) Non-oriented electrical steel	56.69	JG-CORE Grain-oriented electrical steel	59.01
	DC Armature Shaft	Carbon Steel SAE 1090	59.34	Alloy Steel SAE 4027	47.73
	DC Armature Windings	Oxygen-free electronic Copper UNS C10100	59.81	Aluminum 5005-H12	37.84

A compromise programming optimization model is primarily developed to solve the material selection problem of a DC machine armature design using a team-based approach. The material selection problem is faced with two major issues: Firstly, the design conflicts that often arise in engineering design environment because of team members may not be willing to compromise their point of view; secondly, the difficulty of comparing the quality of solution procedures from different multi-criteria approaches. In view of the above challenges, a procedure was formulated by adopting nominal group technique through which input data from experienced individual product design team members were translated into material selection parameter relevant to the proposed model in resolving the conflicts; and a model for comparing the quality of other multi-criteria optimization material selection solution procedures was developed and investigated.

The results indicate that the compromise programming optimization model is capable of identifying the best material among the various alternatives considering the design specification related material criteria for the DC armature core, armature shaft, and armature windings. The model also gives an opportunity for the design team or stakeholder's participation in the decision-making process. Also, a model for comparing the quality of model's solution procedures was established. This was achieved by comparing the compromise gains of known solution. This indicates that some significant difference in the power of achieving compromise gains in the use of the models' algorithms, which shows that the existing algorithm (TOPSIS) that was investigated had a lower performance compared to the compromise programming algorithm.

References

Abdullah M. B., and Rafikul I., (2011). Nominal Group Technique and its Applications in Managing Quality in Higher Education. *Journal of Commerce and Social Sciences.*

Al-Oqla, F.M., Sapuan, S.M., Ishak, M. R., Aziz N. A. (2015). Selecting Natural Fibers for Bio-Based Materials with Conflicting Criteria. American Journal of Applied Sciences, 12(1): 64-71. DOI: 10.3844/ajassp.2015.64.71.

Al-Oqla, F.M., Salit M.S., (2017). Material selection for natural fiber composites, Woodhead Publishing Series in Composites Science and Engineering. DOI:10.1016/B978-0-08-100958-1.09993-X

Ashby, M. (2010). Materials Selection in Mechanical Design. Butterworth-Heinemann, Oxford.

Ashish, G. and Satchidananda, D. (2004). Evolutionary Algorithms for Multi-Criteria Optimisation: A Survey. *International Journal of Computing & Information Sciences* 2.1: 38-57.

Ayrim, Y., Atalay, K. D., Can G. F. (2018). A new stochastic MCDM approach based on COPRAS, *International Journal of Information Technology & Decision Making*, 17: 857-882, ISSN: 0219-6220, DOI: https://doi.org/10.1142/S0219622018500116.

Babanli M.B., Prima F., Vermaut P., Demchenko L.D., Titenko A.N., Huseynov S.S., Hajiyev R.J., Huseynov V.M. (2019). Material selection methods: A Review. In book: 13[th]international Conference on Theory and Application of Fuzzy systems and Soft Computing – ICAFS.

Caliskan H., Kursuncu B., Kurbanoglu C., Guven S.V. (2013). Material selection for the tool holder working under hard milling conditions using different multi criteria decision making methods. *Materials and Design,* 45: 473-479.

Cavallini, C., Giorgetti, A., Citti P., Nicolaie, F. (2013). Integral aided method for material selection based on quality function deployment and comprehensive VIKOR algorithm, *Materials and Design*, 47: 27-34.

Chatterjee P, Manikrao A.V, Chakraborty S. (2010). Selection of industrial robots usingcompromise ranking and outranking methods, International Journal of Robotics and Computer-Integrated Manufacturing, 26:483-489

Chatterjee, P., Athawale, V.M. and Chakraborty, S. (2009). Selection of materials using
compromise ranking and outranking methods, *Materials & Design*, 30, 4043–4053.

Dev S., Aherwar A., Patnaik A., (2020). Material selection for automotive piston component using Enttropy- VIKOR method. *Silicon* 12(1), 155-169.

Farag M. M., (2006). Quantitative Methods of Materials Selection. Mechanical Engineers' Handbook: Materials and Mechanical Design 3rd ed. Myer Kutz. Ed. John Wiley & Sons, Inc.

Jahan A., Mustapha F., Ismail M.D., Sapuan S.M., Bahraminasab, M. (2011). A comprehensive VIKOR method for material selection. *Materials & Design,* 32(3): 1215-1221.

Jahan A., Mustapha F., Sapuan S.M., Ismail M.D., Bahraminasab, M. (2012). A Framework for Weighting of Criteria in Ranking Stage of Material Selection Process. *International Journal of Advanced Manufacturing Technology* 58(1):411-420

Kahraman C, Otay I. (2019). Fuzzy multi-criteria decision-making using neutrosophic sets. Springer, Vol 16, pp. 382-394, ISBN: 978-3-030-00044-8, DOI: http://doi.org/10.1007/978-3-030- 00045-5

Kumar R, Jagadish, Ray A. (2014). Selection of material for optimal design using multi-criteriadecision making, Procedia Materials Science, 6: 590-596.

MacPhail A. (2013). Nominal Group Technique: A useful method for working with young people. *British Educational Research Journal* 27.2: 161-170

Madic M, Antucheviciene J, Radovanovic M, Petkovic D. (2017). Determination of laser cutting process conditions using the preference selection index method, International Journal of Optics & Laser Technology, 89: 214-220, ISSN: 0030-3992, DOI: https://doi.org/10.1016/j.optlastec.2016.10.005.

Maniya K, Bhatt M.G, (2010). A selection of material using a novel type decision-making method: Preference selection index method, International Journal of Materials & Design, 31: 1785-1789, ISSN: 0261-3069, DOI: https://doi.org/10.1016/j.matdes.2009.11.020.

Megan N., Barrett S. C., Mallorie B., Siobhan M. H. (2015). A Systems Engineering Analysis of Team Approaches in Higher Education. *Proceedings 19th Triennial Congress of the IEA, Melbourne 9-14*

Nestsiarovich, K., Pon, D. (2020). Team Role Adoption and Distribution in Engineering Project Meetings. *Behaviorial Science*. DOI:10.3390/bs10020057

Odu and Charles-Owaba, (2017). Development of Team-compromised Instrument for Group Decision-making using Modified Nominal Group Technique. *International Journal of Latest Research in Engineering and Technology*. 3(3): 35-46.

Odu O. G. and Charles-Owaba O. E., (2013). Review of Multi-criteria Optimisation Methods: Theory and Applications. *IOSR Journal of Engineering (IOSRJEN),*3.10: 1-14.

Peng A., Xiao, X. (2013). Material selection using PROMETHEE combined with analytic network process under hybrid environment. *Materials and Design,* 47: 643-652.

Peng, J., Wang, JQ., Wang J., Yang, L., Chen, X., (2015). An Extension of ELECTRE to multi-criteria decision-making problems with multi-hesitant fuzzy sets. *Information Sciences.* 307: 113-126.

Rao R. V. (2008). A decision-making methodology for material selection using an improved compromise ranking method. *Material Design* 29: 1949-1954.

Roth, R.V., Field, F. and Clark, J. (2002). Materials Selection and Multi-attribute UtilityAnalysis. *Journal of Computer Aid Material Design* 1: 325-342.

Sahin, R. (2019). *COPRAS Method with Neutrosophic Sets, Fuzzy Multi-criteria Decision-Making Using Neutrosophic Sets.* Springer International Publishing, Cham, pp. 487-524, ISBN: 978-3-030-00045-5, DOI: https://doi.org/10.1007/978-3-030-00045-5_19.

Shanian A., Savadogo O., (2009). A methodological concept for material selection of highly sensitive components based on multiple criteria decision analysis. Expert Systems with Application. *An International Journal Archive* 36.2: 1362-1370.

Shanian A., Savadogo O. (2006). TOPSIS multiple criteria decision support analysis for material selection of metallic bipolar plates for polymer electrolyte fuel cell. *Journal of Power Sources* 159: 1095-1104.

Terpstra J., (1989). Developing a Design Team Approach. *Journal of Performance and Instruction.* 28(9): 33-35. https://doi.org/10.1002/pfi.4170280910

Thankachan, T.P., Bhasi, M., Madhi, G. (2010). Application of Concurrent Engineering in Manufacturing Industry. *International Journal of Computer Integrated Manufacturing*, 23(5): 425-440.

Van der V. A., Koch, P. (2010). Insight Design Optimization Methodologies. *ASM Handbook* 22B.

Xuan F.Z., Du, H. (2003). Manufacturing process and material selection in concurrent collaborative design of MEMS devices. Journal of Micromechanics and Microengineering. 13(5).

CHAPTER 20

A Review of the 1ffect of Industry 4.0 on Supply Chain Systems

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Abstract

One of the biggest challenges faced by manufacturing companies today is the significant increase in range of supply chain (SC) problems that must be solved. Unfortunately, the traditional planning approach cannot match the diversity of these complex problems. There is a huge place for leveraging new technologies in supply chain and logistics. Industry 4.0 aims to link smart operations and supply chain design and processes to salvage some of the operational shortfalls in the supply chain. Industry 4.0 is expected to be driven by emerging technology breakthroughs to help facilitate network of interaction of products and services with interconnection of robots and artificial intelligence. This technology is gaining so much attention in virtually all sectors particularly in manufacturing operations which require product flow at inbound and out-bound operations. This research is an exposition of Industry 4.0 technologies and how it can aid advance Supply Chain operations in manufacturing settings. The conclusion drawn from this research further reiterates on the gains of attaining high level of performance improvement with the implementation of innovative technologies in all aspect of supply chain network(s). Thus, effective integration of the Industry 4.0 technologies into supply chain operations will greatly improve productivity, product delivery, cost optimization, asset management, reliability, efficient processes, better sales and overall performance of manufacturing systems.

Keywords: Industry 4.0; supply chain; emerging technologies; in-bound and out-bound manufacturing operations.

1 Introduction

Recently, manufacturing organizations are faced with issues of business sustainability that may have significant impact on business operations (Luthra & Mangla, 2018). Another issue confronting manufacturing organization has to do with the complex processes involved in launching into digitization or managing new technologies. There is fundamental transformation in technology from classical to advanced high-tech innovations as a result of intricate rapidly evolving market conditions and consumer demand. There is equally need for organizational versatility and responsiveness (Oberg & Graham, 2016). The value of technical innovations has been recognized by organizations and technology is seen as a powerful strategic tool to ensure total sustainable efficiency and radical progressive change (Chavez et al., 2017; Shrivastava et al., 2016). In order to streamline business processes, several industries are already implementing e-business technology. High level of convergence and new innovations are required to boost operational efficiency in systems, (Srinivasan & Swink, 2015). The fourth industrial revolution require aggressive innovations which has to do with investing extensively in automation and robotics, and to incorporate more sophisticated technical philosophies and concepts to achieve total transformation (Uchechi et al., 2020).

This transformation will result into major production advantages, consequential in the development of smart factories by consenting to comprehensive integration of processes (Rashid & Tjahjono, 2016). Integrating effectively will in no doubt lead to profitability, cost optimization, higher reliability, improved management control and efficiency. Industry 4.0 requires great transformation in every aspect of business operation. Substantial investment and considerable time for effective planning is required to achieve this transformation. Since many companies are struggling to be at the top of the game in the new revolution, competitive strategies which require aggressive approach to responsiveness and diversity in every aspect of supply chain operation is significant (Um, 2017).

As the world's population continues to increase, the need for sustainability in terms of resource utilization becomes necessary (Islam & Managi, 2019; Gorman & Dzombak, 2018). Rahman et al., (2020) anticipated that the fourth industrial revolution will focus on the economic, social and environmental dimensions of sustainability. They equally believe that continuous study focused on technology developments should be strongly supported especially from the economic perspective. Karadayi-Usta (2019) stated that the adaptation of the fourth industrial revolution processes entail high level of adjustment of workforce and infrastructure. Companies operating traditionally must start looking deeper for solution to transformation in all aspect of their production process (Ku et al., 2020).

1.1. The Fourth Industrial Revolution (Industry 4.0)

Industry 4.0 is making rapid progress as a transformational process and this is happening at an exponential speed. The first industrial revolution which surfaced in the eighteenth century (1800) brought about significant improvements to the industries as a result of breakthrough in the steam engine discovery which was used as a source of electricity. This led to migration of people from rural to urban area. The second industrial revolution was witnessed in late 1800, with the implementation of scientific management theories to accelerate production in factories; this led to perfect arrangement of assembly line for mass production. The third industrial revolution witnessed around 1950 to 1960 led to the incorporation of computers and internets in offices and factories which facilitated timely completion of tasks and fast delivery of information and products. (Machesa et al. 2020).

The fourth industrial revolution as a current viewpoint, is gaining attention globally (Uche et al., 2020). This current technology and its enabling proficiencies, however, are believed to have the ability to manipulate available machines thereby making factories and organizations smart, this will greatly facilitate major changes in our society especially the ease of moving products in supply chain and logistics operations (Baur & Wee, 2015). Technology study dwells on exposition of current technologies to improve supply chain performance in manufacturing operations. Other section of this article cover: Supply chain at inbound and outbound operations; enabling technologies to enhance supply chain in the new revolution; the importance of industry 4.0 technologies in supply chain manufacturing and operations; challenges of industry 4.0 technologies; benefits of adopting the technologies; other industry 4.0 technologies which can bring about changes in supply chain network for advancement in manufacturing operations; conclusion and suggestion for further studies.

1.2. Supply Chain

Supply chain is a global network for delivery of products and services from source of raw materials to end customers. As the network of product interaction continues to get complex, new technologies are needed to match the complexity of the system. According to Govindan et al., (2017), good number of companies are currently participating and investing in high-tech innovations to help facilitate and develop collaboration mechanisms and active communication channels which will greatly improve performance of supply chain through improved and sharing of vital information. Supply chain performance improvement is vital in manufacturing organizations (Datta, 2017). For effective information exchange in any organization, supply chain integration is considered important and critical especially in end to end business process (Chavez et al., 2017). For great performance and improvement in supply chain network interaction, flexibility enabled by teamwork or strong collaboration is required (Datta, 2017).

Altay et al., (2018) also confirmed that dexterity and flexibility in supply chain have great impact on supply chain performance. Swift et al., (2019) further pointed out that transparency and higher perceptibility in supply chain network of interface will meaningfully improve effective performance. In supply chain management (SCM), traditional pattern of supply chain operations will not yield great result, therefore, implementing the fourth industrial revolution-enabling-technologies is a positive strategy to revolutionise SCM (Kache & Seuring, 2017). According to Luo et al., (2018), many organisations are currently adopting the new technologies through Electronic business solutions for total enhancement of their integration, capabilities and operational excellence.

1.3. Digitalized Supply Chain and Technologies of Industry 4.0

The fourth industrial revolution as earlier explained is a transformational process which involves the use of contemporary smart technologies to facilitate production, service delivery and other work operations in manufacturing or service systems. The use of technologies in manufacturing and business environment has facilitated Industry 4.0 (Wiengarten & Longoni, 2015). This digitalized global concept encompasses high level of connectivity among people, entrusted customers and agile manufacturing systems. The new revolution is such that supply chain operations are done timely as people are vastly connected with on-time information 24 hours a day and 7 days a week using application software, supply and delivery platforms and other vital means to access and exchange information timely. The current revolution, in no doubt will help companies adjust to swiftly ever-changing patterns in supply chain operations, enthralled on the behaviour of consumers and responding to stochastic and deterministic business operations at all levels.

Ground-breaking ideas, originality and agility are required to match the new revolution. There is no doubt that this new revolution has aided smart process organization which has equally set new standards for effective management of industries (Moeuf et al., 2017). Industry 4.0 is an occupational environment characterised by high-tech innovations which require the use of smart machines for communications. It must be noted that the more complex the supply chain, the more necessary it becomes to setup a structure for ground-breaking or innovative ideas for total business and system transformation. Three major causes of complexity in supply chain system have been discussed elsewhere (Handley, 2020). The sophistication of coordinating and synchronizing all interconnecting supply chain system is a serious task which require great attention and there is no doubt that the easy way or steps to adopt is the implementation of industry 4.0 technologies like artificial intelligence, Big Data Analytics, Internet of Things (IoT) and others (Oberg & Graham, 2016). Autonomous systems are not left out as one of the incredibly significant and advantageous industry 4.0 enabling technologies (Okwu, 2020). If these technologies are properly integrated, there is guarantee for development and total transformation in all aspect of manufacturing systems (Uche et al., 2020). Fisk (2020) listed three innovative companies in the year 2020 based on digitalized system of operations to include Telsa, Microsoft and Snap. This is a testament to the fact that the Industry 4.0 technologies will in no doubt lead to high innovation and performance in manufacturing systems. Some of the fourth industrial revolution enablers for supply chain sustainability are presented in Table 1.

Table 1: Fourth Industrial Revolution Technologies for Supply Chain Sustainability

S/N	Fourth Industrial Revolution Tech. Enabler(s)	Description	Accessible Literature
1	Meta-heuristic analysis of barriers in Supply Chain Activities	Improving supply chain performance by digitizing supply chain activities in supply chain sustainability	Ghasemian Sahebietal.,2017; Okwu et al. 2018; Machesa et al. 2020; Olayode et al. 2020.
2	Digitization of Supply Chain Activities	Technologies of Industry 4.0 and applications in Supply chain for sustainability.	Agrifoglio et al. 2017; Lu, 2017; Müller & Voigt, 2018; Agrawal, 2019.
3	Promoting Knowledge Management in Supply Chain (SC)	Supply chain performance and sustainability is improved by practicing knowledge management in SC.	Latif et al.,2017; Stoychevaetal.,2018; Aggarwal et al., 2019.
4	Commitment of Supplier for Sustainable procurement	High level algorithms for Sustainable procurement	Chen et al., 2018b; Seuring et al., 2019.

5	Supply Chain for SMEs	Optimization of Supply Chain for SMEs	Moeuf et al., 2017; Schwabetal., 2019.
6	Business Process Performance	Importance of procurement 4.0 in business operation	Banker, 2015; Baur & Wee, 2015; Garcia-Muiña et al., 2018; Bag et al., 2020.
7	Smart Factory Operations and IoT	Technologies of Industry 4.0 can facilitate process Improvement in factories	Mishra et al. 2016a. Chen et al. 2018a.
8	Big data Analytics	Improvement in operations management	Acter et al., 2016; Babiceanu & Seker, 2016; Addo-Tenkorang & Helo, 2016; Mishra et al. 2016b; Gunasekaran et al., 2017; Nguyen et al. 2017; Papadopoulos et al., 2017; Wamba, 2017; Choi et al., 2018; Gunasekaran et al., 2018; Olayode et al., 2020.
9	3D Printing Technology		Holmstrom & Gutowski, 2017; Feldmann & Pumpee, 2017.
10	Robotics and Automation, AI and ML.	Path Planning and Navigation of Autonomous Vehicles	Jazdi, 2014; Ukaegbu, 2020.

2 Technologies of the Fourth Industrial Revolution

This section is focused on the major Industry 4.0 technologies that will help facilitate supply chain in manufacturing operations. Some of the industry 4.0 technologies include: Big data analytics, Cloud computing, 3D printing technology, Machine learning and Artificial Intelligence, Internet of Things (IoT), Cyber-Physical Systems, Automation and Robotics and others. These are further explained in detail.

2.1 Big Data Analytics

Big data analytics is a current global digitalization which involves the extraction of knowledge in form of dataset from systems thereby facilitating data-driven decision-making. Big data analysis has been recognized in literature as an area of digital technology which is quite elaborate and extremely useful in decision making process. Robust and unprecedented information can be gathered and converted to digital format. This has become extremely useful since past information can be obtained and stored for future use. There is no doubt that big data analytics can provide tremendous opportunity for maximizing the use of capacity, enhancing customer service, developing new logistics business models and reducing risk in a system.

2.2. Cloud Computing

Cloud computing is a global computing technology capable of computing and storing massive amount of data in such a way that organizations have higher chances of expanding and performing effectively at a larger space (Mitra et al., 2017). Supply chain design and processes can be obtained, computed and stored for future use based on cloud computing technology. Branger & Pang (2015) are of the opinion that cloud manufacturing is anticipated to appear as the next and highly effective model and driver of manufacturing in the fourth industrial revolution. According to Xu et al., (2018), cloud computing can facilitate data sharing and exchange efficiently, thereby promoting complex decision making in manufacturing systems.

2.3. 3D Printing Technology

High-tech automatic manufacturing is possible using 3D printing technology. 3D printing or additive manufacturing offers new potential in manufacturing systems as products can be made available to customers at the right time. 3D printers could be shipped to manufacturing sites where parts can be quickly fabricated on site. Most manufacturing companies are currently introducing the innovative technology of 3D printing to their production process, taking the next step towards fully advanced and automatic manufacturing. This process is based on an automatic production process where products are made faster and easier than ever before and which allow consumers get easy access to products made by manufacturers. Inventory buildup is almost impossible since the exact number of products required periodically can be made available. Also, customized models can be made available to customers. The use of 3D printing at different level of supply chain will enhance service delivery, cut cost and inventory buildup, increase flexibility in manufacturing and product individualization will increase (Feldmann & Pumpe, 2017; Holmstrom & Gutowski, 2017).

2.4. Machine Learning and Artificial Intelligence

Machine learning is the study of computer algorithms and Artificial intelligence is the simulation of intelligent behaviour of machines (Machesa et al. 2019). Very few companies are extremely dominant, considering the ground-breaking and ongoing trend towards computerization or automation and sustained advances in the world of computing, Artificial Intelligence (AI) is speedily changing the pattern of operation of logistics providers.

2.5. Internet of Things (IoT)

The Internet of Things (IoT) implies the interconnection of things (physical objects) using the internet for easy communication and sharing of information with other systems and devices. In a simpler term IoT is the connection between objects and machines using the internet. This is another new wave of technology which can connect practically any useful information to the internet and speed up logistics driven by data. This systematically means that information can easily be sent, received, processed and stored in the form of useful data which can dynamically contribute in event-driven, self-steering, logistics processes. IoT has unlimited capabilities where data can be used from the linked objects to produce actionable insights that drive improvement and innovative ideas to achieve payoffs for logistics providers. Jazdi (2014) concerted his study on the influence of connecting several devices in a system under IoT and the impact of cyber physical systems in the life of individuals daily. He further argued that the fourth industrial revolution will have huge impact on the advances of new technologies and consumers lifestyle.

2.6. Cyber-Physical Systems

Cyber-physical systems are machines in which mechanisms are monitored, controlled or computed by algorithms. It is the connection of machines to interact, visualize and make decision autonomously. Data collected by smart sensors can help professionals understand critical situations faster and more accurately while implementing this technology in in-process supply chain system. This will enable customers to be informed about the pattern of product flow or services rendered. Autonomous vehicles will be made available in few years as many companies are currently testing self-driving vehicles on road in different countries of the world. It is certain that most manufacturing companies are getting ready to launch autonomous ground robots in the form of lorries, buses and vans where vehicle to vehicle can communicate with each other, accidents will be reduced, traffic congestion in unsignalized road intersections will be a thing of the past, new ways of monitoring navigational pattern of vehicles will be established.

2.7 Automatic Guided Vehicles (AGV) and Unmanned Aerial Vehicles (UAV)

One of the useful Industry 4.0 technologies that will enhance supply chain is the autonomous robots. It could be ground robot - automatic guided vehicle or flying robot - unmanned aerial vehicles. AGVs for product distribution in manufacturing settings will be of great economic benefit since they are programmed to function autonomously. AGVs can be implemented in factory settings as material handling devices or delivery agents for moving items from one location to another. Unmanned aerial vehicles (UAV) will be particularly useful either for moving raw materials to factories or for delivering ready items to customers at various locations.

3 Importance of 4IR Technologies in Supply Chain and Manufacturing Operations

3.1 Big data analysis - has been recognized in literature as an area of digital technology which is quite elaborate and useful in supply chain operation. A good example is demonstrated in a research conducted by Simchi-Levi & Wu (2018) which focused on the analysis and application of big data in retail channel. Price optimization model was used for the analysis as retailers strive to grow their revenue, margins and market share. This technology has equally been demonstrated by Nguyen et al., (2017) as a prevalent technique in transportation and logistics. Other areas where big data analytics has been applied in supply chain management include(s) transportation and logistics operation, inventory system in warehousing, routing optimization, safety management (Gunasekaran et al., 2017; Nguyen et al., 2017; Zhong et al., 2017).There is no doubt that big data will provide tremendous opportunity for maximizing the use of capacity, enhancing customer service, developing new logistics business models and reducing risk in a system.

3.2. Cloud Computing is a high-level computing technology capable of computing and storing massive amount of data in such a way that organizations will have higher chances of expanding and performing effectively at a larger space (Mitra et al., 2017). Supply chain design and processes can be obtained, computed and stored for future use based on cloud computing technology. Branger and Pang (2015) are of the opinion that that cloud manufacturing is anticipated to appear as the next and highly effective model and driver of manufacturing in the fourth industrial revolution. According to Xu et al., (2018) cloud computing can facilitate data sharing and exchange efficiently thereby promoting complex decision making in manufacturing systems. Successful implementation of Industry 4.0 is based on intelligent computing of which cloud-based manufacturing is a key driver. The service-orientation in the field of manufacturing is supported and facilitated via cloud computing (Xu et al., 2018).

3.2. 3D-Printing in Manufacturing Systems - Difficult to weld components can be remanufactured with ease and delivered to customers timely using 3D printing techniques. This technology is quite expensive but offer robust benefits which include: It is faster and more precise than the traditional system; wastage is reduced via 3D printing; Internal object can be built unlike traditional machining; complex stochastic structures difficult to produce via conventional method can be produced with ease; It uses the same language used by classical machining process; fantastically complex objects can be produced; lighter weight and stronger structures can be made; customization process is quite affordable; products are delivered timely. In addition, personalized models can be delivered much more easily and quickly to customers as a result of short distance between production and customer. This application is particularly useful in supply chain operations from manufacturing of parts to redesigning of full components for global supply chain production at inbound and outbound level.

3.3. Machine Learning (ML) and Artificial Intelligence (AI) - will make a big difference especially in promoting supply chain processes. Looking at the recent trend in the dynamics and operational performance of companies, it is a clear indication that companies like google, Facebook, Uber operate in such a manner that a single company controls a very large part of the market.

3.4. Internet of Things (IoT) and Cyber-Physical Systems- Internet of things and cyber-physical systems work hand in hand. Considering the manufacturing industry, smart machines can work with humans for easy assembly task, they can also operate autonomously and communicate directly with manufacturing systems, leveraging the capability of the Internet of things, solving complex problems and making decisions independently. This will have an extraordinarily strong impact on the factory of the future. For example, advanced manufacturing process and rapid prototyping will make it very possible for customers to order any kind of product without significant increase in cost. These technologies will greatly reduce cost and time associated with product design and engineering of the production process while prompting simulation and virtual testing throughout the product lifecycle. Advanced human machine interaction handling systems will help increase safety in production plant and reducing physical demand of workers and physical handling of products by man.

3.5. Automatic Guided Vehicles (AGV) and Unmanned Aerial Vehicles (UAV) - Autonomous vehicles offer very specific benefits which include: Safety – Most accidents are caused by human errors, the use of computer algorithms and automation to drive machines or vehicles offer a perfect solution in terms of service delivery; effective coordination and navigational endurance; reduced cost of delivery; great economic benefit as autonomous vehicles are programmed to perform task for a very long time with great endurance limit; social exclusion can be removed by autonomous vehicles; they are more transformational, cleaner, affordable, safer and highly efficient.

4 Discussion

It is no doubt that a new data architecture and global network has emerged where people and machines can interconnect for effective and continuous interaction. This has led to high standard of safety and has changed the society and our daily lives. Currently, the traditional approach to the supply chain is exceedingly popular, particularly in developing and emerging nations. The fourth industrial revolution has ushered modern technological advancement and information network infrastructure to facilitate things. A global network has emerged, which allow direct and continuous interaction between man and machine. This is gradually changing the way we think and carry out our daily operations. Different technologies to support the fourth industrial revolution has been discussed which include big data analytics; 3D printing technology, Internet of things, artificial intelligence and robotics. These technologies are useful to facilitate supply chain operations. There is no doubt that the technologies of the fourth industrial revolution will greatly enhance supply chain design, processes, engineering and management. Considering product delivery aspect, the use of autonomous systems (aerial and ground robots) will facilitate delivery process timely inbound and outbound operations.

4.1. Challenges of the Industry 4.0 Technologies in Supply Chain Operations

According to Elon Mosk, artificial intelligence is considered the biggest existential threat to humanity (Guardian, 2014). While many workers fear losing their jobs, some see AI as a terminator that will wipe out all humans from the surface of the earth. It is important to focus on the impact of the current revolution in our society especially in the manufacturing and service industries. These new technologies will no doubt, significantly transform our system, workforce and path planning process. In the physical world, it is important to take safety into consideration before deploying Industry 4.0 technologies. There is a huge disconnect between using a traditional or non-autonomous vehicle for conveyance and transportation of materials and using a self-driving vehicle. Synchronization of autonomous systems which are key players in the scene of activities is a complex task which requires systematic and strategic approach for effective coordination.

With the ever-growing demand of data in every industry, the need to safeguard and manage sensitive data has increased dramatically. Many countries are already implementing strict regulations, a trend that likely to continue into a conceivable future. ML and AI are required harness and secure data for company use. One of the major challenges with this new technology is the issue of security. However, in the coming years there is tendency of increase in decentralized technology for data security, integrity and privacy especially for machine to machine interaction.

In manufacturing and supply chain operations where machine agents and AIs are the key players, the instructions given to AI must be tested and confirmed satisfactory before using the technologies to avoid any form of disaster. Deploying the technologies could be so complex with multifaceted operational constraints. Setups need to be dynamically routed through a network and other machine agents; such networks are highly unpredictable and much volatile.

Considering the current Industry 4.0 technologies already discussed in this study, there are still lot and more technologies evolving, but very often most of the technologies may not scale through real-life or real-world applications. Some may end up as useful techniques in teaching space or research for solving numerical or quantitative problem solving and not really techniques that can drive innovations. Looking closely at the new technologies discussed in this context, artificial intelligence, robotics and machine learning tend to scale perfectly in supply chain operations if well implemented. There is a great advantage of the new Industry 4.0 technologies over the classical techniques in supply chain management and manufacturing operations.

4.2. Benefits of the Industry 4.0 Technologies in Supply Chain Operations

Fully integrated digital supply chain requires dynamically adjustable and synchronized network. Artificial Intelligence (AI), Machine learning (ML) and Robotics are particularly useful technologies in the current revolution especially in supply chain operations. There is no doubt that they will greatly support intelligent machine agents for product monitoring and fast delivery in manufacturing systems. ML will be fundamental to optimizing production processes and reducing lead time. Some benefits of Industry 4.0 technologies include:

(i) Already available infrastructures can be reused in supply chain operations especially where the methods are well implemented by strategists and managers of manufacturing companies managing the setup. Systems that are in place can integrate with already existing AI infrastructure to facilitate the network system. Many of the machines learning type of approaches can perfectly fit in. A good example is dynamic routing as a new technology, experts can make good use of already existing routing in place in a manufacturing company add the python script to execute task effectively, same is applicable using reinforcement learning and other innovative Industry 4.0 technologies for supply chain operations.

(ii) Faster return on investment - At every point in time, product and service-based organizations currently springing up globally, require network of product or service interaction either at in-bound, in-process or out-bound operations. Some produce similar products where competition abounds. Standing tall and making a difference is a function of strategies implemented in the new era. As already discussed, technologies of the fourth industrial revolution will go a long way to facilitate supply chain network which remain particularly useful in manufacturing companies with great possibility of achieving faster return on investment.

(iii) Work performance can be easily measured- In a manufacturing company or establish, workers are employed to facilitate work operations for efficiency, effectiveness, productivity and profitability. There is no doubt that performance of task could be overly complex and diverse since contextual and environmental factors are considered. It is therefore extremely hard to make a fair assessment of performance of workers in the system. Knowing the rate of performance and strength of workers in a chain system of work operation is important to rate the efficiency, fulfilment or task accomplishment rate of the company. This will equally help assign the right person to the right task. The traditional approach of using the time study -method study and work measurement is time wasting. Machine learning based approaches like extra trees, deep learning algorithm and others can help achieve work performance as they have the capacity and capability to train and view the task by focusing on the history of workers to give a very good prediction of the duration of the task and possible expectation of workers in a complex supply chain network and manufacturing operations.

(iv) Inventory management is equally important aspect of supply chain and the traditional approach often used in manufacturing organizations is time wasting and fundamentally based on assumptions regarding demand distribution which has never guaranteed optimality in terms of replenishment strategy. In the era of fourth industrial revolution, it is important to implement the AI technology focused on deep reinforcement learning for perfect inventory control where learning process is automatic, the process is fast, and no assumptions are required. Though there may be possibility of slow convergence.

(v) Cyber physical systems and machine to machine communication will all work together to share data from the shop floor in order to reduce idle time. Intelligent drones can be used to supply or deliver products timely and analyze vast demand of data's in seconds. Companies like Uber and Google are extremely strong in the machine learning space when it comes to autonomous vehicles. The method adopted by uber which require building retrofit kits, autonomous sensors, and high-level software technologies has made the company stand tall among many other corporate organizations. The interesting part is that the already established knowledge can be reused for developing vehicles and making them autonomous.

5 Conclusion

Industry 4.0 is the major trend in global manufacturing. Organizations need to follow digital transformation to stay competitive and equally achieve sustainability. This ensures gaining environmental, social and economic advantages. This study is focused on exposition of industry 4.0 technologies and the benefits of integrating the technologies into supply chain operations. There are numerous technologies springing up, but the vital few has been discussed. Industry 4.0 technologies, if effectively implemented in supply chain, will greatly improve productivity in manufacturing operations as products will be delivered timely from source to destinations. Other advantages to be gained from the new technology include better asset management, lower cost, better sales and overall improvement in financial performance. To achieve all these, there will be need for strategic planning, improvement in high-tech, holistic global leadership, business process transformation and best knowledge for global practices.

References

Aggarwal, A., Gupta, S., Ojha, M.K., (2019). Evaluation of key challenges to industry 4.0 inIndian context: a Dematel approach. Advances in Industrial and ProductionEngineering. Springer, Singapore, pp. 387–396.

Agrifoglio, R., C. Cannavale, E. Laurenza, and C. Metallo. (2017). "How Emerging Digital Technologies Affect Operations Management through Co-Creation. Empirical Evidence from the Maritime Industry" Production Planning & Control 28 (16): 1298–1306. doi:10.1080/09537287.2017.1375150.

Akter, S., S. F. Wamba, A. Gunasekaran, R. Dubey, and S. J. Childe. (2016). "How to Improve Firm Performance Using Big Data Analytics Capability and Business Strategy Alignment?" International Journal of Production Economics 182: 113–131. doi:10.1016/j.ijpe.2016.08.018.

Addo-Tenkorang, R., and P. T. Helo. (2016)."Big Data Applications in Operations/Supply-chain Management: A Literature Review."Computers & Industrial Engineering101: 528–543.

Bag, S., Wood, L.C., Mangla, S.K., Luthra, S., (2020). Procurement 4.0 and its implications on business process performance in a circular economy. Resour. Conserv. Recycl.152, 104502.

Babiceanu, R. F., and R. Seker. (2016). "Big Data and Virtualization for Manufacturing Cyber-Physical Systems: A Survey of the Current Status and Future Outlook." Computers in Industry 81 (128): 128–137. doi:10. 1016/j.compind.2016.02.004.

Banker, S. (2015). "The smart factory, Industry 4.0, and supply chain optimization." http://logisticsviewpoints.com/2015/05/14/the-smart-factory- Industry-4-0-and-supply-chain-optimization.

Baur, C., and D. Wee. (2015). "Manufacturing's next act – Industry 4.0." Seko. http://www.supplychain247.com/article/manufacturings_next_ act_industry_4_0.

Brettel, M., N. Friederichsen, M. Keller, and M. Rosenberg. (2014). "How Virtualization, Decentralization and Network Building

Change the Manufacturing Landscape: An Industry 4.0 Perspective." International Journal of Science, Engineering and Technology 8 (1): 37–44.

Branger, J. and Pang, Z. (2015), "From automated home to sustainable, healthy and manufacturing home: a new story enabled by the Internet-of-Things and Industry 4.0", Journal of Management Analytics, Vol. 2 No. 4, pp. 314-332.

Chen, B., Wan, J., Shu, L., Li, P., Mukherjee, M., Yin, B., (2018a). Smart factory of industry4.0: key technologies, application case, and challenges. IEEE Access 6, 6505–6519.

Chen, Y., Wang, S., Yao, J., Li, Y., Yang, S., (2018b.) Socially responsible supplier selection and sustainable supply chain development: a combined approach of total interpretive structural modeling and fuzzy analytic network process. Bus. Strategy Environ. 27(8), 1708–1719.

Choi, T. M., S. W. Wallace, and Y. Wang. (2018). "Big Data Analytics in Operations Management."Production and OperationsManagement25: 443.doi:10.1111/poms.12838Crane A. "Orchestrating the complex supply chain," *Supply Chain Management Review*, 2020.

Chavez, R., W. Yu, M. A. Jacobs, and M. Feng. (2017). "Data-Driven Supply Chains, Manufacturing Capability and Customer Satisfaction." Production Planning & Control 28 (11–12): 906–918. doi:10.1080/ 09537287.2017.1336788.

Datta, P. P. (2017). "Enhancing Competitive Advantage by Constructing Supply Chains to Achieve Superior Performance." Production Planning & Control 28 (1): 57–74. doi:10.1080/09537287.2016.1231854.

Fisk P (2020)., "Snap , Microsoft and Tesla are the world ' s most innovative companies of (2020) , according to Fast Company … Siemens , Sprout World and Elvie lead in Europe," *The Genius Works*.

Garcia-Muiña, F., González-Sánchez, R., Ferrari, A., Settembre-Blundo, D., (2018). The paradigms of industry 4.0 and circular economy as enabling drivers for the competitiveness of businesses and territories: the case of an italian ceramic tiles manufacturing company. Soc. Sci. 7 (12), 255.

Gorman, M.R., Dzombak, D.A. (2018). A review of sustainable mining and resource management: transition from the life cycle of the mine to the life cycle of the mineral. Resource Conservation Recycl. 137, 281-291.

Govindan, K., S. K. Mangla, and S. Luthra. 2017. "Prioritising Indicators in Improving Supply Chain Performance Using Fuzzy AHP: Insights from the Case Example of Four Indian Manufacturing Companies." Production Planning & Control 28 (6–8): 552–573. doi:10.1080/09537287.2017.1309716.

Gunasekaran,A., T. Papadopoulos, R. Dubey, S. F. Wamba, S. J. Childe, B. Hazen, and S. Akter.(2017)."Big Data and Predictive

Analytics for Supply Chain and Organizational Performance."Journal of Business Research70: 308–317.

Gunasekaran, A., Y. Y. Yusuf, E. O. Adeleye, and T. Papadopoulos. (2018)."Agile Manufacturing Practices: the Role of big Data and Business Analytics with Multiple Case Studies."International Journal of Production Research56: 385–397. Published online.doi:10.1080/00207543.2017.1395488.

Ghasemian Sahebi,I.,Arab,A.,SadeghiMoghadam,M.R.,(2017).Analyzing the barriers to humanitarian supply chain management: a case-study of the Tehran Red Crescent Societies. Int. J. Disaster Risk Reduct. 24,232–241,http://dx.doi.org/10.1016/j.ijdrr.2017.05.017.

Handley C.O (2020). "The 3 Causes Fueling Suppy Chain Complexity," *Thomas Industry Update*.

Islam, M., Managi, S., (2019). Green growth and pro-environmental behavior: sustainable resource management using natural capital accounting in India. Resour. Conserv.Recycl. 145, 126–138.

Jazdi, N., (2014). Cyber physical systems in the context of Industry 4.0. In: Automation, Quality and Testing, Robotics, 2014 IEEE International Conference on. IEEE, pp. 1–4.

Latif,H.H.,Gopalakrishnan,B.,Nimbarte,A.,Currie,K.,(2017).Sustainabilityindexdevelopmentformanufacturingindustry.Sustain.EnergyTechnol.Assessments.24,82-95,

http://dx.doi.org/10.1016/j.seta.2017.01.010.

Luthra, S., Mangla, S.K., (2018a). Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies. Process Safety Environ. Prot. 117,168–179.

Luthra, S., Mangla, S.K., (2018b). When strategies matter: adoption of sustainable supplychain management practices in an emerging economy's context. Resour. Conserv.Recycl. 138, 194–206.

Kache, F., and S. Seuring. (2017). "Challenges and Opportunities of Digital Information at the Intersection of Big Data Analytics and Supply Chain Management." International Journal of Operations & Production Management 37 (1): 10–36. doi:10.1108/IJOPM-02-2015-0078.

Luo, W., Y. Shi, and V. G. Venkatesh. (2018). "Exploring the Factors of Achieving Supply Chain Excellence: A New Zealand Perspective." Production Planning & Control 29 (8): 655–667. doi:10.1080/09537287.2018.1451004.

Mishra, D., A. Gunasekaran, S. J. Childe, T. Papadopoulos, R. Dubey, and S. Wamba. (2016a) "Vision, Applications and Future Challenges of Internet of Things: A Bibliometric Study of the Recent Literature." Industrial Management & Data Systems 116 (7): 1331–1355. doi:10.1108/IMDS-11-2015-0478.

Mishra, D., A. Gunasekaran, T. Papadopoulos, and S. J. Childe. (2016b.). "Big Data and Supply Chain Management: A Review and Bibliometric Analysis." Annals of Operations Research 270 (1–2): 1–24. https://link. springer.com/article/10.1007/s10479-016-2236-y. doi:10.1007/s10479-016-2236-y.

Moeuf, A., R. Pellerin, S. Lamouri, S. Tamayo-Giraldo, and R. Barbaray. (2017). "The Industrial Management of SMEs in the Era of Industry 4.0." International Journal of Production Research 56 (3): 1–19. doi:10.1080/ 00207543.2017.1372647.

Machesa MGK ; LK Tartibu ; MO Okwu (2020) Sustainable Supplier Selection in a Paint Manufacturing Company Using Hybrid Meta-Heuristic Algorithm. 31st SAIIE. Conference, Capetown, South Africa.

MO. Okwu; MGK Machesa ; LK Tartibu (2020) Fourth Industrial Revolution and Sustainable Impact in Autonomous Fleets for Effective Supply Chain Network in Manufacturing Systems. 31st SAIIE Conference, Capetown, South Africa.

M.O. Okwu and Tartibu L (2020) Sustainable Supplier Selection in the Retail Industry: An ANFIS- Based Evaluating Methodology. *Journal of Engineering and Business Management*, SAGE. DOI: 10.1177/1847979019899542

Müller, J.M., Voigt. K.I (2018): The impact of Industry 4.0 on supply chains in engineer-to-orderindustries—an exploratory case study.

IFAC-PapersOnLine51, 122–127 .https://doi.org/10.1016/j.ifacol.2018.08.245.

Nguyen, T., L. Zhou, V. Spiegler, P. Ieromonachou, and Y. Lin.(2017)."Big Data Analytics in Supply Chain Management: A State-of-the-art Literature Review."Computers & Operations Research, published online.doi:10.1016/j.cor.2017.07.004.

Oberg, C., and G. Graham. (2016). "How Smart Cities Will Change Supply Chain Management: A Technical Viewpoint." Production Planning & Control 27 (6): 529–538. doi:10.1080/09537287.2016.1147095.

Olayede O.I. (2020) Application of Artificial Intelligence on the Traffic Congestion of Autonomous Vehicles at a Signalized Road Intersection. *Procedia CIRP, Science Direct pp 194-200.* https://doi.org/10.1016/j.procir.2020.02.167

Okwu M.O., Olufemi A. **(2018)** A Comparative Study of Artificial Neural Network (ANN) and Adaptive Neuro-Fuzzy Inference System (ANFIS) Model in Distribution System with Non-Deterministic Inputs, *International Journal of Engineering and Business Management, SAGE.* Volume 10. 1-17. DOI: 10.1177/1847979018768421.

Karadayi-Usta, S., (2019). An Interpretive Structural Analysis for Industry 4.0 Adoption Challenges. IEEE Trans. Eng. Manag..

Ku, C.C., Chien, C.F., Ma, K.T., (2020). Digital transformation to empower smart production for Industry 3.5 and an empirical study for textile dyeing. Comput. Ind. Eng. 142,106297.

Gunasekaran,A., T. Papadopoulos, R. Dubey, S. F. Wamba, S. J. Childe, B. Hazen, and S. Akter.(2017)."Big Data and Predictive Analyticsfor Supply Chain and Organizational Performance."Journal of Business Research70: 308–317.

Guardian (2014) https://www.theguardian.com/technology/2014/oct/27/elon-musk-artificial-intelligence-ai-biggest-existential-threat. Accessed: 21/10/2020.

Holmström, J., and T. Gutowski.(2017). "Additive Manufacturing in Operations and Supply Chain Management: No Sustainability Benefitor Virtuous Knock-on Opportunities?"Journal of Industrial Ecology, published online.doi:10.1111/jiec.12580.

Jazdi N. (2014) Cyber physical systems in the context of Industry 4.0. DOI:10.1109/AQTR.2014.6857843 IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR).

Mitra, A., Kundu, A., Chattopadhyay, M. and Chattopadhyay, S. (2017), "A cost-efficient one-time password-based authentication in cloud environment using equal length cellular automata", Journal of Industrial Information Integration, Vol. 5, pp. 17-25.

Nguyen, T., L. Zhou, V. Spiegler, P. Ieromonachou, and Y. Lin.(2017)."Big Data Analytics in Supply Chain Management: A State-of-the-artLiterature Review."Computers & Operations Research, published online.doi:10.1016/j.cor.2017.07.004.

Papadopoulos, T., A. Gunasekaran, R. Dubey, N. Altay, S. J. Childe, and S. F. Wamba.(2017)."The Role of Big Data in Explaining DisasterResilience in Supply Chains for Sustainability."Journal of Cleaner Production142 (2): 1108–1118.

Rashid A. and Tjahjono B., (2016).Achieving Manufacturing Excellence Through the Integration of Entreprise Systems and Simulation. Production Planning and Control. The Management of Operations, 832-852. https://doi.org/10.1080/09537287.2016.1143132.

Rahman S.M., Perry N., Miller J. M., Kim. J., Laratee B. (2020) End of life in Industry 4.0. Ignored as beofe? Resource Conv. Recycling, 154-105139.

Simchi-Levi, D., and M. X. Wu.(2018)."Powering Retailers Digitization Through Analytics and Automation." International Journal ofProduction Research56 (1–2): 809–816.

Shamsuzzoha, A., C. Toscano, L. M. Carneiro, V. Kumar, and P. Helo. (2016). "ICT-Based Solution Approach for Collaborative Delivery of Customised Products." Production Planning & Control 27 (4): 280–298. doi:10.1080/09537287.2015.1123322.

Srinivasan, R., and M. Swink. (2015. "Leveraging Supply Chain Integration through Planning Comprehensiveness: An Organisational Information Processing Theory Perspective." Decision Sciences 46 (5): 823–861. doi:10.1111/deci.12166.

Swift, C., V. D. R. Guide, Jr., and S. Muthulingam. (2019). "Does Supply Chain Visibility Affect Operating Performance? Evidence from Conflict Minerals Disclosures." Journal of Operations Management 65 (5): 1–24. doi:10.1002/joom.1021.

Schwab,L.,Gold,S.,Reiner,G.,(2019). Exploring financial sustainability of SMEs during periods of production growth: a simulation study. International Journal of Production Economics 212, 8–18, http://dx.doi.org/10.1016/j.ijpe.2018.12.023.

Uchechi Ukaegbu; Lagouge Tartibu ;M. Okwu (2020) Deep learning hardware accelerators for high performance in Smart Agricultural Systems: An overview. 31st SAIIE. Annual Conference, Capetown, South Africa.

Uchechi Ukaegbu; Lagouge Tartibu ; Laseinde Timothy; Olayode Issac (2020) A deep learning algorithm for detection of potassium deficiency in a red grapevine and spraying actuation using a raspberry pi3. icABCD 10.1109/icABCD49160.2020.9183810.

Wamba, S. F., A. Gunasekaran, S. Akter, S. J. F. Ren, R. Dubey, and S. J. Childe. (2017). "Big Data Analytics and Firm Performance: Effects of Dynamic Capabilities." Journal of Business Research 70: 356–365. doi: 10.1016/j.jbusres.2016.08.009.

Wiengarten, F., and A. Longoni. (2015). "A Nuanced View on Supply Chain Integration: A Coordinative and Collaborative Approach to Operational and Sustainability Performance Improvement." Supply Chain Management: An International Journal 20 (2): 139–150. doi:10.1108/SCM-04-2014-0120.

Xu F., Feng L. (2019). The influence of big data system for used product agreement on manufacturing- remanufacturing operations. Journal of Clean Production. 209.

Zhong, R. Y., C. Xu, C. Chen, and G. Q. Huang.(2017)."Big Data Analytics for Physical Internet-based Intelligent Manufacturing ShopFloors."International Journal of Production Research55 (9): 2610–2621.

CHAPTER 21

Computer Aided Design (CAD) of a Vertical Transportation System in High-rise Building: Case of Ivory Tower, University of Ibadan Ibadan

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Abstract
In compliance with the global building regulations, building with at least three floors and above must have lift. The Ivory Tower building in the University of Ibadan, Ibadan, Nigeria, for decades has been underutilized due to lack of convenient and less stressful vertical movement of the people within the building. The need therefore arise for the lift design system for the building. Analytical work involves in the design of lift system in building is often time consuming, laborious, rigorous and tedious. This work therefore aims at design and specifies lift system for the Ivory tower building using Computer Aided Design (CAD) approach. Standard Equation based on the lift system design was adopted in the study. Data were collected from the building site which includes the floor to floor distances and floor dimensions. The population in the 10-Storey Ivory tower building coupled with the 4 Storey Administrative building attached to it was determined using the Chartered Institute of Building Services Engineers (CIBSE) design guide (Peters R D Green 1995 and CIBSE 1991). Lift performance analysis for the building was then carried out using FORTRAN IV programming language. Appropriate and suitable lift and its specifications was then selected for the building. The maximum capacity, number of passengers, velocity, Round Trip Time, Handling Capacity, Interval, and number of lift cars of the selected lift system based on the quality of service are 450kg, 6 passengers, 2.0 m/s, 80.3seconds, 86 passengers, 17.54 seconds and 4 cars, respectively. The

lift system therefore selected based on the required quality of services is four numbers 450kg-6passengers machine room less geared traction type. The lift shaft was successfully designed and the number of lift specified using the developed source code; hence the code can be used to design lift system for any building.

Keywords: Handling Capacity, Round trip time, Interval.
Word count: 295 words

Nomenclature

C_d	Car Interval Depth (mm)
C_w	Car Interval Width (mm)
E_h	Car Opening Height (mm)
L	Lift Travel (m)
N	Number of People or Car Capacity
P_h	Pit Depth (mm)
R_a	Machine Room Access (mm)
R_d	Machine Room Depth (mm)
R_w	Machine Room Width (mm)
S	Maximum Number of Stops
S_1	Probable Number of Stops
S_h	Headroom (mm)
T_d	Downward Journey Time(s)
T_o	Door Opening Time (s)
T_p	Passenger Transfer Time (s)
T_u	Upward Journey Time (s)
V	Car Speed (m/s)
V_d	Door Speed (m/s)
W	Door Width (mm)
W_d	Well Depth (mm)
W_w	Well Width (mm)

1. Introduction

Vertical Transport systems in buildings are the systems that are used to move people and goods from one level of a building to another. (Ramesh Nayaka. 2014). These majorly include lifts and escalators. A lift is a type of vertical transport equipment that efficiently moves people or goods between floors (levels, decks) of a building, vessel, or other structure. An elevator (lift) is a permanent lifting installation serving two or more defined landing levels, comprising an enclosed space, or car, whose dimensions and means of construction clearly permit the access of people, and which runs between rigid vertical guides. Elevators are driven directly by an electric motor (electric lifts) or indirectly through the movement of a liquid under pressure generated by a pump driven by an electric motor (hydraulic lifts). Electric lifts are almost exclusively driven by traction machines, geared or gearless, depending on car speed. Hydraulic lifts have become widely used since 1970s for the transportation of goods and passengers, usually for a height not exceeding six floors. Because of wheelchair access laws, elevators are often a legal requirement in new multistory buildings, especially where wheelchair ramps would be impractical. Type of elevators include Direct plunger Hydraulic elevators, Holeless Hydraulic elevators, Roped Hydraulic elevators, Geared Electric Traction elevators, gearless Electric Traction elevators.

Vertical transportation of goods and people has its origin in the depths of history, where simple rope and pulley block systems were used. In 1991, Elisha Graves Otis successfully pioneer vertical transportation systems that still bear his name till today. (Otis elevator PLC 1991). By 1850, steam and hydraulic elevators has been introduced, but it was in 1852 that Elisha Graves Otis successfully put a safety device into a lifting mechanism making possible the first passenger elevator.. Some of the very early passenger lifts installed before 1900 were operated from hydraulic water power and in recent years, the use of hydraulic power has been reintroduced but using oil as the pumping medium with pressure supplied by a motor driven pump. Apart from hydraulic lifts/elevators all earlier types of elevator machines were of driving drum type. In 1903, Otis introduced the design that becomes the backbone of the elevator industry and this is the gearless traction electric elevator. Electric lifts are now more commonly used compared to the hydraulic types. They have a greater performance efficiency, provide speeds up to 7m/s and can travel over fifteen floors unlike hydraulic lifts that cannot travel more than 5 floors and provide speeds up to 0.75m/s. In order to prevent accidents, elevator doors were being equipped with electrical inter locks in the late 1920s, hoist ways and elevator cars were being solidly enclosed and solid car doors were becoming standard. The concept of fireman's lift developed during the 1920's and 1930's, as the need for rapid emergency access responded to the growth in number of tall buildings. By the late 1940s, freight elevator hoist way, gates and gate locking and contact devices were being required, and the days of the worker opening a gate and falling into a hoist way were on the way out. Prior to 1950, there were few or no locks and people fell in regularly.

The elevator industry started to apply microprocessors in 1980 and since then a new generation of the most sophisticated controls has become available representing new and highly advanced technology. The inverter (VVVF – Variable Voltage, Variable Frequency) control is replacing the traditional ward – Lionard or thyristor – leonard for high speed elevator and primary voltage control of induction motors for medium or low speed elevators. Another important change is the use of the helical reduction gear for high speed AC elevators which is competing with the highly satisfactory 100 years application of the d.c. gearless machine. The first variable voltage and frequency elevator drive system was developed in the United States and put into service at the beginning of 1983. Since then, more than a thousand have been built and put into service in the United States. Other countries, in particular Japan, have active variable voltage and frequency elevator development programmes and several elevators of these types have been installed. (KONE 2020). In 2000, the first vacuum elevator was offered commercially in Argentina (KONE Lift. 2000). Otis Elevator Company is working on a new double-deck elevator design that will travel the world's tallest buildings. The company used a similar double-deck elevator car design for the Burj Khalifa, which was finished in 2010, OTIS Lift. (2018).

2. Fundamental bases of lift traffic analysis and performance evaluation

The sizing of the lift systems to serve the demands of a building's population has interested the lift community since the 1920s. The methods being used were somewhat rough. However, by the 1970s a recognized method of calculation had evolved for up-peak traffic sizing based on the mathematical determination of the N, S and P (average highest reversal floor, average number of stops and average number of passengers), Barney et al. (1985). In the 1970s digital computer simulation techniques evolved which allowed specific traffic and lift installations to be examined. The traffic sizing of lift system is conventionally carried out by determining the Round Trip Time (RTT), Graver et al. (1971) of a single lift car serving an up-peak traffic condition.

Methods for Traffic Analysis and Performance Evaluation (Jones, Basset (1923)

$$UPPINT = RTT/N$$

$$UPPHC = \frac{300}{UPPINT} \times 0.8 \times c.c$$

$$\% POP = \frac{UPPHC}{POPULATION} \times 100\%$$

Where
N = No of lift cars
UPPINT = Up Peak interval
CC = Contract Capacity
RTT = Round Trip Time
UPPHC = Up-peak handling capacity over a five-minute period.

The UPPHC is calculated assuming cars fill with passengers (p) to 80% of the contract capacity.

Governing Equations for the lift design ((Alexandris (1986)

(i) A simple expression developed for RTT is

RTT	=	$2Htv + (S + 1)\ ts + 2 + 2Ptp$
Where s	=	means number of stops made above the ground floor
P	=	average number of passengers carried in each trip
t_p	=	time to transfer p passengers into the lift car
t_s	=	time associated with each stop
t_v	=	time taken to travel between two floors at contract speed.
t_u	=	time to transfer P passengers out of the lift car.
t_v	=	$\frac{df}{v}$
t_s	=	$t_f(1) + t_c + t_o - t_v$
t_p	=	$\frac{t_p + t_u}{2}$

P is taken as 80% of contract capacity (Alexandris (1986.)

t_f is a single floor jump time

t_o is the time to open the car doors (s + 1) times

t_c is the time to close the car doors (s + 1) times

df is a standard interfloor height

V is the contract speed.

(ii).Another equations based expression developed for RTT (Jones, Basset (1923))

is RTT	=	$T_u + T_d + T_p + T_o$
S_1	=	$S - S\ \frac{(S-1)^n}{S}$
Where S	=	Maximum number of stops
N	=	Number of people (usually assumed as 80% of the contract capacity).
S_1	=	probable number of stops

$T_u = S_l \left(\frac{L}{S_V} + 2v\right)$ ... 2

Where T_u = Upward Journey Time

L = Lift travel

V = Car speed

$T_d = \frac{L}{V} + 2v$ ... 3

T_d = downward journey time

T_p = 2n or T_p = 3n depending on the depth of the car ... 4

T_p = Passenger transfer time

$T_o = 2(S_l + 1)\frac{W}{V_d}$ ... 5

T_o = Door Opening Time

V_d = Door Speed

W = Door Width

Passenger's arrival process

Observation is the only procedure that can be employed in obtaining data on the arrival pattern of passengers approaching a lift system at the main terminal of a high-rise building. Observation can be made, either over a consecutive number of days or on the same day for a consecutive a rectangular probability distribution function.

3. Computer-Aided Traffic Analysis of Lift Systems

Computer aided design (CAD) enables engineers and designers to use computers to assist in the decision of complex engineering problems. CAD involves three phases; input, computation and output. In the case of CAD for lift systems these phases comprise:

Input Phase: Enter: building data, lift system data, passenger data.

Computation Phase: Perform a discrete digital simulation of the lift system (time consuming).
Output Phase: Examine graphical output; spatial plots; carload; car interval; passenger waiting time: percentiles of waiting time. Examine: numerical tables.

3.1 Computer Analysis and Performance Evaluation based on Lift governing equation

The flow diagram that shows the computation of various lift parameter is shown below in
Figure 2(a b) while figure 1 is the Ivory Tower building.

Case Study: Ivory Tower, University of Ibadan, Ibadan
Building Characteristics

Fig 1. Ivory Tower, University of Ibadan, Nigeria

Number of floors = 10
Floor to floor distances

Ground floor	=	3.3m
First floor	=	3.1m
Second floor	=	3.1m
Third floor	=	3.1m
Fourth floor	=	3.1m
Fifth floor	=	3.1m
Sixth floor	=	3.1m
Seventh floor	=	3.1m
Eight floor	=	3.1m
Ninth floor	=	3.1m
Tenth floor	=	3.3m
Lift travel	=	27.9m

(without considering the ground floor)
Location of the building – University of Ibadan
The building is for unified occupancy.
Population of the Building
Population in tower
Width=11m
Length=6m
Height to Height floor= 3.1m
Floor Area of tower=66m
Population= $\frac{noof floors \times floorarea}{Netarea}$
Using 100sf/person (9.29m^2),
Population= $\frac{8 \times 66}{9.29}$ =66.77 persons
Approximately 67 persons
Population in admin building
Width=68.8m
Length=9.2m
Height to Height floor= 3.1m
Floor Area of tower=632.96m^2
Population= $\frac{\text{no of floors} \times \text{Floor area}}{\text{Net Area}}$
Using 100sf/person,
Population= $\frac{3 \times 632.96}{9.29}$ =204.4 persons

Approximately 204 persons

Total population=Population in tower + population in admin building

$$= 67+204$$

$$=271 \text{ persons}$$

Using a safety net of 25%,

$$\frac{125 \times 271}{100} = 338.75 \text{ persons}$$

Approximately 339 persons

Key design parameters

The following were determined in order to arrive at a suitable lift system for the building.

Average round trip time (RTT)

Interval (I)

Handling capacity (HC)

Preliminary Selections

From standard tables, suitable speeds for the lift are 0.63m/s 1.0m/s and 1.6m/s and 2.0m/s.

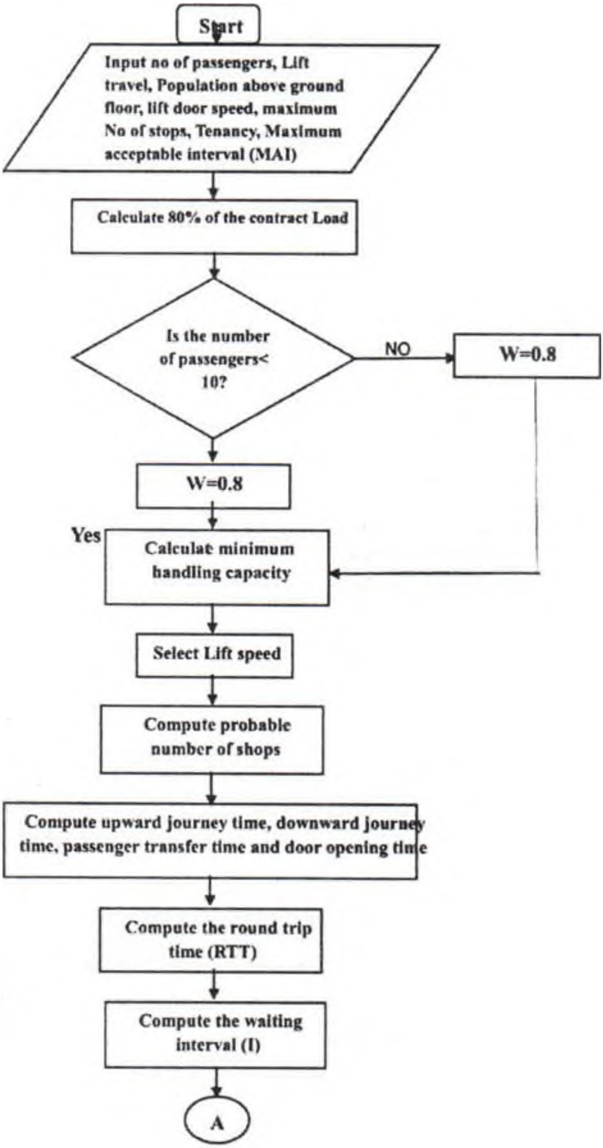
Calculations were done for cars of various sizes / loads (320kg-5persons,450kg-6persons, 630kg-8persons, 800kg-10persons etc.) until a suitable car size is determined.

Design Calculations

The required handling capacity per 5 minutes to handle a 25% of population flow rate.

$$\frac{25}{100} x \; 339 = 84.75 = 85 \text{ persons per 5 minutes}$$

Minimum handling capacity (MHC) = 85 people.


Start
Input no of passengers, Lift travel, Population above ground floor, lift door speed, maximum No of stops, Tenancy, Maximum acceptable interval (MAI)
Calculate 80% of the contract Load
Is the number of passengers< 10?
NO
W=0.8
W=0.8
Yes
Calculate minimum handling capacity
Select Lift speed
Compute probable number of shops
Compute upward journey time, downward journey time, passenger transfer time and door opening time
Compute the round trip time (RTT)
Compute the waiting interval (I)
A

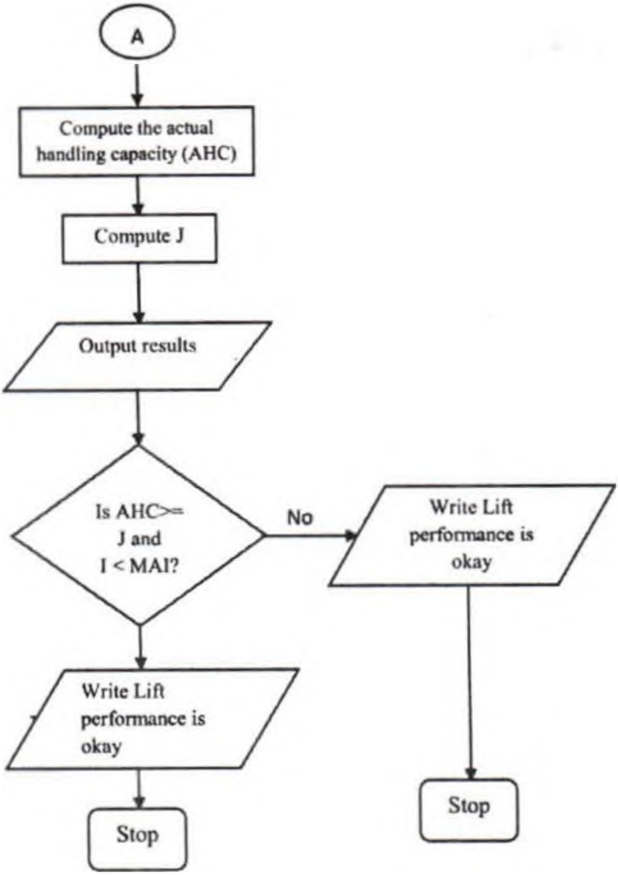


Figure 2a: Algorithm of FORTRAN IV programming for the lift performance analysis

4. Results and Selection

The summary of the result for the lift performance analysis is in here presented in Table 1 below

Table 1. Results of the lift performance analysis in summary

Weight	No of Passengers	Velocity (m/s)	Probable no of stops	No of lift	Round Trip Time	Handling Capacity (%)	Actual handling Capacity	Interval	Remarks
320	5	0.63	3	6	88.1	26.0	81.7	14.68	Interval doesn't fall within range
		1.0		5	69.2	24.5	86.7	13.8	"
		1.6		4	60.1	26.6	79.9	15.01	Interval is excellent Handling capacity is good
		2.0		4	58.6	25.9	81.9	14.65	Interval doesn't fall within range
450	6	0.63	9	6	100	23.7	89.8	16.71	Interval is excellent ,Handling capacity is excellent
		1.0		5	80.3	22.8	93.4	16.06	"
		1.6		4	71.2	25.2	84.3	17.8	Interval is excellent ,Handling capacity is good
		2.0		4	70.2	24.8	85.5	17.54	Interval is excellent ,Handling capacity is excellent
630	8	0.63	5	5	114	22.9	91.7	22.89	Interval is excellent, Handling capacity is excellent
		1.0		4	93.4	23.4	89.9	23.35	"
		1.6		3	84.3	28.1	74.7	28.11	Interval is good, Handling capacity is good
		2.0		3	83.7	27.9	75.3	27.9	"
800	10	0.63	5	4	116	25.7	82.4	29.11	"

		1.0		3	95.4	28.2	75.5	31.8	Interval is fair, Handling capacity is good
		1.6		3	86.3	25.5	83.4	28.78	Interval is good, Handling capacity is good
		2.0		3	85.7	25.3	84.0	28.57	"

Selection

For excellent services (Technically and economically) 4Nos. 6passengers lift are in here selected for the building.

Selected and lift specifications

From the lift service comparison table, the 450kg-6 passengers Machine room less traction lift at 2.0m/s is suitable for the building.

Lift Specifications

No of elevators	-	4 Nos.
Arrangement	-	Side by Side
Load	-	450kg – 6 passenger
Speed	-	2.0m/s
Total Travel	-	27.9m
Serving	-	9Stops, 9 Openings
Machine	-	Machine Room Less Geared traction type
Operation (Control System)	-	Full collective group with independent service key switch
Drive/Control System		Variable frequency drive with microprocessor based control

Power Supply - A single speed, AC
- 3 phase gearless
motor, especially made to
compromise the VVVF drive
control system at:
400 volts and 50 Hz. -Insulation class
"F" - Protection IP 21

Lift well size - 1750mm x 1900-
mm
between finished
walls per lift

Car (inside size) - 1150mm wide x
1080mm deep with side
and rear panels in skin plate from a standard
range to approve colour.

Car façade - Brush stainless
steel finish

Car ceiling - Carved false
ceiling finished in white

Car Flooring - Hard rubber

Car options included - Digital position and
direction o
Indicators

Illuminating car buttons
Overload safety device
Light ray door protection device (photocell)
Hand rails (stainless steel free standing)
Ventilation fan
Alarm bell

Skirting for Car - Stainless Steel

Car doors - Power Operated
centre opening
door constructed in steel 800mm x 2000mm clear openings
Finish-brushed stainless steel

Rope arrangement - 2:1 single wrap

Entrance Surround - Small trims
construction in steel.
Finish – prime Coat.
Safety Gear - Governor Operated
gradual type
- noise and thermal
protection
- Earth leakage
protection
- Voltage drop
protection
- Over speed
protection
- Phase failure and
phase reversal protection

Buffers - Terminal buffers
for Car and
Counter weight
Other items includes - Digital hall
position indicator and
Entrance fire
service
Intercommunicatio
n between car and lobby
Machine beam
supplied and
positioned by lift
contractor for final
fitting by others.

5. Conclusion

The traffic analysis and performance evaluation established 4Nos. 450kg, 6 passenger machine room less traction elevator at 2.0m/s are the most suitable lift system for the Ivory Tower University of Ibadan. This lift system will go a long way in mitigating the movement problems encountered by people in the building. It satisfies the condition of safety devices such as safety gear, buffers, light ray protection device, electric contacts and interlocks are installed in the lift system. The handling capacity of the lift system is found to be generally okay for the building. Manual computations for the design could be more laborious, rigorous and tedious, hence use of computer techniques to obtain optimum solutions is recommended.

References

Alexandris N A (1986). Mean highest reversal floor and expected number of stops in lift-stairs service systems of multi-level buildings Applied Mathematical Modeling 10 139-143.

Barney G C and dos Santos S M (1985) Elevator Traffic Analysis Design and Control 2nd edition. (London: Peter Peregrinus).

CIBSE (1994). The Chartered Institution of Building Services Engineers

Graver, D.P. and Powell B.A. (1971). "Variability in round trip times for an elevator car during up-peak, transportation" Res, Vol. 5, No. 4, Pp. 301 – 307.

Jones, Basset (1923). "The probable number of stops made by an elevator" GE Rev., Vol. 26, No. 8, Pp. 583 – 587.

KONE lifts (2000). Kone lift for residential building Catalogue on ArchiExpo. 2000. pp. 1-10

KONE (2020) Kone Corporation's Annual Reviews 2019

Otis elevator PLC (1991). Otis passenger lift planning guide.

OTIS Lift (2018). Otis Elevator Company Catalogue

Peters R D Green (1995). Proceedings of CIBSE National Conference

Ramesh Nayaka (2014) Vertical Transportation Systems in Buildings

CHAPTER 22

A Synopsis of Major Classical Inventory Management Models

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1. INTRODUCTION

1.1 INVENTORY AND INVENTORY MANAGEMENT COMPONENTS AND FEATURES

1.1.1 Inventory

Inventory or stock or work-in-progress in the most general terms refer to physical assets or goods of a venture kept in stock as raw materials/information, semi-finished assets and or finished or processed assets prior to, during or after processing to forestall stock-out or shortage at any stage of processing where they are needed in anticipation of demand.

In materials management perspective, inventory is defined as a useable though idle resource with economic value kept for use or circulation. In general manufacturing setup it refers to products-in-process, raw materials, and completely finished products before sale and their departure from the manufacturing system. In service systems, inventory is all work done prior to sale or offering of service, including partially processed information.

Much as keeping inventory is desirable and a productive safe-guard against shortfalls, keeping too much or keeping too little for too long or too short a period of time in an instance of its need might be counter-productive and uneconomical. The inventory paradox is thus that of a needed asset which may as well turn counter-productive if not well managed. Two paramount questions that inventory acquisition seeks to answer are (1) How much is needed? and (2) when is it needed? On top of the knowledge of the need is the need to optimally manage the needed inventory in time, quantity and space to forestall shortfalls and gluts, capital tie-down and uneconomical purchases as well as wasteful utilization of inventory infrastructure. This is where effective Inventory Management comes in.

1.1.2 Types of Inventory

Inventory can be seen in different perspectives and thereby the various types involved.

Based on a venture's stage of production or processing three types of inventory can be identified.

i. Raw materials: unprocessed basic ingredients of production or service

ii. Works-in-process: unfinished product or service item in the making

iii. Finished goods or service product

Based on the purpose or position an inventory item serves within a venture, there can be:

i. Cycle stock – inventories for meeting predicted demand between cycles of replenishments.

ii. In-transit inventories / pipeline stock – These are products that are on the way transiting from one location to another. Although they may not be available for sale or shipment until getting to their ultimate destination, they may be considered part of the cycle stock.

iii. Safety or buffer stock – items held in excess of the normal cycle stock in anticipation of uncertainty in demand or in lead time. Quantity held is influenced among other factors by lead time of replenishment, fluctuation of demand and the availability level planned for customers. They usually constitute the majority of inventory in typical production or logistic system.

iv. Speculative stock – items held in stock in anticipation some future occurrence other than for meeting demand. Such anticipated events may include forecasted price fluctuation, materials shortage, quantity discounts and stock need to cushion effects of possible natural disaster or workforce strikes. Products may also be manufactured in periods when they are not in demand for production economic reasons. These also may constitute speculative stocks.

v. Seasonal stock – these are accumulation of speculative stock held in advance of or during a seasonal period.

vi. Dead stock - items which have not been in demand for a specified period of time. They include obsolete products and products which are not in demand in the current season.

1.1.3 Effective Inventory Management Requirements

Essentially, a comprehensive system for Inventory Management comprises of two complementary sub-systems: one to keep track of inventory items and the other to enable management take decisions about inventory size and when to order. For effectiveness, a good Inventory Management must incorporate the following features (Vrat, 2014; Ogunwolu *et al.*, 2012):

1. Ability to keep track of inventory in stock and ordered inventory.
2. Incorporation of dependable demand forecast robust enough to accommodate possible error in forecast.
3. Possess the knowledge of lead times and its variability.
4. Incorporation of reasonable estimates of inventory holding costs, ordering costs, setup costs and shortage costs.
5. An appropriate and effective inventory policy
6. A built-in sub-system for inventory classification
7. Skill in utilization of appropriate models to determine order point, lead time and reorder points.

These inventory components must be well integrated to make inventory management effective, efficient and seamless.

1.2 Inventory Models

Inventory models can be classified according to one or more of the following modes of classification (Vrat, 2014):.

Number of inventory items

Single Item: This type of model recognizes one type of product at a time. If the demand rate changes from period to period, then the problem becomes that of a dynamic lot-sizing problem

Multi Item: This type of model considers a number of products simultaneously. These products must have at least one interrelating or binding factor such as budget or capacity constraint or a common setup

Stocking Point

Single Echelon: Only one stocking location is considered

Multi-Echelon: More than one interconnected stocking locations are considered

Frequency of Review

Frequency of review is the frequency of assessment of the current stock position of the system and the implementation of the ordering decision.

Periodic: Placement of orders is done at discrete points in time, with a given periodicity

Continuous: Order placement can occur at any time.

Order Quantity

Fixed – Order quantity: Order quantity is fixed to the same amount each time

Variable - Order quantity: Order quantity can be variable

Planning Horizon

Finite Horizon: Demands are recognized over a limited number of periods.

Infinite Horizon: Demands are recognized over an unlimited number of periods

Nature of Demand

Deterministic: Demands are known with certainty over the planning horizon

(a) Static demand rate: Demand rate is constant over every period

(b) Dynamic demand rate: Demand rate is not necessarily constant. It changes in magnitude from period to period.

Stochastic (Probabilistic): Demand is random and may follow standard probability distributions

Fuzzy Demand: Demand is imprecise or ambiguous.

Capacity:

Capacitated: There are capacity restrictions on the amount produced or ordered

Un-capacitated: Capacity is assumed to be unlimited

Unsatisfied Demand

Not allowed: demand is met and no shortages are allowed

Allowed: Demand not satisfied in a particular period. It may be retained and satisfied in a future period (backlogging), partially retained and partially lost or completely lost (no backlogging)

2. DETERMINISTIC CLASSICAL INVENTORY MODELS

2.1 BASIC ECONOMIC ORDER QUANTITY MODEL (EOQ) AND ITS VARIANTS

2.1.1 THE BASIC EOQ MODEL (Taha, 2017)

The most rudimentary inventory model by used industrial and service delivery practitioners, which caters for replenishment of depleting inventory over time is the economic Order Quantity (EOQ) model (or Economic Lot-Size model). For this model and its variants, demand is assumed known and constant over the inventory management horizon. The primary concern is to minimize the Total Inventory Cost per unit. This cost is made up of Ordering cost, Setup Cost and holding or carrying cost well as shortage cost where shortage is permitted.

Generally, for the Economic Order Quantity (EOQ) and its variants, the following symbols are adopted for the model parameters and variables

Model Parameters

$\mathrm{K}=$ setup cost of inventory (per ordering cycle)

$\mathrm{c}=$ cost of purchase of inventory (per unit quantity, per time unit)

$\mathrm{H}=$ holding or carrying cost per unit time held in inventory

$\mathrm{D}=$ demand rate for inventory item per unit time

Model Variables

The major decision variables of the EOQ model and its variants are the Order Quantity (Q) and the Shortage (S) for the single item inventory. Equivalently, for multi-item inventory, the decision variables are Q_i and S_i respectively for items $i = 1, 2,. . . n$

Other variables of note are,

$\mathrm{t}_c =$ inventory procurement time or cycle

L

= inventory lead time (time allowance between ordering and delivery of ordered item)

These model parameter and variable symbols are used in the EOQ model presented here from its basic form propounded by in to varieties of the variants of the model that emerged thereafter.

BASIC ECONOMIC ORDER QUANTITY MODEL (WITHOUT SHORTAGE) (Taha, 2017)

For this case depicted graphically as in Figure 1, the Total Inventory cost function is given by,

C_T = Total Cost = Purchasing Cost + Holding Cost + Setup Cost

Purchasing and Setup Costs

For inventory quantity (Q), at c cost per unit, the Ordering Cost is.

$$Ordering\ Cost/\ cycle\ =\ C_O = K\ +\ cQ$$

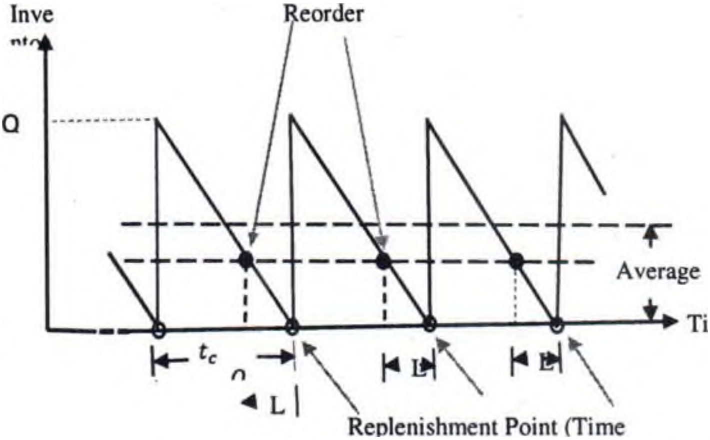

Fig. 1: Inventory Pattern, Reorder Points and Replenishment Points in Basic EOQ

Holding cost

Average inventory utilized per cycle = $\frac{0+Q}{2} = \frac{Q}{2}$

With H cost per unit per unit time, the cost per unit time is $\frac{Q}{2}$H.

Given the demand rate D units, the Cycle duration for consumption of Q inventory units is $\frac{Q}{D}$

Thus the average holding cost per cycle, C_h, is given by,

$$C_H = \frac{Q}{2}\text{H} \times \frac{Q}{D} = \frac{Q^2}{2D}\text{H}$$

The Total Cost per cycle is,

$$\text{C}_\text{T} = \text{C}_\text{O} + \text{C}_\text{H} = K + cQ + \frac{Q^2}{2D}\text{H}$$

For each unit of inventory, over cycle length $\frac{Q}{D}$, the Total Cost per unit, C_{TU} is,

$$C_{TU} = \frac{D}{Q}\left[K + cQ + \frac{Q^2}{2D}H\right] = \frac{D\,K}{Q} + Dc + \frac{HQ}{2}$$

The optimum cost that minimizes the Total Cos per unit, C_{TU} , is obtained by finding the first derivative of C_{TU} with respect to the variable Q and setting the derivative to be equal to zero.

$$\frac{dC_{TU}}{dQ} = -\frac{DK}{Q^2} + \frac{H}{2} = 0$$

From this, the optimal value of Q is obtained as,

$$Q^* = \sqrt{\frac{DK}{H}}$$

The corresponding optimal cycle time, t_c^*, is given by

$$t_c^* = \frac{Q^*}{D} = \sqrt{\frac{2K}{DH}}$$

It is easy to show that C_{TU} at $\frac{dC_{TU}}{dQ} = 0$ above is a minimum solution since,

$$\frac{d^2C_{TU}}{dQ^2} = \frac{2DK}{Q^3}$$

$D > 0, K > 0$ and $H > 0$ implies $Q^* > 0$ thus

$$\frac{2DK}{Q^{*3}} > 0$$

Hence the derivative of the Total Cost per unit inventory with respect to Q set to zero yields a minimum point.

Model Sensitivity and Practical implications

Changes in EOQ inventory model parameters K, D and H results in model responses of change in the optimal values Q^* and t_c^* with practical implications. This is illustrated in Table below (using (+) for increment and (-) for decrement.

Table 1: Sensitivity Analysis of EOQ Model with no Shortages

Parametric Change	Optimal Variable Responses	Practical Implications
K^+	Q^{*+}, t_c^{*+}	Reduction in number of setups
D^+	Q^{*+}, t_c^{*-}	More frequent setups
H^+	Q^{*-}, t_c^{*-}	Smaller Inventory

Inventory Lead Time

A lead time L may be required as the time required between the time of order and the actual time the order is delivered. This is practicable to define the reorder point in time before the exhaustion of the inventory in use.

Thus with a lead time of L and inventory demand rate D, the reorder point is when the inventory drops to LD units. Assuming that $L < t_c^*$, the effective lead time is defined as,

$$L_e = L - nt_c^*$$

The parameter n represents the largest integer value not exceeding $\frac{L}{t_c^*}$. Thus the effective reorder point is when the inventory drops to $L_e D$ (Taha, 2017)

2.1. 2 EOQ (WITH SHORTAGES) (Hillier and Lieberman, 2001)

Shortages may be planned for in inventory management to forestall stock-out, a case where there are no products to deliver or sell to customers which more often than ought may lead to loss of goodwill from customers. Though with a guarantee of safety stock planning for shortages will also mean incurring shortage costs. Thus, a good model that allows for shortages must guarantee an optimal trade-off between safety stock and the extra cost incurred.

As in the Basic EOQ, the Setup and purchasing costs is made up as Ordering cost, C_O

$$Ordering\ Cost/\ cycle \ = \ C_O = K \ + \ cQ$$

The quantity ordered, Q is now made up of the normal purchase, N and the shortage, S = Q - N allowed.

Within normal inventory cycle, the inventory level remains positive for a period $\frac{N}{D}$ with an average inventory level of $\frac{N}{2}$ units. With a holding cost of H per unit per time unit, the holding cost for this period is $\frac{NH}{2}$ per unit time. The normal inventory holding cost per cycle, C_N is thus given by,

$$C_N = \frac{N}{D} \times \frac{NH}{2} = \frac{N^2H}{2D}$$

The remainder of the period $\frac{(Q-N)}{D}$ caters for the shortfall allowed with an average inventory level of $\frac{(Q-N)}{2}$ and corresponding cost of $\frac{(Q-N)p}{2}$ per unit time. Thus the shortage cost per cycle, C_S is given by,

$$C_S = \frac{(Q-N)p}{2} \times \frac{(Q-N)}{D} = \frac{(Q-N)^2p}{2D}$$

In all, the Total Cost of inventory per cycle is given by,

$$C_T = C_O + C_N + C_S = K + cQ + \frac{N^2H}{2D} + \frac{(Q-N)^2p}{2D}$$

The corresponding Total Cost per unit inventory time is,

$$C_{TU} = \frac{D}{Q}\left[K + cQ + \frac{N^2H}{2D} + \frac{(Q-N)^2p}{2D}\right]$$
$$= \frac{DK}{Q} + Dc + \frac{HN^2}{2Q} + \frac{(Q-N)^2p}{2Q}$$

Optimal decision needs to be found for the Total Order quantity, Q and the normal order, N. This obtained by partially differentiating C_{TU} with respect to Q and N, setting each derivative to zero to obtain respective optimal C_{TU} decision point and solving the two resultant equations simultaneously to obtain the optimal values Q^* and N^* .

$$\frac{\partial C_{TU}}{\partial Q} = -\frac{DK}{Q^2} - \frac{HN^2}{2Q^2} + \frac{(Q-N)p}{Q} - \frac{(Q-N)^2p}{2Q^2} = 0$$

$$\frac{\partial C_{TU}}{\partial N} = \frac{HN}{Q} - \frac{(Q-N)p}{Q} = 0$$

The simultaneous solution of these equations in Q and N yields, the optimal values of the variables,

$$Q^{*} = \sqrt{\left(\frac{2DK}{H}\right)\left(\frac{p+H}{p}\right)}$$

$$N^{*} = \sqrt{\left(\frac{2DK}{H}\right)\left(\frac{p}{p+H}\right)}$$

The optimal cycle time, t_c^* is,

$$t_c^* = \frac{Q^*}{D} = \sqrt{\left(\frac{2K}{HD}\right)\left(\frac{p+H}{p}\right)}$$

The maximum shortage, S^* is

$$S^{*} = Q^{*} - N^{*} = \sqrt{\left(\frac{2DK}{p}\right)\left(\frac{H}{p+H}\right)}$$

The time point when normal inventory is depleted is,

$$t_N^* = \frac{N^*}{D} = N^* = \sqrt{\left(\frac{2K}{HD}\right)\left(\frac{p}{p+H}\right)}$$

The fraction of the optimal cycle time, t_c^* for which no shortage occurs is given by,

$$\frac{t_N^*}{t_c^*} = \frac{p}{p+H}$$

From this relationship, which is independent of setup time, K, the sensitivity of the model when the holding cost, H and the shortage cost, p are made substantially larger than each other can be investigated. The sensitivity analysis is summed up in the table below.

Table 2: Sensitivity Analysis of EOQ Model with Shortages

Costs relationship	Optimal Variable Responses	Practical Implications
$p \to \infty$, H constant (shortage cost dominates holding cost)	$S^* = Q^* - N^* \to 0$	As shortage cost dominates holding cost, it is not desirable to accommodate shortages
$H \to \infty$, p constant (holding cost dominates shortage cost)	$N^* \to 0$	As holding cost dominates shortage cost, it becomes uneconomical to have normal inventory. Orders deiivered are used solely to settle shortages.

2.1.3 EOQ WITH PURCHASING PRICE BREAKS (Taha, 2017)

In the previous EOQ models, the optimal inventory policies obtained are not dependent on the cost of purchase. In reality, however, different price regimes, allowing for discounts, may be applicable for purchases depending on the quantity. If this is accommodated in the EOQ model, the optimal inventory policy will be dependent on costs too.

Assuming a single price break,

$$c = \begin{cases} c_1, & \text{if } Q \leq q \\ c_2, & \text{if } Q > q \end{cases} \quad \text{for } c_1 > c_2$$

As result of this cost break and since order per unit time is $\frac{Q}{t_c}$, then the purchasing cost per unit time, C_p is

$$C_p = \begin{cases} \frac{c_1 Q}{t_c} = \frac{c_1 Q}{Q/D} = c_1 D & ; Q \le q \\ \frac{c_2 Q}{t_c} = \frac{c_2 Q}{Q/D} = c_2 D & ; Q > q \end{cases}$$

Aggregating all relevant costs, the Total Cost per unit time C_{TU} as a function of order quantity Q is given by,

$$C_{TU}(Q) = \begin{cases} C_{TU}(Q)_1 = c_1 D + \frac{KD}{Q} + \frac{HQ}{2} & ; Q \le q \\ C_{TU}(Q)_2 = c_2 D + \frac{KD}{Q} + \frac{HQ}{2} & ; Q > q \end{cases}$$

The values of the functions $C_{TU}(Q)_1$ and $C_{TU}(Q)_2$ differ only by a constant value, $(c_1 - c_2)D$ so their

minima are the same and is equivalent to the Basic EOQ minima,

$$Q_m = \sqrt{\frac{2KD}{H}}$$

The graphs of the two functions are as in figure below

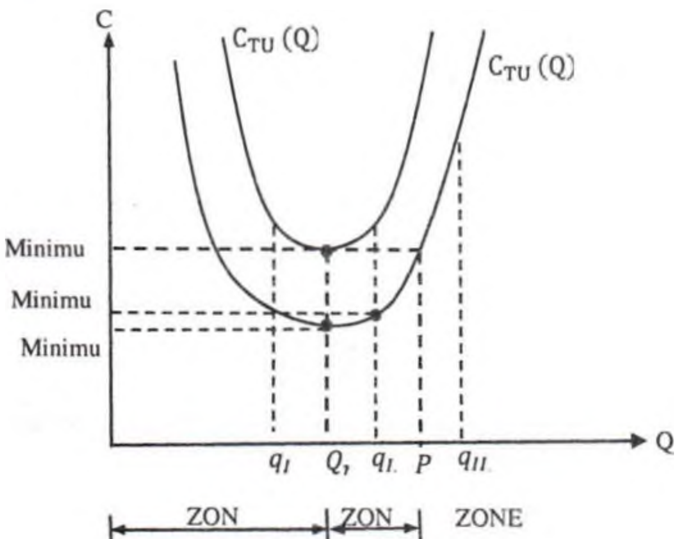

Fig. 2: Inventory Cost functions with **Price Break Zones** and **Optimal** Solutions

The optimal order quantity $Q^{\wedge}$ depends on the location of price break point q out of the three possible

Regions I, II and III representing quantity ranges $(0,\ Q_m)$, $(\ Q_m, P)$ and $(P,\ \infty)$ respectively.

For $P > \ Q_m$ can be determined from the equation,

$$C_{TU}(P)_2 = C_{TU}(Q_m)_1$$

That is,

$$c_2D + \frac{KD}{P} + \frac{HP}{2} = C_{TU}(Q_m)_1$$

This results in a quadratic equation in P

$$P^2 + \left(\frac{2(c_2D - C_{TU}(Q_m)_1)}{H}\right)P + \frac{2KD}{H} = 0$$

The optimal quantity $Q^{\wedge}$ is determined as

$$Q^* = \begin{cases} Q_m & \text{if q is in zone I or II} \\ q & \text{if q is in zone II} \end{cases}$$

The following steps can be used to determine Q^*

Step 1: Determine $Q_m = \sqrt{\frac{2KD}{H}}$. If q is in zone 1, then $Q^* = Q_m$. Otherwise GO TO Step 2

Step 2: Determine P ($> Q_m$) from the equation,

$$P^2 + \left(\frac{2(c_2D - C_{TU}(Q_m)_1)}{H}\right)P + \frac{2KD}{H} = 0$$

With the value of P known, define the zones II and III as the ranges $(\ Q_m, P)$ and $(P,\ \infty)$ respectively.

If q is in zone II, then $Q^* = q$. Otherwise, q is in zone III and $Q^* = Q_m$.

2.1.4 EOQ WITH UNIFORM RATE OF REPLENISHMENT OR REORDER

Instead of instant replenishment (or reorder) assumed in the Basic EOQ model, a uniform rate of reorder

or replenishment of inventory r units per unit time can be assumed where r is greater than the rate of

inventory consumption (demand), D $((r > D)$.

For this case, the maximum inventory is not Q. but $Q - \frac{D}{r}Q = \left(1 - \frac{D}{r}\right)Q$

The Total Cost per unit, C_{TU} is

$$C_{TU}(Q) = \frac{KD}{Q} + cD + \frac{H\left(1 - \frac{D}{r}\right)Q}{2}$$

The EOQ is,

$$Q^* = \sqrt{\frac{2KD}{H\left(1-\frac{D}{r}\right)}} \quad ; r > D$$

2.1.5 MULTI-ITEM EOQ WITH STORAGE LIMITATION

On a general basis, when there are more than one items of inventory, with known demand and no allowance for shortage, the model which minimizes the grand total of the individual Total Cost per unit of each item can be written a constrained Non-Linear Mathematical Programme. The objective function is constrained by Sum of the storage space utilized by individual inventory item which cannot exceed the total storage space available. (Stevenson, 2005)

Using the following notations for inventory items $i = 1, 2, . . . , n$,

D_i = Demand rate for item I

K_i = Set up cost

H_i = Unit holding cost per unit time

Q_i = Order quantity

a_i = storage area required for per unit of item i

A = Maximum available storage space for all n items

The resulting Mathematical Programme is,

$$Minimize\ C_{TU}\ (Q_1, Q_2, \ . \ . \ ., Q_n) = \sum_{i=1}^{n} \left(\frac{K_i D_i}{Q_i} + c_i D_i + \frac{H_i\, Q_i}{2} \right)$$

subject to:

$$\sum_{i=1}^{n} a_i Q_i \ \leq \ A$$

$$Q_i > 0\ ;\ for\ i = 1, 2, \ . \ . \ . \ , n$$

Several approaches can be used to solve this programme:

1. Reduction of the problem to an unconstrained problem (by stepping down the constraints) and determining the solution as the EOQ value,

$$Q_i = \sqrt{\frac{2K_i D_i}{H_i}} \ \ ; for\ each\ i = 1, 2, . . . , n$$

If the solution satisfies the constraint, the Q_is are adopted as the optimal solution Q_i^* for each item i.

On the contrary if the constraint is not satisfied, then it is binding and another method of solution must be sought. Other methods of solution include:

2. Lagrangean algorithm for constrained programmes.

3. Solution as Non-Linear Programme using many proprietary optimization software available such as AMPL, MATLAB and, Excel Solver.

3. Use of evolutionary algorithms such as Genetic Algorithm and Ant Colony Optimization algorithm.

2.2 DYNAMIC DETERMINISTIC INVENTORY MODELS

In this class of inventory management models, the demand per period is both deterministic and varies from one period to another. The inventory level is also reviewed periodically over a finite number of equal periods.

A number of inventory models are in this class. They include;

1. Periodic Review EOQ Model with No Setup Time

2. Periodic Review EOQ with Setup

3. The Silver-Meal Heuristics

4. Wagner-Whitin Algorithm

These models will be briefly discussed and characterized in this section.

2.2.1 PERIODIC REVIEW EOQ WITH NO SETUP (Taha, 2017)

The basic assumptions of this model are:

1. Setup cost is not involved during any period

2. No shortage is allowed.

3. The periodic unit production cost function is either constant or taken as increasing (convex) marginal costs

4. Constant unit holding cost is incurred in during any period

Since no shortage is allowed, delayed production in future period cannot fill the demand in a current period. As a result of this assumption, the cumulative production capacity from the starting period to a particular period i is taken as the cumulative demand for the same periods.

The model is formulated as transportation model with n periods each period consisting of k levels of production (such as regular time and overtime). The supply end of the model is equated to the kn production levels as sources while the demand values are specified by the n periods of demand. The unit transportation cost from a source m to a destination n is taken as the sum of the production and holding costs per unit. The objective of the model will then be to determine the production level per source m that minimizes production cost.

By reason of the assumption of no shortage and convex production cost, it is possible to solve the transportation model without using the comprehensive transportation technique procedure. It suffices only that for each period's demand, starting from the first, the minimum cost allocation satisfying the supply and demand at each cell simultaneously are met and updated first before moving to the next demand period

This procedure is encapsulated in the algorithm presented below with reference to the generalized kn by n transportation model. (Johnson, 1957)

Let $m = rj;\ \ r = 1, 2, \ldots, n;\ \ j = 1, 2, \ldots, k$ for n periods and k production levels

and $S_m \equiv S_{rj} = S_{11}, S_{12}, \ldots, S_{1k}; S_{21}, S_{22} \ldots, S_{2k}; \ldots, S_{n1}, S_{n2}, \ldots, S_{nk}$

$$S_m \equiv S_{rj} = \textit{Supply amount at period } r \textit{ and the } j\textit{th production level of that period}$$

$$C_{mi} \equiv C_{rj,i} = ic_i + H_i = \textit{unit transportation cost from production}$$

source m to demand destination i

$D_i = Demand\ at\ period\ i$

$\overline{D} = Dummy\ destination\ demand$

$\overline{S} = Dummy\ source\ supply\ (production)\ demand$

In this model, transportation from a previous cell $T_{m-p,i} = T_{r-p\,j,i}$ $; p = 1, 2, \ . \ . \ .; p < r$ to a current cell, $T_{m,i} = T_{rj,i}$ to is not allowed because shortage is not allowed, hence those cells are blocked.

Table 3: Abridged Transportation Scheme for Solution of Periodic EOQ with No Setup Cost

Source Subscript Symbols			DEMAND (DESTINATION) (i)					Supply
I	R	Ij	1	2	⋯	N	Dummy	
	1	11			⋯			S_{11}
	2	12			⋯			S_{12}
1	⋮	⋮	⋮	⋮	⋯	⋮	⋮	⋮
	k	1k			⋯			S_{1k}
	k + 1	21			⋯			S_{21}
	k + 2	22			⋯			S_{22}
2	⋮	⋮	⋮	⋮	⋯	⋮	⋮	⋮
	2k	2k			⋯			S_{2k}
⋮	⋮	⋮	⋮	⋮	⋯	⋮	⋮	⋮
	(m – 1)k + 1	m 1			⋯			S_{m1}

M	(m − 1)k + 2	m 2			⋯			S_{m2}
	⋮	⋮	⋮	⋮	⋯	⋮	⋮	⋮
	mk	Mk			⋯			S_{mk}
Dummy Source					⋯			S_D
Demand			D_1	D_2		D_n	D_D	

Step 0: Initialize I = 0

General Step G:

Step G1: For all unblocked and uncrossed cell in Demand column i, select the cell with the least cost (break ties arbitrarily). Allocate as much production units to satisfy the balance of demand,
D_i and supply S_{rj}; $i, r = 1, 2, . . . , n ; j = 1, 2, ... , k$.

Step G2: Adjust and update demand D_i and supply S_{rj}; $i, r = 1, 2, . . . , n ; j = 1, 2, ... , k$ corresponding to the cell at which allocation is made. Cross out any of the row or column that run down to zero (break ties arbitrarily).

Step G3: If updated $D_i = 0$, and $i \neq n$, then make $i = i + 1$ and GO TO G1

Step G4: If updated $D_i \neq 0$, and $i \neq n$ GO TO G1

Step G5: If updated $D_i = 0$, and $i = n$ STOP. The allocations made to the cells are the optimal allocation depicting the production units required for relevant periods and production levels.

2.2.2 PERIODIC REVIEW EOQ WITH SETUP

In the case when setup cost is incurred each time a new production lot is started, several periodic review model variants are used. In this section, two of such are discussed.

2.2.3 WAGNER-WHITIN

The Within Wagner Algorithm (Wagner and Whitin, 1958) was designed to find the optimal policy for lot-sizing decisions by means of a forward recursive algorithm which first solves a one period problem and then sequentially solves sub problems until the overall N periods problem solution is found.

Let D_i, K_i H_i and Q_i be the demand, setup cost per order and holding (or carrying) cost per unit per order for period and quantity to order at period i, $i = 1, 2, \ldots, n$, respectively. The inventory function can be represented as:

$$I = I_0 + \sum_{j=1}^{i-1} Q_j - \sum_{j=1}^{i-1} D_j \geq 0$$

The minimum inventory cost function can be represented as,

$$f_i(I) = \min_{\substack{Q_i \geq 0 \\ I + Q_i \geq D_i}} \left[H_{i-1}\, I + F(Q_i)\, K_i + f_{i+1}(I + Q_i - D_i) \right]$$

F( ) is the Heaviside step function.

The following theorems were proved to support the WW algorithm (Badiru, 2007):

Theorem 1: For any period, I, $I_i\, Q_i = 0$, . This implies that since stockout is not allowed, Inventory from previous period cannot be brought into period i as I_i . Thus if $I_i > 0$ exists, no order is placed hence $Q_i = 0$ and vice versa.

Theorem 2: For some k where $i \leq k \leq n$, an optional policy exists such that $Q_i = 0$ or $Q_i = \sum_{j=i}^{k} D_j$ for all i. This implies that the quantity ordered in period i is either zero or equal to the total demand of some or all of the future periods.

Theorem 3: There exists an optimal policy such that if the demand, D_{i+j} is satisfied by Q_i^*, then demands D_i, D_{i+1}, D_{i+2}, . . . , D_{i+t-1} are also satisfied by Q_i^*.

Theorem 4: Suppose there exists known optimal policy for the first k periods of an n-period inventory plan in which $I_i = 0$, $i < k$. Then it is possible to determine the optimal plan for the periods k + 1 through to period n.

Theorem 5: Suppose there exists known optimal policy for the first k periods of an n-period inventory plan, in which $Q_i > 0$, $i < k$. Then, it is not necessary to consider periods 1 through k − 1 in formulating optimal policy for the rest of n – k periods. The implication, when this is the case is that, the problem will only be re-initialized to start at period k and proceed forward.

Wagner and Whitin (1958) gave the following algorithm for finding the optimal policy for the inventory problem

Initialize the procedure at $i^* = 1$

1. Consider the policies of ordering at periods i^{**}, $i^{**} = 1, 2, \ldots, i^*$ and filling demands D_i, $i = i^{**}, i^{**} + 1, \ldots, i^*$ using this order.
2. Add $F(Q_{i^{**}})K_{i^{**}} + H_{i^{**}} I_{i^{**}}$ to the costs of acting optimally for periods $i^{**} - 1$ determined in the previous iteration of the algorithm.
3. From these i^* alternatives, select the minimum cost policy for periods 1 through i^*
4. Proceed to $i^* + 1$ or STOP if $i^* = n$

2.2.4 SILVER-MEAL HEURISTIC (Badiru, 1996)

The Silver–Meal heuristic (Silver and Meal, 1973) is a forward method recommended for items that have significantly variable demand pattern. The heuristics involves determining the average cost per period as a function of the number of periods the current order is to span. The heuristic stops when the function first increases.

The objective of the Silver-Meal Heuristic is to minimize Total Inventory Cost per unit time for the cycle of replenishment.

Given the ordering cost C_O and the holding cost per unit of demand, H the Total relevant Cost is,

$$C_T = \text{Ordering cost} + \text{Holding cost} = K + C_O = K + HD$$

Defining $C_T\,(T)$ as the average holding and setup cost per period, and let the current order spans the next T periods. If the demands are D_i, $i = 1, 2, \ldots, n$ over n periods.

To satisfy the demand for period 1,

$$C_T\,(1) = K$$

For the second period,

$$C_T\,(2) = \frac{(K + HD_1)}{2}$$

if $C_T\,(2) < C_T\,(1)$ pause and produce or order $Q_r^* = D_1$, Reinitialize process at period 2

Otherwise, compute $C_T\,(3)$

$$C_T\,(3) = \frac{(K + 2HD_2)}{3}$$

if $C_T\,(3) < C_T\,(2)$ pause and produce or order $Q_r^* = D_1 + D_2$, Reinitialize process at period 3. Otherwise, compute $C_T\,(4)$

Thus generally to satisfy the demand for period i,

$$C_T\,(i) = \frac{(K + (i-1)HD_2)}{i}$$

Generally, if $C_T(i) < C_T(i-1)$ pause and produce or order $Q_r^* = D_1 + D_2 + \ldots + D_{i-1}$, Reinitialize process at period i. If $i \neq n$, compute $C_T(i+1)$. If i = n, Stop.

3. 0 STOCHASTIC CLASSICAL MODELS

Just as in the case of deterministic models, Stochastic Inventory Models can be

1. Continuous review Models as typified by Stochastic EOQ models
2. Periodic review Models as typified by Single Period with or without setup cost as well as myriads of multi-period models (Hillier and Lieberman, 2001).

In this section some of these models are examined while a more comprehensive undertaking of summary of features of notable stochastic models is later exhibited.

STOCHASTIC CONTINUOUS REVIEW MODELS

3.1 STOCHASTIC EOQ MODELS

One key family of continuous review stochastic inventory models is the Stochastic EOQ Models.

The inventory prediction capabilities of the deterministic EOQ models can be extended to cases where the demand is random and can be fitted to particular probability distributions. Records of demand data which may qualify to be treated this way will normally exhibit very high coefficient of variation (a ratio of standard deviation to mean of the data). (Bartmann and Beckmann, 1992)

Two approaches are can be used to incorporate random demand into the EOQ models.

1. By treating the effective inventory lead time, L_e and the attendant possible shortage during this period in the deterministic EOQ model as stochastic (the Probabilitized EOQ).

2. By developing a stochastic model from the inventory variables and parameters from first principles. (the Probabilistic EOQ)

3.1.1The Probabilistic EOQ Model

The cost components of the stochastic EOQ model as in the deterministic case are setup cost, expected holding cost and expected shortage cost per unit time. These variables are obtained as follows.

Given K as setup cost per order, D as the expected demand per unit time and an average inventory of $\frac{D}{Q}$, the setup cost per unit time is approximated as $\frac{KD}{Q}$

Similarly, given R as the remnant inventory at the reorder point and H, the cost per inventory unit per unit time, the expected inventory level, I, given y as the demand during the lead time is ,

$$I = \frac{(Q + E\{R - y\} + E\{R - y\})}{2} = \frac{Q}{2} + R - E\{y\}$$

The expected holding cost per unit time is thus, HI, where I is obtained as the average of the sum of the expected starting inventory $E\{R - y\}$ and ending inventory $Q + E\{R - y\}$, ignoring the case where $R - E\{y\} < 0$.

The expected shortage per cycle where $y > R$ is given by,

$$S = \int_{R}^{\infty} (y - R)\, f(y)\, dy$$

The shortage cost, p, per unit inventory item is assumed proportional to the shortage quantity and hence the expected shortage cost is pS. The cycle time is $\frac{Q}{D}$ and hence the shortage cost per unit time is, $\frac{pS}{Q/D} = \frac{pDS}{Q}$.

The Total Cost per unit time function is given by,

$$C_T(Q,R) = \frac{DK}{Q} + H\left(\frac{Q}{2} + R - E\{y\}\right) + \frac{pD}{Q} + \int_R^{\infty} (y - R)\, f(y)\, dy$$

To obtain the optimal values Q^* and R^* the partial derivatives of $C_T(Q,R)$ with respect to Q and R are found, equated to zero and the resulting equations solved.

$$\frac{\partial C_T(Q,R)}{\partial Q} = -\left(\frac{DK}{Q^2}\right) + \frac{H}{2} - \frac{pDS}{Q^2} = 0$$

$$\frac{\partial C_T(Q,R)}{\partial R} = H - \left(\frac{pD}{Q}\right) \int_R^{\infty} f(y)\, dy = 0$$

Solving the two equations yields,

$$Q^* = \sqrt{\frac{2D\,(K + pS)}{H}}$$

$$\int_R^{\infty} f(y)\, dy = \frac{HQ^*}{pD}$$

The optimal values of Q^* and R^* cannot be determined in closed forms. Hadley and Whitin developed an algorithm for solving the equations. If a solution exists, the algorithm will converge in a finite number of iterations.

For R = 0, the two equations yield,

$$\hat{Q} = \sqrt{\frac{2D\,(K + p\,E\{y\})}{H}}$$

$$\tilde{Q} = \frac{pD}{H}$$

Unique optimal values of Q and R exist when $\tilde{Q} \geq \hat{Q}$. The least value of Q^* is $\sqrt{\frac{2KD}{H}}$ which occurs at S = 0.

The steps of the Hadley and Whitin algorithm are:

Step 0: Use the optimal solution, $Q_1 = Q^* = \sqrt{\frac{2KD}{H}}$ and let $R_0 = 0$. Set i = 1, and go to step i.

Step i: Use Q_i to determine R_i from equation (2). If $R_i \approx R_{i-1}$, stop; the optimal solution of $Q^* = Q_i$ and $R^* = R_i$. Otherwise, use R_i in Equation (1) to compute Q_i. Set i = i + 1, and repeat step i.

3.2 STOCHASTIC PERIODIC MODELS

SINGLE PERIOD STOCHASTIC MODELS

The Stochastic Single Period Models are models inventory decision is made in a single time period. This implies that whatever inventory items remaining are disposed of. Furthermore demand within this single period are random characterized by continuous or discrete probability distributions. The single period stochastic models can be divided into two groups of models (1) without setup cost and (2) with setup cost (Hillier and Lieberman, 2001).

3.2.1 THE STOCHASTIC SINGLE PERIOD MODEL WITH NO SETUP TIME (The Perishable Goods Model)

This model usually characterizes the inventory problem of perishable or short life cycle inventories such as periodicals like newspaper, flowers being sold by florist, seasonal clothing among others, which if any is left over at the end of the sales period becomes stale and can only be disposed of.

The model is characterized by

i. Variable uncertain demand occurring instantaneously at the start of the period immediately following receiving of order
ii. No setup cost

Using the usual notation of Q and D for order quantity and demand within the period, $f(D)$, the probability distribution function, $\overline{p}$, the unit cost of shortage and H the holding cost per unit for the period, it follows that for the problem two cases ensues in relation to inventory and shortages. When $Q > D$, then the periods inventory is $Q - D$ for which holding cost H per unit will be incurred and when $Q < D$, shortages of $D - Q$ occurs for which a shortage cost of p per unit will be incurred.

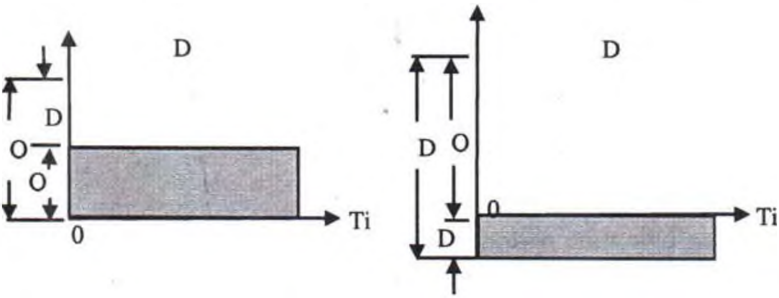

Fig. 3: Illustration of (i) Holding (ii) Shortage Inventory in a Single Period Model

The demand probability function can either be a continuous distribution or discrete mass function$f(D)$.The expected cost for the period, $E\{C_T\ (Q)\}$ can thus be expressed

i. When demand distribution function is continuous as,

$$E\{C_T(Q)\} = H\int_0^Q (Q-D)f(D)dD + \overline{p}\int_Q^\infty (D-Q)f(D)dD$$

ii. When demand function is discrete as,

$$E\{C_T(Q)\} = H\sum_{D=0}^{Q}(Q-D)f(D) + \overline{p} \sum_{D=Q+1}^{\infty}(D-Q)f(D)$$

For either of these cases, the optimal inventory policy can be obtained.

For the continuous model case, the first derivative with respect to Q and setting it to zero yields,

$$\frac{\partial C_T(Q)}{\partial Q} = H\int_0^Q f(D)dD \; - \overline{p}\int_Q^{\infty} f(D)dD = 0$$

This is equivalent to,

$$\frac{\partial C_T(Q)}{\partial Q} = H\,P\{D \le Q\} - \overline{p}[1 - P\{D \le Q\}] = 0$$

$$P\{D \le Q\}[H+\overline{p}] - \overline{p} = 0$$

$$\mathrm{P}\{\mathrm{D} \le \mathrm{Q}^*\} = \frac{\overline{p}}{\mathrm{H}+\overline{p}}$$

For the case where $f(D)$ is discrete, the optimum policy on what quantity to order is given by the following optimality conditions which are both necessary and sufficient,

$E\{C_T(Q)\} \le E\{C_T(Q-1)\}$ and $E\{C_T(Q)\} \le E\{C_T(Q+1)\}$

This yields the range of optimal solution,

$$\mathrm{P}\{\mathrm{D} \le \mathrm{Q}^* - 1\} \le \frac{\overline{p}}{\mathrm{H}+\overline{p}} \le \mathrm{P}\{\mathrm{D} \le \mathrm{Q}^*\}$$

3.2. 2 STOCHASTIC EOQ MODEL WITH SETUP COST

In this model allowance is made for a setup cost, K per order. The expected cost, $E\{\overline{C}_T(Q)\}$, using the same notations as for the case without setup cost with expected cost $E\{C_T(Q)\}$, is

$$E\{\overline{C}_T(Q)\} = K + E\{C_T(Q)\}$$

$$E\{\overline{C}_T(Q)\} = K + H\int_0^Q (Q - D)f(D)dD + \overline{p}\int_Q^\infty (D - Q)f(D)dD$$

As derived earlier and since K is a constant, the optimal policy on the quantity to order, Q, must satisfy,

$$P\{D \leq Q^*\} = \frac{\overline{p}}{H + \overline{p}}$$

Thus, Q^*, the minimum value of $E\{\overline{C}_T(Q)\}$ is derivable therefrom.

For the two cost functions, $E\{\overline{C}_T(Q)\}$ (for setup cost inclusion) and $E\{C_T(Q)\}$ (with no setup inclusion), the minimum occurs at the same point, $Q = Q^*$ and the ordinates of the graph of the two against order quantity, Q, differs by K, as illustrated in the graph below.

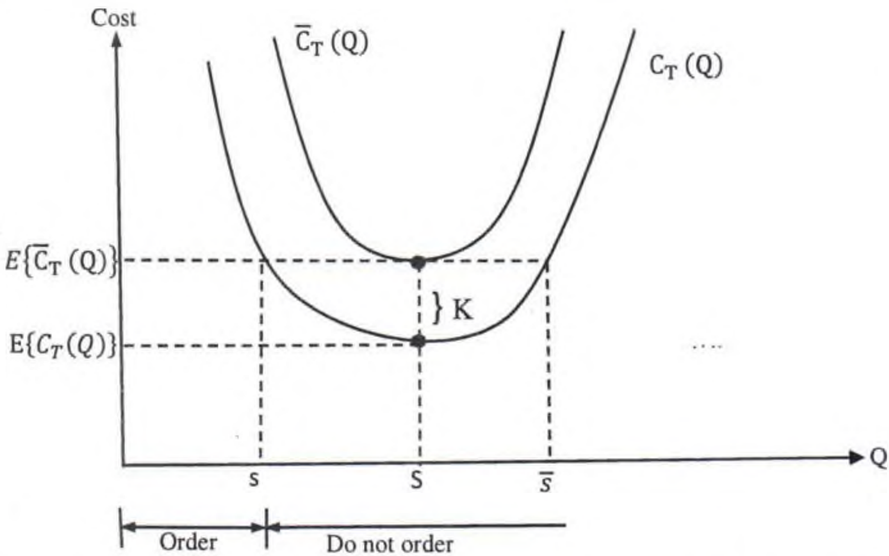

Fig. 5: Optimal Ordering Policy in Single Period (s, S) Model with Setup Cost (Taha, 2017)

From the Figure above, three regimes of order quantity ranges can be obtained from equating the two cost functions,

$$E\{C_T(s)\} = E\{\overline{C}_T(S)\} = K + E\{C_T(S)\}$$

giving rise to order cut points, s, $S = Q^*$ and $\overline{s}$ on the Q-axis. These are order quantity ranges, $Q < s$, $s \leq Q \leq S$ and $Q > \overline{s}$.

If the amount of available inventory prior to placement of order is y, the question this model answers is that under this condition, how much inventory should be ordered? The answer to the question can be tackled for the three different quantity order regimes stated above.

Case 1 (when y > s), Since y is already on hand, its expected cost is $E\{C_T(y)\}$ From the figure, if any additional quantity Q – y is ordered for, the expected cost of y is,

$$\min_{Q>y} E\{\overline{C}_T(S)\} = E\{\overline{C}_T(S)\} < E\{C_T(y)\}$$

The implication of this is that the optimal inventory policy is to order S – y inventory units.

Case 2 (when $s \leq y \leq S$) In this case, referring to the figure above,

$$E\{C_T(y)\} \leq \min_{Q>y} E\{\overline{C}_T(S)\} = E\{\overline{C}_T(S)\}$$

This shows that it is not advantageous to order in this cases as $Q^* = y$

Case 3 (when $y > S$) From the figure, if Q > y,

$$E\{C_T(y)\} < E\{\overline{C}_T(Q)\}$$

As in case 2, it is not also advantageous to order in this case as again, $Q^* = y$

In summary, the optimal inventory policy for the Stochastic Single period Model with setup cost incurred, otherwise known as the s – S policy is:

$$(s - S)\text{Policy} = \begin{cases} \text{If inventory on hand}, y < s, \textit{ then order } S - y \textit{ units to level up to } S \\ \text{If Inventory on hand}, y \geq s, \text{do not order} \end{cases}$$

VARIATIONS OF THE SINGLE PERIOD NO SETUP COST MODEL

There variations of the stochastic single period model. Two important ones among such variations are: (Nahmias, 2005)

1. The Single Period Model (No Setup Cost) with Initial Stock Level
2. The Single Period Model (No Setup Cost) with Non-Linear Cost

In the case of the variation with initial stock level,y, if the policy decision to be made is to determine the value of inventory, Q after replenishment, $Q - y$ has been made. The expected inventory cost can be written as,

$$E\{C_T(Q)\} = c(Q - y) + H\int_0^Q (Q - D)f(D)dD + \overline{p}\int_Q^\infty (D - Q)f(D)dD$$

3.2.3 STOCHASTIC TWO-PERIOD MODEL WITH NO SETUP COST

A method of dealing with multi-period stochastic inventory model which can only yield approximate solutions is when the single-period stochastic model is used to plan ahead one period at a time. This will not yield optimal solution even for just two periods. The optimum solution can however be guaranteed when the probabilistic distribution of the demand for each of a multi-period problem is known using probabilistic dynamic programming approach. Obviously since dimension of the problem will make the problem difficult to solve using probabilistic dynamic programming. For a two-period model, however, the problem of dimension can relatively be easier to surmount.

A number of assumptions can be made to develop the two-period model. These are that:

1. Only one type of inventory units are under consideration.

2. Unsatisfied demand of period 1 can be back-logged to be met in period 2 but that of period 2 cannot be back-logged.

3. The probability distributions of the demands in periods 1 and 2 (D_1 and D_1) are both independent and identically distributed random variables with specifiable probability density function $f(D)$ and cumulative distribution function, $\varphi(D)$.

4. The initial inventory level in period 1 prior to replenishment at the beginning of the period is y_1 units ($y_1 \geq 0$).

5. The decision required is to determine the inventory levels, Q_1 and Q_2 to reach by replenishment (if any) at the beginning of periods 1 and 2 respectively.

6. The expected sum of total costs for the two periods is to be minimized.

In developing the model, using the normal symbols in previous deductions, c, H and $\overline{p}$ represent the purchasing or producing cost per unit, the holding cost per unit remaining at the end of each period and the shortage cost per unit of unsatisfied demand at the end of each period. These parameters are assumed the same for each period. However, in reality, they may differ in the two periods.

Let $E\{C_1(y_1)\}$ ($E\{C_2(y_2)\}$) be the expected total costs for both periods (period 2 only) at an optimal policy given that y_1 (y_2) is inventory level prior to replenishment at the beginning of period 1 (period 2).

The dynamic programme approach first solves for $E\{C_2(y_2)\}$ and Q_2^* with a balance of one period thereafter. The result is then used to solve for $E\{C_1(y_1)\}$ and Q_1^*.

Using the result of the single-period model with no setup cost earlier found, the optimal quantity for period 2, Q_2^* can be obtained by solving,

$$P\{D \leq Q_2^*\} = \frac{\overline{p}}{H + \overline{p}}$$

Since y_2 is given, the resulting optimal policy is given by,

Period 2, Policy

$$= \begin{cases} \text{Order } Q_2^* - y_2 \text{ if } y_2 < Q_2^* & (\textit{to bring inventory up to } Q_2^*) \\ \text{Do not order} \quad \text{if } y_2 \geq Q_2^* \end{cases}$$

The corresponding cost of this optimal policy is

$$C_2(y_2) = \begin{cases} S(y_1) & \text{if } y_2 \geq Q_2^* \\ c(Q_2^* - y_2) & \text{if } y_2 < Q_2^* \end{cases}$$

Where $S(z)$ is the expected shortage cost plus holding cost for a single period when the inventory level after replenishment is z. This cost is expressed as

$$S(z) = E\{C_T(Q)\} = c(Q - y) + H\int_0^z (z - D)f(D)dD + \overline{p}\int_Q^\infty (D - z)f(D)dD$$

For period 1, using the dynamic programme approach, the cost incurred sum of the ordering cost $c(Q_1 - y_1)$, the expected shortage plus holding cost $C(Q_1)$ and the cost associated with an optimal policy during the second period. Thus the expected cost following the optimal policy for the two periods is

$$E\{C_1(y_1)\} = \min_{Q_1 \geq y_1} [c(Q_1 - y_1) + S(Q_1) + E\{C_2(y_2)\}]$$

Since $y_1 = Q_1 - D_1$ is a random variable at the beginning of period 1, then $E\{C_2(y_2)\}$ can be obtained from,

$$C_2(y_2) = C_2(Q_1 - D_1)$$
$$= \begin{cases} S(Q_1 - D_1) & \textit{if } Q_1 - D_1 \geq Q_2^* \\ c(Q_2^* - Q_1 + D_1) + L(Q_2^*) & \textit{if } Q_1 - D_1 < Q_2^* \end{cases}$$

This also shows that

$C_2(y_2)$ is also a random variable. Its expected value can be obtained from

$$E\{C_2(y_2)\} = \int_0^{\infty} C_2(Q_1 - D)\, f(D)dD$$

$$= \int_0^{Q_1 - Q_2^*} L(Q_1 - D)\, f(D)dD$$

$$+ \int_{Q_1 - Q_2^*}^{\infty} [c(Q_2^* - Q_1 + D) + L(Q_2^*) f(D)dD]$$

Hence,

$$E\{C_1(y_1)\} = \min_{Q_1 \geq y_1} \Bigg[c(Q_1 - y_1) + L(Q_1)$$

$$+ \int_0^{Q_1 - Q_2^*} L(Q_1 - D)\, f(D)dD$$

$$+ \int_{Q_1 - Q_2^*}^{\infty} [c(Q_2^* - Q_1 + D) + L(Q_2^*) f(D)dD] \Bigg]$$

$E\{C_1(y_1)\}$ has a unique minimum and it can be shown that, Q_1^* , the optimal value of Q_1 satisfies the equation,

$$-\overline{p} + (\overline{p} + H)\, f(Q_1^*) + (c - \overline{p}) f(Q_1^* - Q_2^*)$$

$$+ (\overline{p} + H) \int_0^{Q_1 - Q_2^*} f(Q_1 - D)\, f(D)dD = 0$$

The optimal policy for period 1 is thus, Period 1, Policy

$$= \begin{cases} \text{Order } Q_1^* - y_1 \ \text{ if } y_1 < Q_1^* & (\textit{to bring inventory up to } Q_1^*) \\ \text{Do not order} \ \text{ if } y_1 \geq Q_1^* \end{cases}$$

3.2.4 STOCHASTIC MULTI-PERIOD MODEL WITH NO SETUP COST

The two-period model can be extended to n periods (n > 2) with the same assumptions as used earlier. In order to calculated the expected total cost for the n periods, a discount factor α, $0 < \alpha < 1$ will be used.

Giving that inventory levely_i, $i = 1, 2, . . . , n$ as level of inventory entering a period i, prior to replenishment, the optimal policy can be generally specified as,

Period i, Policy

$$= \begin{cases} \text{Order } Q_i^* - y_i \quad \text{if } y_i < Q_i^* \text{ to level up to } Q_i^*) \\ \text{Do not order in period i} \ \text{ if } y_i \geq Q_i^* \end{cases}$$

In addition,

$$Q_n^* \leq Q_{n-1}^* \leq Q_{n-2}^* \leq . . . \leq Q_2^* \leq Q_1^*$$

For the infinite period case (ie = ∞), all critical optimal Q values are equal,

$$Q^* = Q_n^* = Q_{n-1}^* = Q_{n-2}^* = . . . = Q_2^* = Q_1^*$$

It can be shown that Q^* satisfies,

$$F(Q^*) = \frac{\overline{p} - c(1 - \alpha)}{\overline{p} + H}$$

3.2.5 STOCHASTIC MULTI-PERIOD MODEL WITH SETUP COST

This case is also identical to the single period case with setup cost. In the single period case, also referred to as the (s, S) policy model, s dictates when to order (when the inventory level is less that s) and how much to order to bring inventory level to S level. In the multi-period case, these values may differ from period to period.

For the multi-period case, let critical quantity cuts be represented as s_i and S_i for each period i, $i = 1, 2, . . . , n$ while y_i is the inventory level at beginning of period i before replenishment.

The optimal policy is,

$$Period\ i, Policy = \begin{cases} Order\ S_i - y_i & if\ y_i < S_i\ (to\ bring\ inventory\ up\ to\ S \\ Do\ not\ order\ in\ period\ i & if\ y_i \geq S_i \end{cases}$$

Conclusion

An exhaustive coverage of all known Inventory Management Models cannot be treated in a chapter of a book. Attempts have been made in this chapter to cover the basic and seminal models of inventory management. The classical inventory models may not account for many practical considerations of the inventory challenges like competitions and the ever changing industry dynamics that contemporary industries face, in the sense that they were formulated at the product level and not the firm level. However, insights and guides gleaned from the understanding of these basics can greatly enhance the understanding of the basic and rudimentary parts of inventory concerns that make the whole and hence contribute to gaining understanding of the dynamics of the entire industry. Interestingly, inventory practitioners and researchers in the field still bend back to the basics to garner understanding for the basis of the robust models and systems they work on. Hence, an understanding of these seminal models prepares a practitioner, student or researcher for the bedrock of inventory issues.

References

Badiru, A. B. (1996). *Project management in manufacturing and high technology operations*. John Wiley & Sons.

Badiru, A., Badiru, A., & Badiru, A. (2007). *Industrial project management: Concepts, tools, and techniques*. CRC Press.

Bartmann, D., & Beckmann, M. J. (1992). Inventory control (models and methods). *Lecture notes in economics and mathematical systems*.

Hillier, F., & Lieberman, G. (2001). Introduction to Operations Research, McGraw-Hill Higher Education ISBN 0072461217.

Johnson, S. M. (1957). Sequential production planning over time at minimum cost. *Management Science*, *3*(4), 435-437.

Nahmias, S., Production and Operations Analysis (2005). 5th ed., Irwin, Homewood, IL.

Ogunwolu, L., Alli, O. A., Onyedikam, C., & Sosimi, A. A. (2012). Multi-Item Multi-Period Dynamic Capacity-Constrained Lot-Sizing Model with Parallel Machines and Fuzzy Demand. In *Advanced Materials Research* (Vol. 367, pp. 627-638). Trans Tech Publications Ltd.

Taha, H. A. (2017). *Operations Research: An Introduction*. © Pearson Education Limited 2017.

Silver, E. A., & Meal, H. C. (1973). Production and Inventory Management.

Stevenson, W. J. (2005). *Operations management. Tata* McGraw-hill

Vrat, P. (2014). Introduction to Integrated Systems Approach to Materials Management. In *Materials Management* (pp. 1-19). Springer, New Delhi.

Wagner, H. M., & Whitin, T. M. (1958). Dynamic version of the economic lot size model. *Management science*, *5*(1), 89-96.

CHAPTER 23

Redesign of Organisational Structure of a Manufacturing Firm

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Abstract

The business of managing human resource in an organization has continued to task the managers' ability on how to be efficient and effective often done by focusing on the three components of organizational structure involving organisational design, Job and People. This has evolved through theory building of various concepts to the development of structures. Yet the changes in the marketplace suggest the most current approaches lack proven principles and acceptable criteria. This has posed challenges for managers who wish to propose a new structure or determine the level of performance of an existing one. This study is an attempt to adopt a mathematically rigorous approach to redesign an organisational structure of a manufacturing firm using the Operations Research paradigm.

The amount of work content was determined using work sampling technique while the number of lowest level personnel (N_0) computed using the man-hours/available work-hours function. Personnel utilization (H) objective function was formulated in terms of subordinate-superior consulting rate (λ), superior-subordinate attending rate (μ) and daily working hours (A) as parameters while span of control (K), number of supervisors/managers (N_i) and number of management levels as design variables were adapted from the literature. The values of λ, μ were

determined using queuing theory and data on A collected from the firm's records. A management structure design problem was then defined and solved by systematically selecting K_i, N_i and M to maximize H using optimisation approach, and a new structure was proposed.
The newly proposed structure was then compared to the existing using t-statistics ($\alpha \leq 0.05$).

The firm's operating labour man-hours were 414336; the associated N_0 is 166; the objective function $H(A, \lambda, \mu, N_i, M, K_i)$ was nonlinear while span of control, number of supervisors, number of lowest, middle and topmost level managers and the number of management levels were the structure design variables. It was a nonlinear constrained maximization problem. The number of floor personnel (166), supervisors (34), lowest level managers (9), middle (3), topmost (1), spans of control {5, 4, 3, 3} and management levels (4) with a maximum personnel utilization (95.29%) were significantly better than the existing (180, 36, 10, 4, 1; {5, 4, 3, 4}). N22, 103,900, the monthly personnel management running cost favourably compared with the existing 23,903,000 (N1,799,100 being savings per month).

It was concluded that the quantitative approach to organization design is feasible for designing an optimal management structure for a tobacco processing firm. It is a useful tool for cost reduction and productivity improvement.

SECTION 1: INTRODUCTION

1.1 Overview of Organisation Design

The business of managing human resource in an organization has evolved through theory building of various concepts to the development of structures. The changing organization environment in the marketplace is also tasking the managers' ability on how to use and manage people, material and time by focusing on the three components of organization structure i.e. organisation, Job (tasks/activities) and People.

Organisation can refer to an Organised group of people with a particular purpose, such as business or government. It also refers to the framework of many interrelated activities taking place in order to achieve set goals, while Jobs are the activities performed in an organization and are achieved through the functional departments.
People, often referred to as the personnel or the manpower have different skills, which are very vital in building an organisational structure.

According to Charles-Owaba (2002), personnel has three components: the muscle (source of energy for physical work), brain (essential for decision making, creativity solving difficult problems) and the will power i.e. ability to endure odd circumstances; be resolute on previously accepted principles and decisions). However, despite the will to choose one's actions, man must be subject to control and management by others, to get the right mix, type, quality and quantity of human power essential for good operations and results.
Design is a plan or specification for the construction of an object or system or for the implementation of an activity or process and the result of that plan or specification in the form of a prototype, product or process, (Wikipedia, 2020).

*A business organization*is an entity formed to carry on commercial enterprise, by providing goods or services, to meet the needs of the customers. Such an organization could have different types and forms including service, merchandising, manufacturing(Lamarco, 2018). The structure of ownership of a business may be a sole proprietorship, partnership, limited liability, corporation, non-profit corporation, or cooperative. According to Anyaeche and Oluwanimifie (2011), ownership structure affects not only how businesses are run, but also the organisational structure, the productivity and the reporting relationships among the personnel and their activities.

Burton (2013) opine that organisational design addresses two issues i.e. how to divide the organisation's work into small units and how to reassemble those parts into a whole, these may lead to complexity and interdependence. There are engineering approaches for designing of human work environments; however, information is sparse on similar procedures for organisational structure design Stewart,(1993);Charles-Owaba, (2002); Alberts, (2012); Burton (2020).

Kulik and Baker (2008) suggest that a proposed model should be not be limited to the characteristics of the type of organisation for which development is pursued but also to the influence of external factors like the business environment.

Business Organisational Structure is chosen mostly through evolution and contingency theories (Charles-Owaba, 2002). The focus of the former is that business evolves naturally, but the latter are contingently designed. Over the years, the evolution theory has dominated the process of organisational structure design, because, it allows a benchmarking approach which enables the business owners to imitate a structure working in one establishment with the hope that it will work in others. Hax and Majiluf (1981) explained that this proposition has appeal because most organisations are too soft and mostly lack a qualitative approach to organization structure design that would lend itself to mathematical modelling and optimization. However, the business environments' complexity, dynamism, and ever-changing complicated consumers' characteristics have made a simple selection of structure unappealing. Also, mass customization, global competition, cheap foreign labour, and free trade agreements require dynamic, but consistent organisational transformation (Roberts, 2004)

An organization structure is the accepted working relationship of employees towards the achievement of the primary goals of the establishment (Charles-Owaba, 2002). The structure may be a framework for decision making and the network for transmitting such decisions to the point where they are translated to action. Since organization structure involves a grouping of related activities into strategic positions, the number of such positions, their levels, skills-mix, together with prescribed working relationships among positions specify the structure.

Literature is sparse on the quantitative framework for developing the organization structure for optimum performance Charles-Owaba (2002), Ofiabulu, *et al.*, (2013a)

1.2 Statement of the Problem

With the drive to achieve and retain leadership in business as well as the recent global pandemic, companies would wish to right size rather than just downsize by reducing their workforce. They need to apply reengineering, job enlargement, and synchronizing roles in developing new ways of doing work, work culture, online work, more virtual work, including mass customization which invariably increases the pressure to satisfy all customers. However, the tools to achieve optimality in these challenges appear sparse, and not readily available.Some scholars Hax and Majiluf (1981), Ofiabulu*et al.*, (2013b,c), have adopted the quantitative method of organisational design in all their approaches, whereby organisation variables like personnel utilisations, redundancy, productivity, etc are used as determinantsfor the organization structuredesign and shapeprove more effective, however, using a quantitative framework to design organizations that will help in addressing these challenges is the thrust of this work.

1.3Study Objectives

The main objective of this study is the Redesigning of the OrganizationStructure of a manufacturing firm, which hopefully will be achieved by pursuing the following sub-objectives:

(a) Observe the existing organisational structure of a manufacturing firm.
(b) Redesign the OrganisationalStructure of a manufacturing firm, addressing the observed gaps, to improve the system.
(c) Compare the redesigned and existing organisational structures of themanufacturing firm.

1.4 Scope and Limitations of the Study

This study is limited to the re-design of the organization structure of the production department in a manufacturing company. Itdoes not include departments like Human Resources, Finance Supply Chain etc. Although organization structure could take many forms including Hierarchical, matrix, circular, flat, network, team-based, etc._only theorganization structure where subordinates report to and get feedback from their bosses and there may be delay leading to queue formation, is considered.

1.5 Definitions of Terms

Here we present some of the terms used in this work.

Design: Creation of a plan or convention for the construction of an object, system or measurable human interaction.

The six basic elements of organisational structure are departmentalisation, chain of command, the span of control, centralisation, decentralisation, work specialisation, and the degree of formalisation.

Departmentalisation (or departmentalisation) refers to the process of grouping activities into departments.

Chain of Command is how tasks are delegated and work is approved. In other words, it shows who tells whom to do what, as well as how are issues, proposals, requests are communicated down (instruction) that the ladder and up the ladder (feedback). If a bottleneck appears, a queue is formed and avoidable costs and other consequences.

Span of Control indicates who falls under a manager's unit and which tasks fall under a department's responsibility.

Centralization involves bringing together as many decision units as possible. A business Organization can lean toward centralised structure, where final decisions are made by just one or two entities; or decentralized, where final decisions are made within the team or department that will implement the decisions.

Work specialisation, sometimes called division of labour, refers to the degree to which an organization divides individual tasks into separate jobs. It involves breaking down complex tasks into smaller, more precise tasks that individual workers can complete and the degree of formalization.

The degree of formalization is the extent that roles are independent of specific personal attributes of individuals occupying the roles. Formalization tries to standardize and regulate behaviour. It also is an attempt to make the structure of relationships more visible and explicit (Scott, 1981)

SECTION 2: ORGANIZATIONAL DESIGN CONCEPTS

2.1 OrganizationalStructure Design

2.1.1 Mechanistic and Organic Structure Design

Organisational structures can be mechanistic or organic. The mechanistic structure represents the traditional, top-down approach, whereas the organic structure represents a more collaborative, flexible approach as shown in figs 2.1 and 2.2.

Mechanistic structure Organic structure

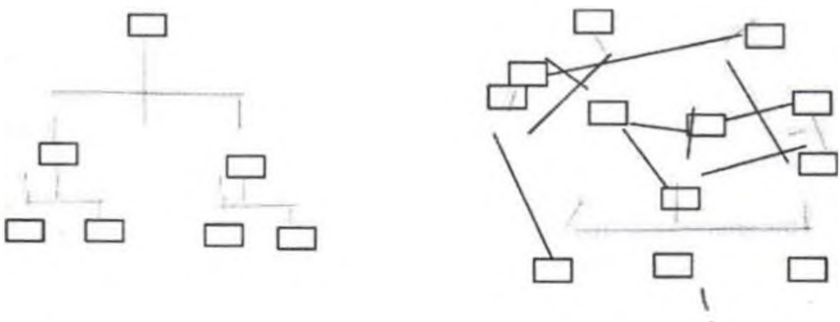


Fig. 2.1 and 2.2: Mechanistic and Organic Structure Design Source

As a company gets bigger, its organizational structure can also help know who manages what processes and how work flows. This is usually represented by organisational structure diagrams referred to as organogram or organisation chart.

An organisational chart depicts the diagrammatic representation of the people in an organisation showing their subdivision in various specialisation, departments, or sections as well as the internal lines of authority, communications, and responsibilities. An organisational structure usually has decision-making centres, Operation centres, and Communication lines as the basic elements.

2.1.2Types of Organization Structures

Simple Structure: A simple structure is a design with low departmentalisation, wide spans of control, centralised authority and little formalisation. It is more common in small businesses with fewer employees. Often employees work in all aspects of the business and just do not focus on one job-creating little, if any departmentalisation.

Functional Structure is designed as a cluster of similar or related occupational specialists together. It is the functional approach to departmentalisation established throughout the organisation.

Divisional structure is made up of separate semi-autonomous units or divisions. Within one establishment, there may be many divisions with each division having its own specific goals to achieve. A manager oversees the division and he is responsible for the success or otherwise of it. This enables the manager to direct his energy more on getting results as he is held accountable for his division.

The hierarchical structure is a pyramid-shaped organization chart. It is the most common type of organisational structure—the chain of command goes from the top (manager) down (e.g., entry-level and low-level employees) and each employee has a supervisor.
Hierarchical Organization Structurebetter defines levels of authority and responsibility and shows who each person reports to or who to talk to

about specific projects. However, it can slow down innovation or important changes due to increased bureaucracy as well as cause employees to act in the interest of the department instead of the company.

A boundaryless organisation is not designed by or limited to boundaries and can be horizontal, vertical or externally imposed by a predesigned structure(Harvard Business Review 2011). It is an unstructured design and flexible because there are no boundaries like a chain of command, departmentalization, organisation hierarchy to deal with. instead of the department, the organisation uses a team approach.

Galbraith *et al.*, (1978) introduced the matrix type of organization structure in which a person may report to one or more supervisors in line with business process Re-engineering (BPR) organisation structure. This they define as the fundamental rethinking and radical design of business process to achieve dramatic improvement in critical measures of performance such as cost, product quality or develop timely service delivery.

An organisationthat has the capacity to develop and continuously learn, adapt, and change is referred to as a Learning Organisation. A learning organization is skilled at creating, acquiring and transforming knowledge and at modifying it behaviour to reflect new knowledgeand insights. Some of its characteristics are systems thinking, personal mastery, mental models, shared vision, and team learning.

Hax and Majiluf, (1981) investigated the possibility of using Operations Research approach for organisational design and opine that the existing theories are lacking in quantitative approach that would lend itself to mathematical modelling. We can therefore infer from the foregoing review that the manager-subordinate ratio and other structural inferences on production deserve more attention than they receive as there has not been a one fit for all model to the organization structure designs using the concept of span of control.

2.2Theories of Organizational Management

Theories of Organizational Management include Classical theory, Human relations, organizational and decision making, contingency, Projectized (Babcock and Morse, 2005).

The Classical theory states that for good performance, the design of an organisation structure may have to follow certain universal management principles. The exponents of this theory are the scientific management school of Taylor (1911), Bureaucratic model of Taylor (1911). Given the copious volume of materials on these, readers are referred to Taylor (1911), Charles -Owaba, (2002), Babcock and Morse (2002), for detailed information

2.3 Attributes and Criteria of organization structure

Drucker (1973) called for systematic approaches to organisational design, while Hax and Majluf, (1981) called for an investigation into the possibility of using the "Operation Research paradigm of theory, for organizational design. The organization structure design has also been viewed from the standpoint of "fixed workload principle" that is every person in the organization is assigned to aworkload, which is neither overload nor an underload). Although at variance with the concept of small group approach and the Business Process Re-engineering (BPR) concept of Hammer and Champy (1993).

Charles-Owaba (2002) shared the view that there is a remarkable difference in the requirement for organisational design and organisational management. In managing an organisation, jobs may be assigned to group (BPR requirement) instead of individuals as in the division of labour. However, in the design of organisational structure, the designer needs to know the exact number of personnel to run the structure. Even in the situation of small or large group management approach, there is still the need to know thenumber of personnel per group. This information is required to determine the number of groups to work in the organisation. Once the exact number to run the structure is known, management may group and train them as deemed fit. Thus the designer

may use ergonomics, physics, and mathematical principles to determine the appropriate standard workload per worker for anorganization, thus by combining such information with the concept of standard workload per personnel, the correct number of personnel may be easily determined.
For more detailed information on Classical principles, attributes, and criteria readers may consult Fayol (1949), Samuel (1996) and Charles-Owaba (1989, 2002).

From the above, a very clear contextual framework to define the organisational structure through a mathematical modelling can be proposed

2.4 Queuing Theory

Waiting for service occurs in restaurants, stores, and post offices. Jobs wait to be processed on a machine, planes for permission to land, and cars stop at traffic lights. These may form queues and the measures of performance include average queue length, average waiting time in queue, and average facility utilization (Taha, 2007;Hillier and Lieberman, 2007;Anyaeche, *et al*2015).
Queueing theory is the study of waiting. Not providing enough service capacity results in excessive waiting and costs. The models enable finding an appropriate balance between the cost of service and the amount of waiting Queuing and simulation deal with the study of waiting lines, they are not optimizationtechniques; rather, they determine measures of performance of the waiting lines.

Queuing models utilize probability and stochastic models to analyse waiting lines, and simulation (is flexible and can be used to analyse practically any queuing situation) estimates the measures of performance by imitating the behaviour of the real system. The main difference is that queuing modelsare purely mathematical. For on this see Taha (2007), Hillier and Lieberman 2007, Anyaeche, *et al* 2015.

To study public establishment is often structurally complex because the number of hierarchical management levels is usually numerous and sometimes difficult to specify and results in low personnel utilisation, high level of ineffectiveness, and inefficiency.

Charles-Owaba (1998, 2002) observed that the number of management (decision) levels may be a major factor that determines the organisation performance (Ofiabulu, 2013d). We use queuing theory instead of simulation because of our interest.

There are different nomenclature and discipline in queuing theory, generally given by the following format: (a/b/c) : (d/e/f)
where
a = Arrivals distribution
b = Departures (service time) distribution
c = Number of parallel servers (= 1,2, ...,∞)
d = Queue discipline
e = Maximum number (finite or infinite) allowed in the system (in-queue plus in-service)
f = Size of the calling source (finite or infinite)
For this work we use Kendall's notation with one channel queuing model (Taha 1976, 2007); m/m/1:(FCFS/K_{ij}/K_{ij}) as the corresponding factors.

3.0 THEORETICAL CONSIDERATIONS AND METHOD OF STUDY

3.1 Some elements of organisational structure

a) Decision centre: A position (head of a section) for decision making in an organisation with the authority and responsibility to make policies, give instruction or prepare procedures for subordinates.
b) Operation Centre: These are work centres at the bottom of an organisational structure where the decision taken at decision centres are carried out.
c) Superior: One in charge of a decision centre
Interested readers may consult Charles-Owaba (2007) for more detailed information

3.2 Organisational Design

Charles-Owaba (2002) appliedOperationsResearch techniques to organisational design. He argued that the present-day organisation could be represented by a quantitative structure that can lead themselves to mathematical modelling for optimal performance. This appears novel. Because of the copious volume of information on this (Charles-Owaba, 2002), only a summary is presented here. This formulation is adopted in this work for our analysis.

3.2.1 Definition of Symbols

L_{ij} Average number of arrivals for supervisor or manager's attention in a day at decision or management level i, decision position j.

W_{ij} Average waiting time of subordinates at decision level i, position j

P_{ij} Probability of having no one attended to by supervisor at the decision centre (i,j).

A: Available working hours per period for each subordinate and superior.

K_{ij}: Number of subordinates reporting to centre j at the i^{th} level.

H_{ij}: Human resource utilisation function at decision level i, position j.

L_q: Average daily man-hours spent working by a subordinate who left their workstation to seek information from the superior.

L_w: Daily man-hours spent by a subordinate who had no reason to seek information from the boss'

L_b: Daily man-hours actually spent working by the head of unit / superior at decision centre (i ,i).

L_z: Daily man-hours scheduled for work by both subordinate and superior.

H: Human utilization for the entire organization.

N_o: Number of operation positions that perform terminal activities

Note:

$i = 1,2.........M$

$j = 1,2.........N,$

λ_{ij}: Rate at which subordinates at centre j of level i consult the boss at decision centre(i,j).

μ_{ij}: Rate at which superior's spent with subordinates at decision centre (i,j).

P_{ij}: Utilisation factor: traffic intensity for system$\left[\frac{\lambda_{ij}}{\mu_{ij}}\right]$

M: Total number of decision levels (hierarchy)

N_i: Number of decisions, position at level Position

N_1: Number of supervisory positions at level 1

N_2: Number of purely decisions or management positions at management level 2.

N_m: =1: Chief Executive Position

M,N_i,K_{ij}, N_m: Organisation structure variables

N_o,A,λ_{ij},μ_{ij}: Organisation structure Parameters

The total number of hours available for work at a decision centre is the combination of hours of the superior and the subordinates.

This work has assumed that the call source is finite and the Queuing discipline of FirstCome, First Served(FCFS)discipline holds

3.2.2 Computation of Human utilization

Human utilization (H_{ij}) is defined as the proportion of man-hours actually spent on useful work to the total establishment man-hours provided for work.

Mathematically human utilisation is defined as:

$$H_{ij} = \frac{Man - hoursactuallyspentforusefulwork}{Totalestablishment'sman - hoursprovidedforwork}$$

Man-hours spent for useful work is given by:

$L_q + L_w + L_b$

Total establishment's man-hours provided for work is given as L_z Hence

$$H_{ij} = \frac{L_g+L_w+L_b}{L_z} \qquad 3.1$$

but $L_g = L_{ij}(A_{ij} - W_{ij})$

3.2

$$L_w = (K_{ij} - L_{ij})A_{ij}$$
3.3
$$L_b = (1 - P_{ij})A_{ij}$$
3.4
$$L_z = A_z K_{ij} + A_{ij} = A_{ij}(K_{ij} + 1)$$
3.5

Combining expressions 3.2, 3.3, 3.4, and3.5 into 3.1

$$H_{ij} = \frac{L_{ij}(A_{ij} - W_{ij}) + (K_{ij} - L_{ij})A_{ij} + (1 - P_{ij})A_{ij}}{A_{ij}(K_{ij} + 1)}$$
3.6

By mathematical manipulation, expression 2.6 becomes:

$$H_{ij} = 1 - \frac{L_{ij}W_{ij}}{A_{ij}(K_{ij}+1)} - \frac{P_{ij}}{K_{ij+1}}$$
3.7

By Kendall's notation with one channel queuing model (Taha 1976); m/m/1:(FCFS/K_{ij}/K_{ij}), (Taha, 2007, Hillier and Lieberman,2007)

$$L_{ij} = \bar{L}_{ij} + 1 - P_{ij}$$
3.8
$$W_{ij} = \frac{\bar{L}_{ij} + 1 - P}{(1 - P_{ij})\mu_{ij}}$$
3.9
$$P_{ij} = \left(1 + \sum_{n=1}^{kij} C_n^{kij} n!\, e_{ij}^n\right)^{-1}$$
3.10
$$\bar{L}_{ij} = \frac{\sum_{n=2}^{Kij} (n-1) C_n^{kij} n! e_{ij}^n}{1 + \sum_{n-1}^{kij} C_n^{kij} n! e_{ij}^n}$$
3.11

Where $e = \frac{\gamma_{ij}}{\mu_{ij}}$
3.12

Combing expressions 3.8, 3.9, 3.10, 3.11, and 3.12 into 3.7

$$H_{ij} = 1 - \left[\frac{\frac{\sum_{n=2}^{K_{ij}}(n-1)C_n^{kij} n! e_{ij}^n}{1+\sum_{n=1}^{Kij} C_n^{kij} n! e_{ij}^n} + 1 - \left(1 + \sum C_n^{Kij} n! \, e_{ij}^n\right)^{-1}}{\mu_{ij}\left[\left[\sum_{n=1}^{K_{ij}} C_n^{kij} \, n! \, e_{ij}^{n-1}\right]^{-1}\right]} \right] - \frac{1 + \sum_{n=1}^{Kij} C_n^{kij} n! \, e_{ij}^n}{K_{ij}+1}$$

Expressing H_{ij} in terms of decision centre j parameters i and the variables.

$$H_{ij}(K_{ij}, A, \mu_{ij}\lambda ij) = 1 - \frac{1}{A_{ij}(K_{ij}+1)} \left[\frac{\frac{\sum_{k=2}^{kij}(n-1)C_n^{kij} n!\left(\frac{\lambda ij}{\mu_{ij}}\right)^n}{1+\sum_{k=2}^{kij} C_n^{kij} e_{ij}^n} + 1 - \left[1+\sum_{n=1}^{kij} C_n^{kij} n!\left(\frac{\lambda ij}{\mu_{ij}}\right)^n\right]^{-1}}{\mu_{ij}\left[1-\left(\sum_{n=1}^{kij} C_n^{kij} n!\left(\frac{\lambda ij}{\mu_{ij}}\right)^n\right)^{-1}\right]} \right] - \frac{1+\sum_{n=1}^{kij}\left(C_n^{kij} n!\left(\frac{\lambda ij}{\mu_{ij}}\right)^n\right)^{-1}}{K_{ij}+1} ..$$

3.14

In expression 3.14, the span of control K_{ij} is the only variable since it is the human utilisation in one decision position. The daily work hours A, rate of at which the boss at decision centre (i, j) attends to the subordinate μ_{ij} and the rate at which subordinate arrives for consultation $\lambda_{ij}$are the parameters of the organisational structure at decision centre (i, j).

For the design of the entire organisational structure which is a combination of all decision position j and decision level i, the human utilisation;

$$H(K_{ij}N_i M, \theta h) = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N_i} H_{ij}}{\sum_{i=1}^{M} N_i}$$

3.15

Where $\theta\text{h} = (\text{A}, \lambda_{ij}, \mu_{ij}, N_0)$

3.16

The organisation variables are therefore $K_{ij}, N_i and M$ while the parameters are $\theta_h(A, \lambda_{ij}, \mu_{ij}, N_0)$.

The purpose of this study, therefore, is to determine experimentally in the workplace or establishment the values of K_{ij}, $\lambda_{ij}, \mu_{ij}, and N_0$ (A is standard; 8 hours) so that variables K_{ij} N_i and M will be selected to give the maximum possible value of H (K_{ij}, N_i M; (A, $\lambda_{ij}, \mu_{ij}, N_0$). This can be stated in the standard operations research form as:

Maximize H(K_{ij}, N_i M_i; A A_{ij}, μ_{ij}, N_0).

Subject to

$$\sum_{i=1}^{N_i} K_{ij} = N_{i-1}; N_0$$

Nm = 1

K_{ij}, N_i, M > 0

Design Parameters

The work sampling techniques, widely applied to monitor the performance of workers, was used in this study basically to find the parameter values of the operation position N_0, and human dynamic parameter λ_{ij} and μ_{ij} at the decision positions/management level. The sampling method for determining the operation position N_0 differs from that of the human dynamic parameter λ_{ij} and μ_{ij} for the management level, hence the experiments to determine both parameters were carried out in two phases.

Phase one uses the work sampling or activity sampling technique for estimating the work content of each of the existing operation positions. This method requires fewer man-hours and cost less, than using the other alternatives such as the continuous-time study (Barnes, 1968). Its accuracy depends on the number of observations and randomness. In this study, only the aspect of dealing with the determination of the amount of work content available in operation positions in the firm was presented.

The second phase is to determine experimentally, the values of the human dynamic interaction parameters $\lambda_{ij}$the rate at which subordinates arrive to consult the boss for instruction, etc; and the rate at which superior attends to the subordinates and μ_{ij}.

The parameter personnel interactions or information flow. Relative high values of λ_{ij} may mean inexperienced personnel who would want to see the boss frequently for more clarifications, a complex job situation while low values of λ_{ij} may mean experienced personnel who may have only a few cases for the attention of the boss. High values of μ_{ij} might mean an experienced boss who is naturally fast or also be that the problems taken to the boss for solutions are relatively simple. Low values of μ_{ij} might mean supervising personnel with complex tasks, experienced personnel with complex tasks, an inexperienced or lazy boss who takes a longer period per subordinate who reports to him.

To solve the problem of redesigning of the organisational structure using the quantitative approach of work sampling technique, the procedure includes the following:

i Determination of the amount of annual work available at operation positions by using the expression below;

$$No. of\ Staff(ops\ position) = \frac{Grandtotal\ standard\ man - hour\ perannual}{Available\ hours\ x\ usefactor} (Charles - Owaba\ 2002)$$

ii Determination of Parameter set $\theta_2 = (A_1, \lambda_i, \pi_i)$

iii Optimal span of control

iv Analysis of optimal personnel utilization, size, and shape

3.4 Procedure for determining the number of operation positions (N_0)

The following steps were used for phase 1 of the study to collect and analyse the data for the operation position N_0.

Step 1 All the operation positions of the production departments of the manufacturing firm taken from available records. The respective positions were visited and a route was mapped out for taking an observation of workers to ascertain the busy or not busy status of each operation position.

Step 2 The data collection form was designed to reflect the departments and sections where the study was carried out.

Step 3 The preliminary number of observations to determine the study parameter, P, the proportion of time an observed staff was found busy on the paid job was carried out. At this preliminary number of observations, only few of the positions were randomly picked and twenty observations were carried out for each operation position to determine P. The value of the study parameter was then determined by the expression.

$$P = \frac{Number\ of\ times\ staff\ were\ found\ busy}{Total\ number\ of observations\ for\ all\ observedstaff} \quad 3.21$$

Step 4 At this stage, the number of observations N for the actual study was computed using a desired accuracy or level of confidence (A). The number of observations N was modelled as follows:

Let;

N = Number of observations

A = Desired relative accuracy

K = number of standard deviations away from the mean

Hence,

$$AP = K\sqrt{\frac{P(1-P)}{N}}$$

$$N = \frac{K^2(1-P)}{A^2P}$$

3.22

For most purposes, Barnes (1968) observed that with K=2, A=5% a confidence limit of 95% is adequate. In this case expression, 3.22 becomes:

$$N = \frac{4}{(0.05)^2}\left[\frac{1-P}{P}\right] = \frac{1600(1-P)}{P}$$

3.23

The recording form was filled in the appropriate space, for date, department or section, the start time and names of positions to be observed. At each position, the following was noted and recorded as soon as each observation was concluded:

- Busy or not busy mode
- Performance rating of the individual

At the end of each study day, the number of busy modes for each position was counted; the total number of observations and end of study time was also recorded. Also determined was the average performance rating for each position.

Step 5

The data analysis in the information conducted in step 5 was carried out at this stage and the following quantities were computed:

- Utilisation factor (μ_i) for each position i
- Estimated Annual Man-Hours EAM_i
- Estimated Basic Man-Hours, (EBM_i)
- Estimated Standard Man-Hours (ESM_i)

The expressions that follow were then used to compute the Total Annual Standard Man-hours (TAM).

$$U_i = \frac{Numberofobserved\ busy\ mode\ for\ position\ i}{total\ number\ of\ observations}$$

$$EAM_i = U_i x Available\ hours\ of\ work\ in\ the\ year$$

$$EBM_i = EAM_i x \frac{Performance\ Rating\ in\ Positions\ i}{100}$$

3.24

$$ESM_i = EBM_i x \frac{ESM_i x PA_i}{100}$$

3.25

where PA_i is percentage allowance for each type of job done in position i

$$TAM = \sum_{i=1}^{M} ESM_i$$

3.26

The number of operation position N_0 is thus;

$$N_0 = \frac{Total\ standard\ man\text{-}hours\ per\ annum}{available\ hours\ x\ use\ factor}$$

3.27

3.3Investigation of organisational structure of the selected firm: Case Study

The selected organisation for this study manufacturers and sales Tobacco in Nigeria. This company has an investment of $150million in2001 through foreign direct investment agreement. The investment is an integrative activity that impacts on all aspects of the tobacco business from leaf growing, through manufacturing to the distribution of tobacco products.The company has two factories in different locations in Nigeria and its stable arethe popular brands and many more products.

Scope and Limitation of Study

This study was carried out to redesign the organization structure of production department of a Tobacco in Nigeria, this study would not include other departments in the organization like Human Resources, Finance Supply Chain etc and henceit is focused on production, so the service sector like education institutions, consulting firms or construction firms are not included.

An investigation carried out showed that the existing structure is made up of four; decision levels; supervisory positions (36); 1st level managers (10); middle-level manager (4); Top-level executive (1); and the operation positions (180). The existing organization structure isas in figure 3.1.

The following categories of workers can be identified
Manufacturing Manager (MM)
Pry Manufacturing Department (PMD)
Secondary Manufacturing Department (SMD)
Cell Manager (CM)
Shift supervisor/Tech Support (SS)
Technician (TECH)
Operators (OPS)

The first phase of the study was carried out to determine the number of operation position N_o, which is one of the parameters of Organisation structure. The operation positions are labelled P_1 to P_{180}.
Other information about the company include the following:

The annually available man-hours were deduced as follows:
The Organisation runs through the year, but the personnel work an average of 48hrs per week running 3 shifts per day and work 52 weeks per annum including public holiday.

Hence, the available Man hour per annum = (48x52) = 2496 hours per annum

1. The organisation works through the year running 24hours daily.
2. The personnel work in a shift with variant schedules, for instance, some work 12hrs daily running 2 shifts, others work 3 shifts with shift schedule 7-7-10hrs. However, each personnel work average of 48hrs per week and 52 weeks in a year.
3. The percentage allowance. PA=0.15
4. The factory utilisation factor, U_i=0.8= 80%
5. Hence, the available Hour = 48x52= 2496 Man hours.

Since the use factor = 0.8 , then K= 2496 X0.8

The data to determine the number of operation positions N_o, was gathered for 5 days at 10 trips per day for each identified operation position. The total observations were 50 observations.

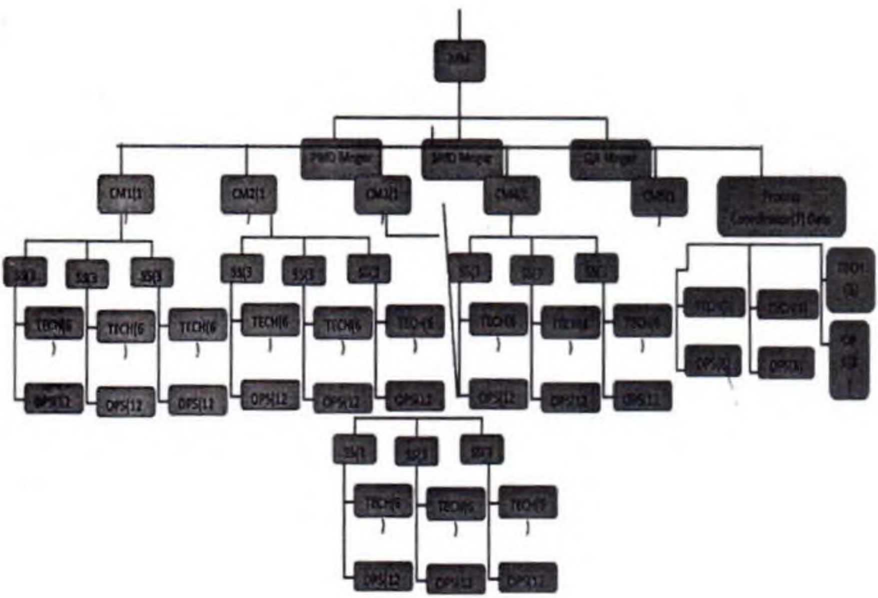
The organisation operating parameters such as described above, was applied to the work sampling expression 3.4, 3.5, 3.6 and 3.7. An excel application package was used to perform the computation for operation position 1 to position 180, that is P_1 to P_{180}. The outcome of the analysis is presented in Table 4.1

Note: Although, there are three shifts, some workers work two shifts while other work three shifts.

In order to have a fair engagement, every worker works for 48 hours a week. Also, it is assumed that weekends, public holidays, leave must apply. To account for this the company allows a 15% personnel allowance. Furthermore, a fair structure should allow every boss to have same number of subordinates. This work also assumes a fair structure.

These are the applicable situation in this firm. Other organisations may have different arrangements and theirs would apply in the design and analysis. It is enough that the structure is fair and the work content properly captures and distributed.

FIGURE 3.1: EXISTING ORGANOGRAM



3.4 Re-design of Procedure organisational structure understudy

3.4.1 Determining the human dynamic parameter (λ_{ij} and μ_{ij})

In the second phase of the study, the human dynamic interaction parameters λ_{ij} and μ_{ij} were determined using the following steps as depicted below:

Step 1 The study period was picked to cover low, moderate and peak levels of activities.

Step 2 The time study commenced at each decision position j, level i was noted and recorded.

Step 3 As each subordinate arrived to consult the supervisor, it was noted whether the subordinates waited and received attention from the boss. The total number of cases at position j of level i, was taken as TNC_{ij} . The observation taken was either an immediate boss to a subordinate interaction or a subordinate to a boss interaction.

Step 4 The amount of time the personnel occupying position j, level i spent attending to each case was noted and recorded. Let the time for case α be $t_{ij\alpha}$.

Step 5 The completed cases were counted within the study period and labelledTCC_{ij} (Total completed cases).

Step 6 The total working time (hours) spent observing the activities at the decision position of interest was recorded and this was taken as TTS_{ij} (Total time of the study).

Step 7 The values of λ_{ij} and μ_{ij} are then calculated thus,

$$\lambda_{ij} = \frac{Total\ number\ of\ the\ case\ at\ position\ (i,j)}{Total\ time\ (hours)\ for\ study\ at\ the\ position} = \qquad \lambda_{ij} = \frac{TNC_{ij}}{TTS_{ij}}$$

3.28

and

$$\mu_{ij} = \frac{Total\ completed\ cases\ at\ position\ (i,j)}{Time(hours)\ spent\ to\ treat\ all\ completed\ cases} \quad = \quad \mu_{ij} = \frac{TCC_{ij}}{\sum_{\alpha=1}^{TCC_{ij}} t_{ij\alpha}}$$

3.29

For a fair organisational structure where the span of control is assumed to equal for each decision position at the same level, let μ_i be the case

completion rate at level i and λ_{ij} ; the arrival rate. These values may be estimated at the mean values of μ_{ij} and λ_{ij} respectively.
Hence,

$$\mu_i = \sum_{i=1}^{N_i} u_{ij}/\mathrm{N_i}$$

$$\text{and } \lambda_i = \sum_{i=1}^{N_i} \mu_{ij} \frac{\lambda_{ij}}{N_i}$$

With N_0, λ_i , μ_i and A known, the variable M, N_i and K_{ij} can now be picked from the human utilization Table (Charles-Owaba 2002) for the design of the organisational structure.

SECTION 4: APPLICATIONS, RESULTS, AND DISCUSSION

The first phase of the study was carried out to determine the number of operation positions N_o, which is one of the parameters of Organisational structure. The operation positions are labelled P_1 to P_{180}.

Vital information about the company operating system was collected and included the following:

6. The organisation works through the year running 24hours daily.
7. The personnel work in a shift with variant schedules, for instance, some work 12hrs daily running 2 shifts, others work 3 shifts with shift schedule 7-7-10hrs. However, each person works average of 48hrs per week and 52 weeks in a year.
8. The percentage allowance PA=0.15
9. The factory utilisation factor, U_i=0.8= 80%
10. Hence, the available Hour = 48x52= 2496 Man hours.

The data to determine the number of operation positions N_o werecollected for 5 days at 10 trips per day for each identified operation position. The total observations were 50 observations.

The organisation operating parameters described above were applied to the work sampling expressions3.24, 3.25, 3.26, and 3.27to compute for operation positions 1 to 180, which is P_1 to P_{180}. The total man-hour per annum, being the summation of required man-hour for each identified operation position was 333,025.6hrs.

4.1 The number of operation position N_0.

Two scenarios are considered here at 80 % and 100% utilization use factor respectively as shown as it Table 4.1

From expression 3.7, we have that

$$N_0 = \frac{Total\ standard\ man\ hour\ per\ annum}{Annual\ available\ man\ hour\ x\ use\ factor}$$

For P_1. $N_0 =$

$$\frac{1840 + 1932 + 2185 + 1584.125 + 2021.125 + 1474.875 + 2021.125 + 1911.875 + 2021.125 + 1584.125}{2496\ x\ 0.8}$$

$$= 9.3026$$

By fractional man principle and agreement between the management and the in-house onion, >0.5 is taken as 1.0, while <0.5 is rounded off to 0.0.

Hence, $N_{1-10} = 9$ personnel at 80% use factor.

For 100% the value is 7.

The above procedure of computation of operation position in 4.1 was repeated for other operation positions fromP_{11-180}as well as for both 100% and table 4.1 was deduced.

Table 4.1: Proposed operation positions N_0.

	P_{oi}	$\sum(N_{oi})_{i=1}$at 80%	$\sum(N_{oi})_{i=1}$at 100%
1	P_{1-10}	9	7
2	P_{11-20}	9	7
3	P_{21-30}	9	7
4	P_{31-46}	14	11
5	P_{47-67}	19	15
6	P_{68-90}	21	17

7	P_{91-122}	28	23
8	$P_{123-138}$	15	12
9	$P_{139-160}$	21	17
10	$P_{161-180}$	21	17
	TOTAL	**166**	**133**

The total operation positions $T_{op80\%} = \sum_{j=1}^{ii}(N_{oi})$
$=9+9+9+14+19+21+28+15+21+21 = 166$
The total operation positions $T_{op100\%} = \sum_{j=1}^{ii}(N_{oi})$
$=7+7+7+11+15+17+23+12+17+17 = 133$

The implication is that the company can operate at either 80% or 100% use factor.

4.2 Determination of λ_{ii} and μ_{ii} at Supervisory level and Managers

The study for determination of both λ_{ii} and μ_{ii} was carried out in 3 days for each decision level. A total of 9, 10, 11 and 11 hrs respectively were used as study hours, while 6.4, 5.2, 5.06 and 6.28 hours respectively were observed as consultation hours. Total number of cases who arrived for consultation was 45 while only 40, 32, 33 and 33 cases actually consulted at each level.
The data computed and analysed and the result presented in the Table 4.2

The summary of analyses of human dynamic interaction at the supervisory, 1st level management, the middle level and Top-level management is shown in the table 4.2a:

Table 4.2a: TheHuman dynamic interaction at decision levels

Criteria	Supervisor	1st level Manager	Middle Level Manager	Topmost level
λ	5.0	4.5	4.09	4.09
μ	6.25	6.06	6.5	5.25
K_l^*	4	4	4	4
H_l^*	0.9621	0.9612	0.9633	0.9565

Table 4.2b: The Human dynamic interaction at decision levels

Criteria	Supervisor	1st level Manager	Middle Level Manager	Topmost level
λ	5.0	4.5	4.09	4.09
μ	6.25	6.06	6.5	5.25
K_l^*	5	5	5	5
H_l^*	0.9621	0.9612	0.9633	0.9565

4.3 Span of Control at decision levels

The first phase of the study gave the total number of proposed operation positions for the new
organisational structure as 166. The span of control at the supervisory K_1^* as shown in the Table 4.2a.is $K_1^*= 4$.

Hence, the required number of supervisors, N_1^* to oversee the 166operation positions is $N_1^* = \frac{N_0^*}{K_1^*} = \frac{166}{5} = 33.2 = 34$

The number of First Level Manager required to direct the affairs of the supervisors with value of N_1^* =34 and Span of Control K_2^*=4 is deduced as follows:

$$N_2^* = \frac{N_1^*}{K_1^*} = \frac{34}{4} = 8.5 \cong 9$$

Hence, 9 first level managers are to oversee the 34 supervisors.
The number of middle level manager to oversee the first level managers with span of control K_3^*=3 is thus

$$N_4^* = \frac{N_2^*}{K_3^*} = \frac{9}{3} = 3$$

Therefore, 3 middle level managers would oversee the affairs of 9 first level managers.
The Top executive position N_4 with span of control K_4^*=3 is thus;

$$N_4^* = \frac{N_3^*}{K_4^*} = \frac{3}{3} = 1$$

4.4 Computation of proposed Personnel Utilisation

Personnel utilization, H* is calculated from expression 3.15 as

$$H^*(K_{ij}, N_{ij}, M, \theta_n) = \frac{\sum_{i=1}^{M} \sum_{i=1}^{N_i} (H_{ij})}{\sum_{i=1}^{M} (N_i)}$$

Where $\theta_n = (A_{ij,ij}, \mu_{ij}\ N_0)$.
Thus, from expression 3.16

$$H^* = \frac{(N_1^* \ x \ H_1^*(K_1^*, A, \lambda i, \mu_i) + (N_2^* \ x \ H_2^*(K_2^*, A, \lambda_2, \mu_2) + (N_3^* \ x \ H_3^*(K_3^*, A, \lambda_3, \mu_3) + (N_4^* \ x \ H_4^*(K_4^*, A, \lambda_4, \mu_4)}{N_1 + N_2 + N_3 + N_4}$$

$$H^* = \frac{34(0.9513) + 9(0.9612) + 3(0.9467) + 1(0.9512)}{34 + 9 + 3 + 1} = \frac{38.5584}{41} = 94.04\%$$

$$H^* = \frac{34(0.9513) + 9(0.9612) + 3(0.9467) + 1(0.9512)}{34 + 9 + 3 + 1} = \frac{38.5584}{41} = 94.04\%$$

Now, the size and shape of the organisation is computed as follow, while the proposed operation positions stood at 166, the required supervisors were computed as 34. The 1st level manager to oversee the supervisors would be 9, even though computed at 8.5, but a fractional man principle applies here, so the required 1st level manager was taken at 9. The middle level management is 3 as the span of control for each manager was taken at 3 for optimal performance.

Finally, the top-level management requirement is 1 as his span of control was 3.
From the above, the size and shape of the organisation is as follows;

$$S^{*}(size) = N_0 + N_1 + N_2 + N_3 + N_4$$
$$= 166 + 34 + 9 + 3 + 1$$
$$= 213$$

The height of the organisation $M^* = 4$
The width of the organisation, $Z = (N_1 + N_2 + N_3 + N_4)/M^*$

$$= \frac{34 + 9 + 3 + 1}{4}$$
$$= 11.75$$
$$= 12 \ (to\ the\ nearest\ whole\ number)$$

The organisational structure is thus given as

$$\in = (S\ M^{*}Z)$$
$$\in = (213, 4, 12)$$

This in matrix is given as:

$$\in = \begin{bmatrix} 4 & 1 \\ 3 & 3 \\ 2 & 9 \\ 1 & 34 \\ 0 & 166 \end{bmatrix}$$

This is the proposed organisational structure for the firm

4.5 A comparative analysis of Existing and proposed Structure

A comparative analysis of existing and proposed personnel utilization at the decision levels was carried out to know the impact of the redesign of the organization.The personnel utilization and respective human dynamic interaction were computed for both existing and proposed organization structures and results presented in the Table 4.3.

Table 4.3 showing a comparison of Existing and Proposed structure

Criteria	Existing structure	Proposed Structure
Operation Position	180	166
Supervisor (span of control)	36(5)	34(5)
1st Level Manager(span of control)	10(4)	9(4)
Middle Level Manager(span of control)	4(3)	3(3)
Top Level Manager (span of control)	1(4)	1(3)
Human Utilization Factor	0.9529	0.9404

4.5.1 Grouping of Operation positions into Supervisory tasks

The operation positions have been reduced from 180 to 166 personnel and consist of both Machine operators, Mechanical technicians and Electrical technicians; and they are to be supervised by 34 supervisors from the existing 36 supervisors.
Hence, the grouping of operation position into supervisory tasks is as shown in the table below:

Table 4.4: Grouping of Personnel into Supervisory tasks.

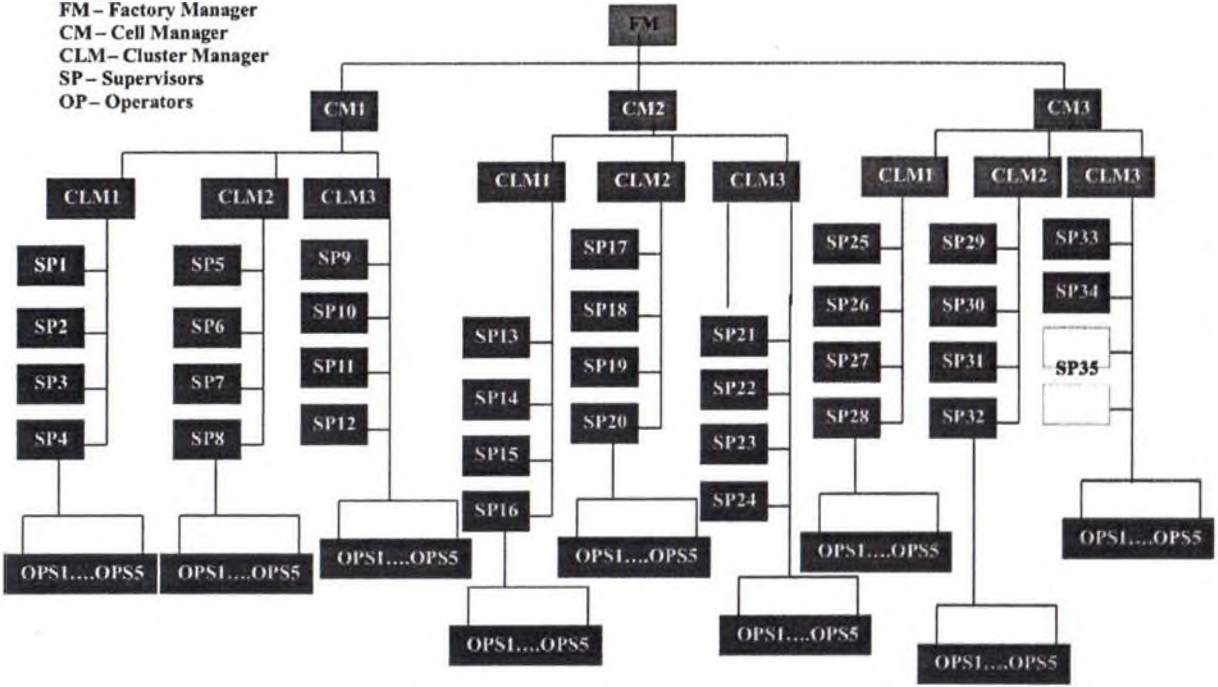
S/N	Supervisors	No of Operators	No of Technicians
1	Mech 1	3	2
2	Mech 2	3	2
..	..	..	..
30	Mech 2	3	2
31	Elect 1	..	4
..	..	..	..

34	Elect I	..	4
TOTAL	**34**	**90**	**76**

The proposed organisational structure is shown in figure 4.1. All positions are represented in the proposed Organogram

FIG 4.1:PROPOSED ORGANOGRAM

KEY:
FM – Factory Manager
CM – Cell Manager
CLM – Cluster Manager
SP – Supervisors
OP – Operators



4.5.2 Grouping of Supervisors into the 1st level management tasks

34 supervisors are being proposed for the new organisational structure and 9 first-level managers are to oversee their activities. It should be noted that the existing 1st level managers were 10 personnel while 9 was being proposed. Hence, their grouping follows this trend as shown in Table 4.5 below:

Table 4.5: Showing Supervisory personnel grouping

S/N	1st Level Manager	No of supervisors
1	Electro Tech 1	4
2	Mechanical 2	4
..	..	..
9	9	2
TOTAL	9	34

4.5.2 Grouping of 1st Level Manager into Middle-Level Managerial Tasks

In the existing organisational structure, 4 middle-level managers oversee the activities of 10 1st level managers. This is a case of underloading of personnel and this will affect their productivity. However, in the proposed structure, the middle-level manager was computed to be 3 personnel to oversee the activities of the 9 first-level managers. Each middle-level Manager oversees the activities of 3 first-level managers.

4.5.3 Grouping of Middle-Level Managers into Topmost Executive

There is only one existing topmost manager and in the proposed organization structure, the number was retained. Hence, one topmost manager is to oversee the activities of the 3 middle level managers.

Table 4.7 Comparison of Cost Implications of Redesigning the Organization Structure

Position	Existing Structure	Cost (N)	Total	Proposed Structure	Cost	Total	Difference (Desired Reduction)
Ops Position	180	95000	17100000	166	95000	15770000	14
Supervisors	36	122000	4392000	34	122000	4148000	2
1st level Manager	10	205000	2050000	9	205000	1845000	1
Middle-level Manager	4	285000	1140000	3	285000	855000	1
Topmost Manager	1	310000	310000	1	310000	310000	0
Total24,992,000			22,992,000			22,928,000	2,064,000/month

From the above cost analysis table, in 12month, N (2064000) x 12 = N24768000 would be saved. Meanwhile, if the allowances and other emoluments were considered, more money would be saved by the newly proposed organisational structure, implying more profits for the business as the recurrent expenses would decline substantially.

4.6 Discussion of Results

The data garnered from the work sampling on the shop floor indicated that there should be changes in the number of operations in the proposed structure. Also, the values of the human dynamic interaction deduced at the hierarchy of the organization as shown in Tables 4.2 and 4.3 showed disparity in the span of control of the supervision even though, the span of control of supervisor at the existing structure was 5, but the scope of work did not justify the number of operation position. Hence, the span of control for supervisor, K1 still remain at 5, while the number of supervisors is reduced to 34.

The 1st level manager position was also reduced from 10 to 9, with a span of control

K2=3 retained. The middle-level manager in the existing structure seemed to be underloaded,

while 4 of them managing 10 lower level managers-, 2 of these managers were underloaded.

However, this has been corrected in the new structure with the number of middle-level managers reduced to 3 and a span of control of K3=3.

The topmost manager was overloaded in the existing structure with a span of control of 4, but the new structure would afford the topmost manager to supervise only 3 middle-level managers.

In all, the human utilization of the proposed structure is almost in tandem with the existing, but with a lower headcount and consequently, cost implications. The benefits of this redesigning are more pronounced in the logical arrangement of the personnel and the monetary value of about ?24,768,000 per annum this is excluding another emolument like allowances and estacode.Finally, in the proposed structure 18 personnel were redundant and the rest working with an ideal span of control.

SECTION 5: CONCLUSION AND RECOMMENDATION

5.1: CONCLUSION

The feasibility of applying a quantitative approach to redesign a tobacco processing firm was demonstrated. The firm's annual work content was observed and the number of lowest-level personnel determined. Personnel utilization mathematical expression was given in terms of organization design variables and parameters and applied as the design objective function. The firm's organizational design problem was then defined and solved using the Operations Research paradigm. The redesigned proposed structure compared favourably to the existing organization structure.

Based on this, the following conclusions were drawn:

" The existing organization structure has four management/supervision levels, thirty-six supervisors, ten first line and four middle and one higher manager with a monthly running cost of N23,903,000

" The firm's mathematical model of an operating Organisational structure indicating personnel utilization (H), human dynamic parameters (?, ?), daily working hours (A), number of manual workers (N0), number of supervisors (N1), number of managers (Nij) per level, their respective span of control (Ki) and number of management levels (M) was established.

" The optimal organization structure showing N0=166; N1=34; N2=9; N3=3; and N4=1; H=96% with N22,103,900 monthly running cost was derived.

" The redesigned outperformed the existing organization structure.

5.2 RECOMMENDATION

The personnel utilization function, the complement of personnel redundancy, were taken as organisational design performance measures. Other performance measures such as supervision cost, total personnel operating cost, etc were left out. These are recommended for further study.

Finally, it is recommended that the management of the firm should review the existing organisational structure to know the impact of the proposed organisational structure design and then adopt the proposed design to increase the overall Organisation efficiency. Implementing a companywide redesign would likely generate some synergy. This is also recommended for further studies.

REFERENCES

Alberts D.S. (2012). Rethinking Organisation Designs for complex endeavours. Journal of Organisational Design, Vol. 1, No. 1, pg. 14-17.

Anyaeche, C. O., Fatuase, L. O. and Adedeji, P. A. (2015). A Performance Evaluation

Model For Automated Teller Machines In Selected Locations Of Some Banks In Nigeria Proceedings of the International Conference of the Nigerian Institute of Industrial Engineers.

Anyaeche, C. O, and Oluwanimifise M, K. (2011). Productivity and Profitability Evaluation of Selected Nigerian Hospitals under Private and Public Management, Proceedings of 2011 International Conference of the Nigerian Institute of Industrial Engineers.

Babcock, D. L. and Morse, L. C. (2005).Managing Engineering and Technology Third Edition, Prentice-Hall of India, Private Limited, New Delhi

Barnes, R. M. (1968). Motion and Time Study: Design and Measurement of Work, John Wiley and Sons, New York

Galbraith, J. and Nathanson, D. A. (1978) Strategy Implementation: The Role of Structure and Process. West Publishing, St. Paul Minnesota

Burton R.M. (2013). The Future of Organisation design: An Interpretative Synthesis in three them, Journal of Organisation Design, Vol. 2, No. 1, pp. 41-42.

Burton, R. M. (2020). Fit, Misfit, and Design: JOD studies that touch reality Burton Journal of Organization Design https://doi.org/10.1186/s41469-020-00081-0. (Accessed September, 18, 2020)

Charles-Owaba, O.E. (1987). On the Organization Structure Design Problem.Journal of Nigeria Institute of Industrial Engineers, Volume 1, No. 1, June.

Charles-Owaba, O. E. (1998). Evaluation of the Nigerian Civil Service Organization Structure Design Problem.Nigerian Institute of Industrial Engineers, Proceedings of the 1998 Productivity Conference vol. 1, pp 217-234.

Charles-Owaba O.E. (2002). Organisational Design: A quantitative approach, Oputoru Books, Ibadan

Drucker, P.F. (1973). Management: Tasks, Responsibilities, Practice, Harper and Row.

Fayol, H. (1949). General and Industrial Management. Pitman and Sons London.

Hammer, M. and Champy, J. (1993). Reengineering the corporation: A manifesto for business revolution. Harper Collins, New York.

Harvard Business Review (2011). The Organisation today.Journal of Business OrganisationVol. 2, No. 1, pg. 24.

Hax, C. and Majluf, N.S. (1981). Organizational Design: A Survey and an Approach, Vol. 29, pp. 417-477.

Kulik, B.W; Baker T. (2008). Putting the Organisation back into Computation Organisation Theory: Computational and Mathematical Organisation Theory Vol. 14, No. 2, pg. 84-119.

Hillier, F.G. and Lieberman, G. J. (2006).Introduction To Operations Research, McGraw- Hill Books, New York, 7th edition.

Lamarco, N. (2018). Importance of product packaging in Business|; Advertising & Marketing; |; Marketing Products.

Ofiabulu C. E. and Charles- Owaba, O. E (2013a). A Personnel Cost Model for Organisational Structure Design, Industrial Engineering Letters www.iiste.orgVol.3, No.6, 2013, (Accessed September, 18, 2020)

Ofiabulu C. E. and Charles- Owaba, O. E. (2013b). A Dynamic Programming Model for Organisational Designing Industrial Engineering Letters www.iiste.org, Vol.3, No.7, 2013 (Accessed September, 18, 2020)

Ofiabulu C. E. and Charles- Owaba, O. E. (2013c). On the Personnel Utilization Model for Organizational Design IOSR Journal of Engineering (IOSRJEN) Vol. 3, Issue 7 (July. 2013), ||V6 || PP 26-36 www.iosrjen.org (Accessed September, 18, 2020)

Ofiabulu C. E. and Charles- Owaba, O. E. (2013d). Minimising the Supervision Costs of the Organizations IOSR Journal of Engineering (IOSRJEN) Vol. 3, Issue 8 (August. 2013), ||V2 || PP 28-38 www.iosrjen.org (Accessed September 18, 2020)

Robert E. Lucas, (2004). Industrial revolution: Past and future: 2003 annual report essay

Scott W.R. (1981).Organization: Rational, Natural and Open Systems Englewood Cliffs, N.J.Prentice-Hall, pp 22-23

Stewart R. (1993). Information technology, organization restructuring and the future of Middle level management. Oxford 8 (1)

Taha, H. A. (1976). Operations Research: An Introduction. MacMillan New York

Taha, H.A. (2007). Operations Research: An Introduction. MacMillan New York

Taylor, F.W (1911). The Principle of Scientific Management, Harper and Row. New York

Wikipedia (Sept 22, 2020) https://www.google.com/url?sa

CHAPTER 24

Anthropometric Evaluation of Bus Drivers And Their Workstations

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Abstract

This study conducted an anthropometric evaluation of bus drivers and their workstations in southwest Nigeria. Thirty (30) anthropometric measurements were obtained from one hundred and fifty (150) commercial bus drivers. The assessment of the structural dimensions of their workstation was from two categories of buses, mini-buses, and midi-buses from ten different models of buses predominantly used for public transport in seven urban centers in three Southwestern states of Nigeria. The data collection instruments for this study were a stadiometer, digital Vernier caliper, a 3.5m stainless steel retractable tape, and a universal bevel protractor. Analysis of the anthropometric variable of the drivers showed that human body characteristics varied across different tribes, locality, and nation. The results of the analysis showed that drivers' workstations in the commercial urban buses used in South-Western Nigeria did not ergonomically fit the urban bus drivers in the region. This study concluded that there were mismatches between the drivers' anthropometric variables and the design measurements of the present driver workstation. There is a need to consider the human body anthropometric variables of the drivers in the nation at the design stage of the vehicles for safe occupational health, work efficiency and performance.

Keywords: anthropometry, ergonomics, workstation, drivers, buses, Nigeria

1.0 Introduction

Realyvásq seeuez-Vargas *et al.* (2020) described workstation design as a strategy to increase human factor performance and productivity. Inadequate workstation designs in automobiles represent an occupational risk factor of drivers (Realyvásquez-Vargas *et al.*, 2020; Samuel *et al.*, 2016). The workstation design determines the adoption of work posture, the concentration, work performance, and well-being of the drivers (Kushwaha and Kane, 2016). Studies revealed that poor design of workstations results in fatigue, loss of concentration, increases probability of mistakes, affects comfortable work postures, imposes musculoskeletal disorders, and consequently, affects work performance and well-being of workers (Kushwaha and Kane, 2016; Yeow *et al.*, 2014). Accumulated risk of chronic injuries, discomfort, and muscle movement disorders development in professional drivers from their work station negatively influences their personal and professional lives (Okunribido *et al.*, 2006; Sadri, 2002; Bernard and Putz-Anderson, 1997). The impact of physical pressure from the work conditions on the musculoskeletal system of drivers depends on the driving hours and the working conditions (Jensen *et al.*, 2008; Okunribido *et al.*, 2006). The design, features, and manufacture of automobile operator's workstation determine the level of comfort, safety, and performance of a driver in the workspace envelope (Samuel *et al.*, 2016; Onawumi and Lucas, 2012).

The human factor and vehicular performance requirements misfit in the workstation of the drivers can lead to fatal accidents, resulting in loss of life, motor vehicle, and properties contained in it (Igboanugo *et al.*, 2002). Phillips (2000) opined that the human biological system is significant in vehicle-related road accidents. One of the ergonomic risks and the peculiar challenge to drivers in Nigeria is in the drivers' workstation. Studies revealed that the design of these vehicles was without the anthropometric data of Nigerians (Onawumi and Lucas, 2012; Ismaila *et al.*, 2010; Igboanugo *et al.*, 2002). The use of these vehicles deprives the vehicle users in the nation the user-friendliness of vehicle, forces people to be fitted into the non-fitting technological systems that are available in the market (Onawumi and Lucas, 2012; Igboanugo *et al.*, 2002). Studies revealed that the mismatch between the vehicle drivers and the workstations of the vehicles imported and used in Nigeria is a potential contributor to health risks experienced by the drivers (Onawumi and Lucas, 2012; Igboanugo *et al.*, 2002). Ismaila *et al.* (2010) added that the workstations in these vehicles, especially, the seats are designed or redesigned locally based on the assumptions of the local manufacturers, often without consideration to the users' safety and comfort. This challenge was buttressed by Lucas and Onawumi (2013), who observed poor design and mismatches between the anthropometric characteristics of the drivers and in-vehicle requirements of automobiles imported into Nigeria.

The integration of anthropometric design in the standardization of workstations facilitates the sustainable development of a workplace (Realyvásquez-Vargas *et al.*, 2020). The consideration of anthropometric variables at the onset design of the workstation accounts for the measurement and the characterization of the human body (Lee and Krause, 2002). Anthropometry in workstation design establishes the physical geometry, mass properties, and strength capabilities of the human body for the development of standards and evolving of specific demands associated with the product manufactured, product usability enhancement, and suitability for the user population (Samuel *et al.*, 2016; Agrawal *et al.*, 2010; Del Prado-Lu, 2007; Muzammil and Rizvi, 2007; Caragliu, 2006). The application of human anthropometry in the design of a workplace is through evaluation of work postures, making of a detailed specification of the relationship between the control point and the workstation, and analysis of forces and torque of the human operation at work (Hertzberg, 1972; Pheasant, 1986; Del Prado-Lu, 2007). Samuel *et al.* (2016) opined that the least expectation from an ergonomically designed workplace is an accommodation of a large range of users typically between the 5th and the 95th percentiles of females, and males. The design or redesign of any workstation by considering anthropometric variables of the workers improves the body posture and reduces the risk of WMSD (Colim *et al.*, 2019). Other studies added physical suitability of workplace design and enhanced sustainability as benefits of anthropometric variables in workstation design (Kim *et al.*, 2017; Nadadur and Parkinson, 2013). Considering the variability among people of a different race, tribes, and nations, correct use of anthropometry in workstation redesign influences the postures and improves the well-being, health, comfort, and safety of operators (Realyvásquez-Vargas *et al.*, 2020; Hitka *et al.*, 2018; Gaudez *et al.*, 2016).

Tailoring the anthropometric database towards the implementation of design for drivers' workstations should involve a defined representation of the drivers, researchers, information scientists, and manufacturers (Samuel *et al.*, 2016). Studies affirmed that anthropometric variables of a specific population is necessary for an ergonomic suitability determination of a product and a workplace (Ismaila *et al.*, 2010; Agrawal *et al.*, 2010). In this way, the mismatches between drivers' anthropometric characteristics and the workstation requirement observed by Lucas and Onawumi (2013) become addressed. Anthropometric variables and ergonomics principle in the design of a workstation, in the light of global industrialization, guarantee a reduction of human error in system performance, minimization of workers hazards in the work environment, a decline in the adverse occupational health effects on workers, and an enhanced system efficiency (Anema *et al.*, 2004). Evaluation of the workplace health and safety through match analysis between the anthropometric variables of workers and workstation is essential for the reduction of work-related illnesses and injuries incidence (Del Prado-Lu, 2007). The anthropometric evaluation of drivers and their workstations in Nigeria demands an ergonomics approach in the design of automobile used in the nation, serve as a survey for the manufacturers on the health and work issues on their product, the legislation regarding the importation of vehicles into the country, and for an enhanced workstation and performance of commercial drivers (Nishint and Apurava, 2015; Onawumi and Lucas, 2012; Del Prado-Lu, 2007). The above factors are the terms governing the concept of this study as it evaluated anthropometric variables of Nigerian bus drivers and their workstations in South-Western Nigeria.

2.0 MATERIALS AND METHOD

2.1 Data collection instruments for the study

The instruments used for data collection include

Stadiometer, (model PD300DHR, Cardinal scale manufacturing company, UK) (Fig 1) is a digital height and weight measurement device. It also calculates the body mass index. It has maximum capacity of 220 kg with an accuracy of 0.1 kg.

Digital Vernier Caliper (model Mitutoyo 500-506-10, Mitutoyo Corporation, Japan) (Fig 2) is digital precision device for linear measurement of inside and outside diameters, depth, and step of items of objects. it has a measurement range of 0 to 600mm, resolution of 0.0005" (0.01mm), and an accuracy of ± 0.05mm.

A 3.5m stainless steel retractable tape (Model TU-3516, Komelon, U.K) (Fig 3) is linear measuring device made of stainless steel. It has a measuring range of 0 - 3.5m

A universal bevel protractor (model Mitutoyo 187-906, Mitutoyo Corporation, Japan) (Fig 4) is an angle and linear dimension measuring device. It has a 12 inches vernier scale for resolution of 5 minutes. The angle measurement can either be in clockwise and counterclockwise directions, with a measuring range of 3 x 90 degrees.

Fig 1. Stadiometer

Fig 2. Digital vernier caliper

Fig 3. Stainless steel retractable tape

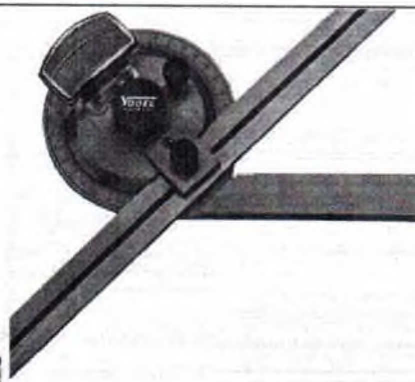

Fig 4. Universal bevel protractor

2.2 Collection of anthropometric and workstation variables

The data collection for analysis in this study involved human anthropometric variables of professional drivers and the design specifics of their workstations. Thirty (30) anthropometric variables were collected from one hundred and fifty (150) professional male drivers in seven urban centers (Abeokuta, Ilaro, Sagamu, Ijebu-ode, Oshodi, Yaba, Ibadan, and Oyo) in three South-West states (Lagos, Ogun and Oyo states) of Nigeria. The data collection was carried using a random sampling technique. The details of the anthropometric variables assessed are presented in Table 1. The drivers' workstation assessment was carried out on fifty (50) buses used for urban transportation in the study area. The workstation assessment was based on the use of the dimensions of the workstations relevant to the body anthropometry of the drivers. The buses considered and assessed were in two categories. Category 'A' comprises of six vehicle models of urban mini-buses. The models were Mitsubishi, Toyota- coaster, Mazda, Honda odyssey, and Nissan–Urvan. Models of buses assessed in Category 'B' were midi-buses from four different models Foton, Ashok, Tata, and Comil. The selection criteria for the buses were that they were predominantly used for both inter- and intra-city transportation in the urban centers in South-Western Nigeria. Measurement of the workstation parameters and the seat dimensions in all selected buses were done.

Table 1: Anthropometric parameters of urban bus drivers and their relevance

S/N	Human body variables	Relevance drivers' workstation part
P1	Stature	Cabinet total height
P2	Sitting height	Seat backrest height
P3	Eye to floor	Seat pan height from cabin floor
P4	Shoulder width	Seat backrest (thoracic level) width
P5	Shoulder height	Seat backrest height
P6	Shoulder to elbow	Armrest placement height
P7	Knee height	Steering wheel height from floor
P8	Popliteal height	Seat height and pedal placement
P9	Foot length	Pedal placement from SRP
P10	Foot width	Pedal width
P11	Hand length	Steering wheel rim thickness

P12	Hand breath	Armrest surface width
P13	Chest width	Steering wheel diameter
P14	Elbow angle with steering	Steering wheel distance from SRP
P15	Elbow angle with gear	Gear-lever distance from SRP
P16	Popliteal angle (leg on floor)	Placement of pedal
P17	Foot angle (leg on pedal)	Placement of pedal
P18	Back angle (sitting)	Placement of steering wheel
P19	Hip width	Backrest width
P20	Stomach depth	Steering wheel placement
P21	Knee length	Seat distance from steering rack
P22	Head width	Headrest width
P23	Head height	Headrest height
P24	Stomach to steering	Steering rack placement
P25	Popliteal length	Seat depth
P26	Elbow to wrist	Steering wheel placement/armrest
P27	Chest to steering wheel	Steering wheel placement
P28	Knee to dashboard	Placement of seat from dashboard
P29	Knee to steering rack	Placement of seat
P30	Arm length	Placement of steering wheel

2.3 Procedure for Statistical Data Analysis

The dimensions of the interior compartment of drivers' workstation of category A (mini-buses) and category B (midi-buses) were analyzed using Microsoft Excel Starter 2010 and SPSS 20.0 to obtain the mean values, standard deviations, 5th, 50th, 75th, and 95th percentiles. Independent sample t-test analysis was used to determine the mean difference of the anthropometric variables and dimensions of the interior compartment of drivers' workstation of the category A (mini-buses) and category B (midi-buses) at a confidence level of 0.05 for significance.

3.0 RESULTS AND DISCUSSIONS

3.1 Human body anthropometry analysis of the bus drivers

Table 1 presents the anthropometric variables of the urban bus drivers and their relevance. The summary of the anthropometric variables of the one hundred and fifty urban bus drivers assessed in this study is presented in Table 2. The anthropometric variables guide the physical geometry, mass properties, and strength capabilities of the human body for the establishment of the standards and the specific demands for the commercial bus drivers' workstation design. The evaluation carried out in this study was with respect to the work postures which will guide in providing a detailed specification of the drivers' control point in the workstation. Table 2 shows that the mean stature of the drivers was 173.15 cm (SD = 3.32) while the average mean of their sitting height was 83.18cm (SD = 4.52). The 5th and the 95th percentiles represented the minimum and maximum expectations from an ergonomically designed drivers' workstation (Samuel *et al.*, 2016). The extreme statures of the drivers that the buses accommodated using the 5th and the 95th percentiles were 168.8 and 179.1 cm respectively. The extreme sitting height of the drivers was 76.9cm for the 5th percentile and 90.0cm for the 95th percentile. The anthropometric variables in this study were within the average range of the anthropometric variables obtained by Samuel *et al.* (2016). The sitting height determines how high the head of the driver is from the sitting position. Studies showed that inadequate space for sitting height of the driver's workstation contributed to neck pain through awkward bending of the neck (Funakoshi *et al.*, 2004; Okuribido *et al.*, 2007).

Table 2: Summary of the anthropometric variables of Nigerian male urban bus drivers (N = 150)

S/N	Variable	Mean	SD	Min.	Max.	Percentile			
						5th	50th	75th	95th
P1	Stature	173.15	3.32	166.00	180.00	168.80	173.00	175.50	179.10
P2	Sitting height	83.18	4.52	74.00	91.00	76.90	83.00	86.25	90.00
P3	Eye-Floor height	73.40	5.23	50.00	88.00	60.00	77.00	81.00	83.15

P4	Shoulder width	44.50	3.25	39.00	51.00	40.00	44.00	46.20	50.00
P5	Shoulder height	55.40	1.97	53.00	62.00	53.00	55.00	56.00	58.15
P6	Shoulder-elbow length	34.61	1.91	31.00	38.00	31.48	35.00	36.00	37.05
P7	Knee height	59.25	1.48	55.00	62.00	56.95	59.00	60.00	61.05
P8	Elbow-wrist length	30.29	1.35	28.00	33.00	28.00	30.00	31.00	33.00
P9	Knee length	60.71	1.68	57.00	63.00	57.95	61.00	62.00	63.00
P10	Popliteal length	48.75	1.45	45.00	51.00	49.95	49.00	50.00	50.00
P11	Hip breadth	37.02	1.98	32.40	41.00	34.70	37.00	38.00	40.15
P12	Tommy depth	20.33	3.06	11.70	25.00	14.93	21.00	22.40	25.00
P13	Popliteal-height	47.46	1.22	45.50	50.00	46.00	47.50	48.00	50.00
P14	Foot length	26.53	0.83	25.00	28.00	25.00	26.40	27.10	28.00
P15	Foot breadth	9.52	0.74	8.20	11.20	8.40	9.70	10.00	10525
P16	Hand length	20.06	0.70	18.80	21.00	19.00	20.00	20.63	21.00
P17	Hand breadth	9.75	0.57	8.70	11.00	8.99	10.00	10.00	10.51
P18	Shoulder -wrist length	64.8	2.93	60.00	70.00	60.48	65.00	67.00	70.00
P19	Head breadth	14.98	0.73	13.80	16.10	13.90	14.95	15.53	16.00
P20	Head length	20.21	0.99	19.00	22.00	19.00	19.90	21.00	22.00
P21	Tommy - steering	19.70	3.19	15.00	26.00	15.95	19.50	22.00	24.10
P22	Chest–steering distance	32.20	2.95	26.00	38.00	27.00	33.00	34.00	36.00
P23	Right knee - dash board distance	12.45	2.26	9.00	16.00	9.00	12.00	15.00	16.00

P24	Left knee -dash board distance	12.95	2.34	10.00	17.00	10.00	12.00	15.00	16.05
P25	Knee-steering rack distance	8.28	1.88	5.50	11.00	5.50	8.00	10.00	11.00
P26	Elbow angle, with steering	144.19	3.88	139.50	162.00	140.00	144.25	146.00	147.15
P27	Elbow angle with gear	165.30	3.38	158.00	171.00	160.00	166.00	168.00	171.00
P28	Knee angle - foot on floor	123.08	1.92	120.00	130.00	120.95	123.00	123.25	126.03
P29	Ankle angle foot on pedal	95.68	4.75	91.00	110.00	91.00	94.00	98.00	104.25
P30	Back angle sitting	100.98	4.02	96.00	112.00	96.00	101.00	102.25	111.05

3.2 Analysis of the drivers' workstation

The information in Tables 3 and 4 is the statistical analysis (mean, standard deviation, and percentiles) of the data obtained during the fieldwork for the seat reference point used for the placement of the controls for two categories of buses: mini-buses and midi-buses. The total number of drivers' workstation variables for the two bus categories were 38 for mini-buses and 37 for midi-buses. The variation observed in the workstation variables in the two bus categories was from the absence of armrest in the midi-buses.

Table 3: Summary of data obtained from mini-bus workstations (Category A) (N = 30)

S/N	Variable	Mean	SD	.Percentile			
				5th	50th	75th	95th
1	Cabin height	142.17	13.39	142.17	122.00	148.00	149.50
2	Cabin width	92.67	6.53	92.67	90.00	90.00	90.00
3	Cabin length	90.17	2.32	90.17	87.25	90.50	91.75
4	Seat to door dist.	5.33	3.44	5.33	3.00	4.00	5.50
5	Cabin floor to road	59.00	16.54	59.00	36.50	61.50	67.50
6	Pedal to seat	42.83	4.49	42.83	38.50	41.50	45.25
7	Steering to floor	66.83	4.12	66.83	61.00	68.50	70.00
8	Dashboard-backrest	77.50	10.65	77.50	62.50	79.50	81.50
9	Steering to backrest	45.00	3.58	45.00	40.50	45.50	46.75
10	dashboard width	92.67	6.53	92.67	90.00	90.00	90.00
11	Dashboard height	41.67	7.34	41.67	32.00	42.50	44.50
12	Steering wheel Dia.	40.50	4.72	40.50	38.00	38.50	39.75
13	Steering rim thickness	3.58	0.92	3.58	2.63	3.50	4.00
14	Pedal angle	46.67	2.58	46.67	45.00	45.00	48.75
15	Steering rack angle	64.00	2.00	64.00	61.00	65.00	65.00
16	Door width	113.33	9.29	113.33	101.25	116.00	120.00
17	Door height	134.83	5.78	134.83	127.00	135.00	139.00
18	Dashboard to seat	26.33	8.14	26.33	14.50	29.00	30.00
19	Gear lever to seat	16.00	5.33	16.00	10.00	16.50	19.50
20	Bus total height	194.17	30.06	194.17	162.00	190.00	197.50
21	Steering rack to seat	23.33	13.60	23.33	9.50	21.50	24.25
23	SRP to steering (horizontal)	50.67	5.79	50.67	42.50	51.50	54.50
24	SRP to steering (vertical)	32.00	2.45	32.00	30.00	31.00	34.25
25	SRP to pedal (horizontal)	91.67	3.33	91.67	87.25	93.00	93.75
26	SRP to pedal (vertical)	27.17	2.32	27.17	25.00	26.50	29.25
27	Floor to seat height	32.67	6.09	25.50	33.50	34.75	40.25
28	Seat front width	50.33	1.97	48.50	50.00	50.00	53.00
29	Seat pan back width	41.00	2.76	38.00	41.00	43.50	44.00
30	Seat pan depth	49.67	0.52	49.00	50.00	50.00	50.00
31	Backrest width (lumbar level)	49.00	2.00	47.00	49.00	50.00	51.50
32	Backrest width (thoracic level)	44.50	2.26	42.25	44.00	45.75	47.50
33	Backrest height	53.67	3.14	50.00	54.50	55.00	57.25
34	Headrest width	26.50	4.09	22.00	25.50	28.25	32.00
35	Headrest height	23.00	8.44	16.00	22.00	22.75	35.00
36	Armrest length	30.00	0.00	30.00	30.00	30.00	30.00
37	Armrest width	7.00	0.00	7.00	7.00	7.00	7.00
38	Armrest thickness	8.00	0.00	8.00	8.00	8.00	8.00

Table 4: Summary of data obtained from midi-buses workstations (category B) (N = 20)

S/N	Variable	Mean	SD	Percentile			
				5th	50th	75th	95th
1	Cabin height	198.75	23.39	192.60	199.50	203.25	203.85
2	Cabin width	104.50	10.63	80.25	105.00	120.25	128.05
3	Cabin length	122.75	8.81	109.85	127.00	128.50	129.70
4	Seat to door distance	17.25	8.02	10.15	15.00	21.50	27.50
5	Cabin floor to ground	103.75	7.33	94.10	106.50	107.75	109.55
6	Pedal to seat distance	30.50	3.32	23.60	29.50	34.00	38.80
7	Steering to floor	72.50	12.53	70.00	71.50	74.00	76.40
8	Dashboard to backrest.	81.75	6.53	69.60	82.50	92.25	92.85
9	Steering to backrest distance	42.00	9.80	35.20	42.00	44.00	48.80
10	Steering wheel diameter	54.70	1.37	49.49	50.00	54.85	66.49
11	Steering rim thickness	3.53	7.47	2.48	3.10	3.85	5.17
12	Pedal angle	133.13	2.95	124.38	135.00	136.25	139.25
13	Steering rack angle	76.13	0.71	73.30	75.75	77.38	79.48
14	Door width	79.50	12.73	79.05	79.50	79.75	79.95
15	Door height	165.00	2.83	156.90	165.00	169.50	173.10
16	Dashboard to seat distance	28.00	10.79	24.60	29.00	30.00	30.00
17	Gear lever to seat distance	20.50	0.00	8.25	22.00	25.25	30.65
18	Total height from ground	310.00	14.84	310.00	310.00	310.00	310.00
19	Steering rack to seat dist.	30.50	21.00	13.95	33.50	42.25	42.85
20	Pedal to seat distance	50.50	2.06	28.10	54.00	68.00	68.00
21	SRP to steering (horizontal)	54.75	2.22	52.45	55.00	55.50	56.70
22	SRP to steering (vertical)	23.75	4.92	22.15	23.00	24.00	26.40
23	SRP to pedal (horizontal)	88.25	2.99	82.35	90.00	90.50	91.70
24	SRP to pedal (vertical)	42.75	23.39	40.30	42.00	43.25	46.25
25	Floor to seat height	41.25	2.06	39.15	41.50	43.00	43.00
26	Seat pan thickness	11.75	2.36	10.00	11.00	12.75	14.55
27	Seat pan back width	41.50	4.36	38.00	40.50	44.00	46.40
28	Backrest angle	102.50	7.37	95.20	102.00	104.50	110.50
29	Backrest thickness	10.25	2.63	8.00	10.00	12.25	12.85
30	Backrest width (lumbar level)	48.67	3.86	45.73	47.50	50.25	53.25
31	Backrest width (thoracic level)	39.47	4.39	34.60	40.00	42.47	43.59
32	Headrest Angle	127.33	28.31	110.20	112.00	136.00	155.20
33	Headrest width	27.79	1.92	26.57	26.82	28.41	29.68
34	Headrest height (with stand)	37.00	1.73	35.30	38.00	38.00	38.00
35	Headrest height (no stand)	22.00	2.00	20.20	22.00	23.00	23.80
36	Seat pan depth	47.50	5.00	41.50	50.00	50.00	50.00
37	Backrest height	44.25	5.06	38.75	44.50	47.00	49.40

3.3 Analysis of the drivers' workstation dimensions for categories 'A' and 'B' and the drivers' anthropometric variables

Studies highlighted the mismatch between the anthropometry variables of drivers and their workstation when the seat height was > 95% or < 88% of the popliteal height (Parcells *et al.*, 1999) when the seat length and buttock – popliteal length differed by > 95% or < 80% (Ismaila *et* *al*., 2010). The mean seat height of 68.8% (< 88%) to the mean popliteal height observed in this study was a mismatch between the drivers' popliteal height and seat height (Table 4) for the mini-bus category. The seat height dimension implied that the seats were too low for the popliteal height of the drivers. Hence, there is tendency for discomfort for the drivers as the driver must bend while driving. This posture may result in low back pain and sprain of the thigh, as well as hitting the knees against the steering wheel. The mean seat length/depth was 101.8% (> 95%) of the buttock to popliteal length. The variation in the seat length/depth of the buttock to popliteal length was a mismatch for the user as the seat was longer than the popliteal length of the user. The discomfort associated with this was that the legs of the drivers do not touch the workstation floor, or the driver had to shift forward so that his leg could touch the workstation floor. To do this, the driver may have to lose contact with the backrest. As such, the driver is subjected to the risk of leg, back, and shoulder pains. Also, there was a mismatch between the seat width and the hip-width.The seat width was 110.8% (> 95%) of the hip-width.

Similarly, for category B, the mean seat height was 86.8% (< 88%) of the mean of the popliteal height having the same effects of being slightly low for the comfort of the Nigerian bus drivers (Table 4). The side effects may include back pain, spraining an ankle, hitting the steering wheel with the thigh, and the dashboard with the knees. The mean seat length/depth here was 97.4% (> 95%) of the mean buttock to popliteal length. The seat length/depth of the mean buttock to the popliteal length relation observed in this study was also a mismatch for the drivers, as suggested by Parcells *et al*. (1999). In the same manner, the results from this study showed that the mean seat width of the driver seat was 41.00 cm for 37.02 cm mean hip width of the midi-bus drivers (97.43 (> 95%) of the hip-width implying a mismatch for the users and leading to back pain and discomfort when in use. Parcells *et al*. (1999) suggested that seat height should not be < 88% or > 95% of the popliteal height. It then follows that the mean seat height for a mean popliteal height of 47.46cm should be between 41.76 and 45.09cm, rather than 25.50 to 40.25cm; and 39.15 to 43.00cm representing the 5th and 95th percentiles obtained from mini-buses (A) and midi-buses (B) respectively. Similarly, for the seat depth/length, Parcells *et al.* (1999) suggested that good seat depth should not be <80% or >95% of the buttock - the popliteal length. Therefore, ergonomic driver's seat depth for a mean buttock - the popliteal length of 48.75cm, should range between 39.00 and 46.71cm rather than 49 to 50cm and 41.5 to 50 cm representing the 5th and 95th percentiles in the mini-buses (A) and midi-buses (B) respectively. Ismaila *et al.* (2010) quoted Molebrook *et al.* (2003) that the seat width should be equivalent to 99 percentile of the hip value plus 15%. With this, the ergonomic seat width range should be 41 to 47.15 cm and not 38 to 44cm and 38 to 46.4 cm representing the 5th and 95th percentiles for category A (mini-buses) and category A (midi-buses), respectively. This study also noted a mismatch between the anthropometric data of the drivers and the dimensions of the backrest. Some of the seats have a square or rectangle shape with short heights. While in some, the lower parts dimension was larger than the upper parts of the backrest. This shape of the backrest affects the comfort of the drivers and may lead to neck and shoulder pains. This study suggests that the ergonomic driver's seats should have 95th percentile of the shoulder height as the backrest height, 95th percentile of the shoulder width as the dimension of the upper part, and the seat width dimension for the low back level. The seat should have the following dimensions: 58.15cm height, upper shoulder level width of 50cm, and the low back/hip level width of 47.15cm rather than the mean of the height upper width, low back width of 53.66, 49, 41.5; and 44.25, 48.67, 39.47cm in that order for the category A (mini-buses) and category B (midi-buses) respectively

Table 4. Comparative analysis of the drivers' seat dimensions for categories 'A' and 'B' and the relevant drivers' anthropometric variables in this study

Drivers' workstation dimensions					Drivers' Anthropometric Data		
Seat parameters	Category A (minibuses)		Category B (midi-buses)		Relevant human body variables	Dimensions	
	Mean	SD	Mean	SD		Mean	SD
Floor to seat height	32.67	6.09	41.30	2.06	Popliteal height	47.46	1.22
Seat pan depth	49.62	0.52	47.50	5.00	Buttock – popliteal	48.75	1.45
Seat pan back width	41.00	2.76	41.50	4.60	Hip width	37.02	1.98
Backrest height	53.67	3.14	44.25	5.06	Shoulder height	55.40	1.97
Backrest width (lumbar level)	49.00	2.00	48.67	3.86	Shoulder breadth	44.50	3.25
Backrest width (thoracic level)	44.50	2.26	39.50	4.39	Hip width	37.02	1.98
Headrest height	23.00	8.44	22.00	2.00	Shoulder height	27.78	N/A
Headrest width	26.50	4.09	27.79	1.92	Shoulder breadth	44.56	3.25
Armrest length (right hand only)	30.00	0.00	N/A	N/A	Elbow to wrist length	30.29	1.35
Armrest width (right hand only)	7.00	0.00	N/A	N/A	Hand breadth	9.75	0.57

3.4 Relationship between drivers' workstation dimensions for categories 'A' and 'B' and the drivers' anthropometric variables

The dimensions of the driver's workstation interior compartment of category A (mini-buses) and category B (midi-buses) were analyzed using an independent sample t-test to determine whether there was a difference between their means. The mini-buses represented in category A buses had a lower mean value of 45.00 cm (SD = 26.12) compared to category B buses (midi-buses) that had 52.08 cm (SD = 31.87), $t(23) = -1.181$, $p = 0.250$ (Table 5). The means of category A and B buses were not significantly different as the value was greater than 0.05. The p-value obtained indicated that the parameters for the structural dimensions of the anterior compartment of the driver workstation for the mini-buses and midi-buses fit a particular population. It also implies that the same set of drivers can operate mini-buses and midi-buses drivers' workstation.

Table 5. Independent sample t-test for interior compartment of drivers' workstation in the buses between Category A (mini-buses) **and Category B (midi-buses)**

Descriptive statistics					t-test for Equality of Means		
Commercial buses	N	Mean	SD	SEM	T	df	*p*-value
Category A (mini-buses)	24	45.00	26.12	5.33	-1.181	23	0.250
Category B (midi-buses)	24	52.08	31.87	6.50			

Relevant design dimensions of the driver's workstation compartment from the six mini-bus models were compared with relevant anthropometric variables of the drivers to obtain useful inferences on the relationship between the drivers and the workstations. Independent sample t-test carried out showed that the anthropometry data of the drivers had a higher mean value (mean = 55.43 cm, SD = 4.75) as compared to the mean driver's workstation compartment dimension of category A (mini-buses) (mean = 40.16 cm, SD = 18.73) (Table 6). The difference between the means of the anthropometry data variable and the drivers' workstation parameters was significant (p-value = 0.00). The obtained p-value was an indication that the mismatch between the anthropometric variables of the drivers and the mini-bus model workstations was significant.

Table 6. Independent sample t-test for interior compartment of drivers' workstation in the buses between Category A (mini-buses) and Category B (midi-buses)

Descriptive statistics					t-test for equality of means		
Assessed variables	N	Mean	SD	SEM	T	Df	*p*-value
Category A (mini-buses)	18	40.16	18.73	4.41	-3.46	17	0.00
Anthropometry data	18	55.43	20.16	4.75			

The independent-samples t-test results between the relevant anthropometric variables of the drivers and the relevant dimensions of the driver workstation compartment of the midi-bus models showed that the mean value of the category B (midi-buses) dimensions of driver's workstation compartment had a lower mean value (mean = 46.57 cm, SD = 29.53) compared to the mean value of anthropometry data of the drivers (mean = 55.43 cm, SD = 4.75) (Table 7). However, the difference in their mean values was not significant since the p-value obtained was greater than 0.05.

Table 7. Independent sample t-test for interior compartment of drivers' workstation in the buses between Category A (mini-buses) and Category B (midi-buses)

Descriptive statistics					t-test for equality of means		
Commercial buses	N	Mean	SD	SEM	T	Df	*p*-value
Category B (midi-buses)	18	46.57	29.53	6.96	-1.86	17	0.08
Anthropometry data	18	55.43	20.16	4.75			

4.0 CONCLUSIONS

The analysis of results showed that there were mismatches between the drivers' anthropometric variables and the dimensions of the present driver's workstation. The drivers' workstations in the commercial urban buses used in South-Western Nigeria did not ergonomically fit the urban bus drivers in the region. The observed ergonomics challenge was due to the non-consideration of anthropometric variables of the Nigerian male bus drivers in the design phase of the buses. There is need for the enhancement of the drivers workstation for efficiency and availability of urban bus drivers. This study, therefore, provided body anthropometric variables of bus drivers for appropriate dimensions for the design and fabrication of ergonomic drivers' workstations in the urban buses for Nigerian drivers. The anthropometric variables of male adults provided in this study can be used beyond the drivers' workstation's enhancement. It can be used for other designs and production of safety and clothing materials such as hand glove, footwear, goggle, and apron for the drivers.

5.0 REFERENCES

Agrawal, K. N., Singh, R. K. P., & Satapathy, K. K. (2010). Anthropometric considerations of farm tools/machinery design for tribal workers of northeastern India. *Agricultural Engineering International: CIGR Journal*, *12*(1), 143-150.

Anema, J. R., Cuelenaere, B., Van Der Beek, A. J., Knol, D. L., De Vet, H. C. W., & Van Mechelen, W. (2004). The effectiveness of ergonomic interventions on return-to-work after low back pain; a prospective two year cohort study in six countries on low back pain patients sicklisted for 3–4 months. *Occupational and Environmental Medicine*, *61*(4), 289-294.

Bernard, B. P., & Putz-Anderson, V. (1997). Musculoskeletal disorders and workplace factors; a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back. *Occupational Safety and Health (NIOSH)*, *104*, 97–141

Caragliu, B. (2006) Fitness for Drivers. *G. Ital Med Lav Ergonomics, 28*, 82-84.

Colim, A., Carneiro, P., Costa, N., Arezes, P. M., & Sousa, N. (2019). Ergonomic Assessment and Workstation Design in a Furniture Manufacturing Industry—A Case Study. In *Occupational and Environmental Safety and Health*, *202*, 409–417.

Del Prado-Lu, J. L. (2007). Anthropometric measurement of Filipino manufacturing workers. *International Journal of Industrial Ergonomics*, *37*(6), 497-503.

Funakoshi, M., Tamura, A., Taoda, K., Tsujimura, H., & Nishiyama, K. (2004). Risk factors for low back pain among taxi drivers in Japan. *Sangyo Eiseigaku Zasshi Journal of occupational health*, *45*(6), 235-247.

Gaudez, C., Gilles, M. A., & Savin, J. (2016). Intrinsic movement variability at work. How long is the path from motor control to design engineering?. *Applied Ergonomics*, *53*, 71-78.

Hertzberg, H. T. E. (1972). Engineering Anthropology: Human Engineering Guide to Equipment Design. *HP Van Cott and R. Kinkade. US Printing Office*.

Hitka, M., Sedmák, R., Joščák, P., & Ližbetinová, L. (2018). Positive secular trend in slovak population urges on updates of functional dimensions of furniture. *Sustainability*, *10*(10), 3474.

Igboanugo, A. C., Egharevba, F., & Ibhadode, A. O. A. (2002). Anthropometric survey of Nigeria adult working class. *Nigerian Journal of Engineering Management*, *3*(2), 7-20.

Ismaila, S. O., Akanbi, O. G., Adekunle, N. O., Adetunji, O. R. and Kuye, S. I. (2010). An ergonomics assessment of passenger seats in buses in south western Nigeria. *Sigurnost 52* (4) 329 – 334.

Jensen, A., Kaerlev, L., Tüchsen, F., Hannerz, H., Dahl, S., Nielsen, P. S., & Olsen, J. (2008). Locomotor diseases among male long-haul truck drivers and other professional drivers. *International Archives of Occupational and Environmental Health*, *81*(7), 821-827.

Kim, J. Y., You, J. W., & Kim, M. S. (2017). South Korean anthropometric data and survey methodology:'Size Korea'project. *Ergonomics*, *60*(11), 1586-1596.

Kushwaha, D. K., & Kane, P. V. (2016). Ergonomic assessment and workstation design of shipping crane cabin in steel industry. *International Journal of Industrial Ergonomics*, *52*, 29-39.

Lee, P. T., & Krause, N. (2002). The impact of a worker health study on working conditions. *Journal of Public Health Policy*, *23*(3), 268-285.

Lucas, E. B., & Onawumi, A. S. (2013). Ergonomic Evaluation of In-Vehicle Interface Design of Taxicabs in Nigeria. *International Journal of Engineering Research and Applications, 3,* 566-572.

Molenbroek, J. F., Kroon-Ramaekers, N. & Snidjers, C. J. (2003). Revision of the design of a standard for the dimensions of school furniture. *Ergonomics*, *46*(7): 681-694.

Muzammil, M., & Rizvi, S. (2007). Anthropometric Data with Special Reference to the Indian Needs- an Overview. *Journal of the Institution of Engineers (India) Part PR, Production Engineering Division*, *87*, 14-19.

Nadadur, G., & Parkinson, M. B. (2013). The role of anthropometry in designing for sustainability. *Ergonomics*, *56*(3), 422-439.

Nishint, S. & Apurava, A. A. (2015). Literature review on ergonomics of Indian seat design for passenger comfort and safety. *International Journal of Technology Innovations and Research, 15*.

Okunribido, O. O., Magnusson, M., & Pope, M. (2006). Delivery drivers and low-back pain: A study of the exposures to posture demands, manual materials handling and whole-body vibration. *International Journal of Industrial Ergonomics*, *36*(3), 265-273.

Okunribido, O. O., Shimbles, S. J., Magnusson, M., & Pope, M. (2007). City bus driving and low back pain: a study of the exposures to posture demands, manual materials handling and whole-body vibration. *Applied Ergonomics*, *38*(1), 29-38.

Onawumi, A. S., & Lucas, E. B. (2012). Ergonomic investigation of occupational drivers and seat design of taxicabs in Nigeria. *ARPN Journal of Science and Technology*, 2(3), 214-220.

Parcells, C., Stommel, M., & Hubbard, R. P. (1999). Mismatch of classroom furniture and student body dimensions: empirical findings273.

Pheasant, S. (1986) *Body space: anthropometry, ergonomics and design*, London; Taylor & Francis.

Phillips C. A. (2000). Human Factors Engineering. New York; John Wiley and Sons, 3-125.

Realyvásquez-Vargas, A., Arredondo-Soto, K. C., Blanco-Fernandez, J., Sandoval-Quintanilla, J. D., Jiménez-Macías, E., & García-Alcaraz, J. L. (2020). Work Standardization and Anthropometric Workstation Design as an Integrated Approach to Sustainable Workplaces in the Manufacturing Industry. *Sustainability*, *12*(9), 3728.

Sadri, G. H. (2002). A model of bus drivers' disease: risk factors and bus accidents. *Iranian Journal of Basic Medical Sciences, 27*(1):39–41.

Samuel, O.A., Israel, D. and Moses, F. (2016) Anthropometry Survey of Nigerian Occupational Bus Drivers to Facilitate Sustainable Design of Driver's Workplace. *World Journal of Engineering and Technology, 4*, 176-182.

Yeow, J. A., Ng, P. K., Tan, K. S., Chin, T. S., & Lim, W. Y. (2014). Effects of stress, repetition, fatigue and work environment on human error in manufacturing industries. *Journal of Applied Sciences, 14*(24), 3464-3471.

Advancing Industrial Engineering in Nigeria through Teaching, Research and Innovation is a twenty-four-chapter book written by the former students and colleagues of Professor Oliver Charles-Owaba, a Professor of Industrial Engineering. Professor Charles-Owaba who has all his degrees in Industrial Engineering retired from the University of Ibadan, having put in over forty years in Teaching and Research.

The chapters in the book straddle the areas of: Production/Manufacturing Engineering, Ergonomics/Human Factors Engineering, Systems Engineering, Engineering Management, Operations Research and Policy. They capture challenges and developments in various aspects of Industrial Engineering while shining light on how they can be mitigated in creative and innovative ways while meeting societal needs.

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