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Readings in Sustainable Tropical Forest Management

ESSAYS IN HONOUR OF PROFESSOR LABODE POPOOLA

Edited by
S. Kolade Adeyoju and S. Obafemi Bada

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DEDICATION

To the glory of God, the Honoree will like this book to be dedicated to the following persons who have played key roles in shaping his career and life:

Professor Ephraim Ediale Enabor, *FFAN* (1939 to 2002), his Doctoral supervisor and mentor who initiated him into academic culture in 1988;

Emeritus Professor Kolade Adeyoju, *FFAN*, his mentor who initiated him into forestry and also supervised his B.Sc Project in 1984, and has refused to wean him;

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(But for God, but for you)

and;

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APPLICATION OF MULTIPLE USE MODELS, IN SUSTAINABLE FOREST MANAGEMENT PLANNING

Saka.O. Jimoh

Multiple use forest management is not an entirely new idea. According to Shea (1993), the early men used their forests to satisfy most of their needs including food, housing, shelter, health, socio-cultural and religious purposes. However, as the global population increased rapidly, the number of constituencies with interests in the forest and its resources has also risen dramatically, thus leading to increased pressures on the world's forests. This has in turn resulted in the renewed effort to manage the forests in an integrated manner and for the full benefits of its goods and services.

The concepts of sustainability and multiple benefits are very popular in forestry literature, but yet, forest managers find it difficult to apply them. There is virtually no technical reason why a large proportion of the world's forests should not be managed and used for a variety of purposes. Forests may be managed to provide the general public with fish and wildlife, outdoor recreation, forage, environmental amenities, water and timber. Managing the forest to supply these diverse goods and services entails adequate and precise planning, which is what multiple use management planning is out to achieve.

The implementation of multiple use forest management involves the determination of levels of demand for particular uses and an attempt to reconcile the demand with the capacity of the forest to supply these needs on a sustainable basis (Shea, 1993). There is also the need to identify areas within the forest, where the various uses are allocated priority. The need to utilise the resources of the forest in a sustainable manner necessitates an initial assessment of the supply potential of the forest ecosystem before decisions are made on utilisation regimes.

Global trends in forest management in the last three decades show that several nations have commenced the implementation of multiple use forest management. In Agenda 21- the action plan emanating from the 1992 United Nations' Earth's Summit on Environment and Development; Chapter II based on desertification and control, tagged "Combating Deforestation" states *inter-alia* "Nations agreed here to sustain the multiple roles of all types of forests; to enhance sustainable management and conservation; to rehabilitate degraded forests; to value and use forest goods and services more fully and to improve the quality and availability of information about forests (Saint-Lauret, 1997).

The 1990 Resource Planning Act of the United States of America (USA) concerning the strategic direction for managing the national forests emphasised among other things, the balance of management investments among the various multiple uses through increased attention to recreation, wildlife and fisheries (Salwasser *et al.*, 1994).

Furthermore, following the recommendation by Mayers and Kotey (1995), based on a study jointly carried out by the International Tropical Timber Organisation, (ITTO), International Institute for Environment and Development (IIED) and the Forestry Department of Ghana; the 'timber first' orientation in the country is now giving way to a more collaborative multiple use forest management. Also Cunningham (1996) proposed the establishment of multiple use zones alternatives around the Biwindi impenetrable National Park in Uganda and the forest is being currently managed based on this suggestion.

FORMECU (1999) having carried out a comprehensive Forest Resource Study in Nigeria, using various experts and consultants, agreed that for Nigerian forests to be managed sustainably, the new direction for forest management development plans in the country should be towards multiple use forest management and the inclusion of all stakeholders in resource management plans and benefit sharing from the resource base.

The challenge to the modern forest managers therefore, is how to make decisions about relative weights of the values held by different groups, from local to global, and how to integrate them or how to make choices between them where integration proves impossible. For forest management planning to cope with the enormous task of decision-making, which involves several possibilities of inputs and outputs, the application of planning tools becomes inevitable.

This paper presents an analysis of some important mathematical modelling tools commonly used in multiple use forest management planning, pointing out the strengths and weaknesses of each.

Many decision-making tools based on different mathematical techniques have been applied in forestry. Beginning with the application by Kidd *et al.* (1966) and two others by Ware and Clutter (1971) and Navon (1971), several scientists have developed many models, Chapelle *et al.* (1972); Tedder, *et al.* (1980), Walker (1971). Although some models are based on hypothetical data, most models are based either on wholly or partly but carefully collected data. Also, while early models were based only on small number of trees located on a square lattice (Okojie, 1983, quoting Mitchel 1969); Subsequent models accommodate large populations of trees, and in some cases, whole stands.

The needs of the society have become more diverse, and the role of forestry and the responsibility of foresters have also expanded accordingly. Timber is no longer the sole objective of public forest management. Public forests are now being managed to provide the general public with fish, wildlife outdoor recreation, forage, environmental amenities, water and timber (Chang and Buongiorno 1981 quoting Alston 1972). This has necessitated the planning of public forest management such that it satisfies, at least partially if not fully, the legitimate demands of these interest groups. This development also implies that appropriate models, which will accommodate multiple use programmes should be developed. Following the development of linear programming models by Clutter (1968) and Narvon (1971); Fields (1970); Chang and Buongiorno (1981); Leuschner (1984) and Buongiorno and Gilles (1987) have all developed different multiple use programming models aimed at optimising net value or minimising the effect of externalities in forest resources management.

Linear Programming (LP)

Linear programming originated in about 1947 during the Second World War, when certain officials of the US Department of the Air Force developed an L.P. for planning the war strategies of the air force (Aruofor, (1990) quoting Koopman, (1951) and Dorfman *et al.* (1958). Since that time, the programming technique has been further developed and applied in different fields including agriculture, economics, management and administration. The basis for the adjective "Linear" relates to the assumption that:

(a) the relationship between the input and output variables in each elementary activity are proportional

(b) the result of simultaneously carrying out two or more activities is the sum of the results of separate activities (Koopman, 1951).

Linear programming involves the optimisation of a linear objective function by allocating resources among activities subject to linear constraints. The uses of linear programming in forestry were first suggested in the late 1950s (Paul, 1956; Bethel and Harrel, 1957). These early applications were for optimising harvest schedules, production mixes and production distribution. By the late 1960s, more detailed and realistic models have been developed. Examples include MAX-MILLION (Ware and Clutter, 1971); Timber RAM (Navon, 1971) and R.C.S. (US Department of Agriculture).

These various models have been applied with varying successes to situations such as timber harvest scheduling, wood procurement, mill management, product distribution, inventory control and land use planning. There has been a rapid increase in the application of linear programming since 1976 and other variant models based on linear programming have been developed e.g. the US Forest Service uses linear programming in both timber management and land use planning.

Linear programming is one of the most frequently used techniques in forestry (Fields, 1970, Leuschner 1984, Buogiorno and Gilles, 1987). The heavy reliance of management and natural scientists on linear programming techniques may have to do with certain peculiar characteristics of the technique which include:

(i) the technique is relatively young and there is still room for further development;

(ii) L.P. can handle large data sets with many alternative solutions in a very efficient way using the revised simplex algorithm technique;

(iii) L.P. is also very flexible and can be applied to a wide range of problems ;

(iv) L.P. computer algorithms are well documented and generally available on most computer systems, so there is little difficulty in running a L.P.

(v) Finally, sensitivity analysis is performed easily therefore, the characteristics of the optimal solution can be easily examined.

Linear programming has three major components viz.: the objective function, the non-negativity constraints and the inequality constraints. The objective function addresses the maximisation or minimisation of specific objective(s) e.g. timber volume to be cut by deciding on how many hectares to cut in a given area. It may also express the relationship between the decision variables and the possible outputs from different combinations of input resources. The non-negativity constraints stipulates that none of the decision variables must be zero e.g. if two decision variables X_1 and X_2 are involved in an optimisation problem, then the non-negativity constraint is written as $X_1 \geq 0$; $X_2 \geq 0$ or $X_1, X_2 \geq 0$. This implies that, all the inputs are either directed towards the production of X_2 alone while nothing at all of X_2 is produced which means $X_2 = 0$ or the resources may all be diverted for the production of X_2 alone in which case $X_1 = 0$. The resources may also be proportionally shared between the two outputs. Other constraints e.g. resource constraints, may also affect the realisation of the objectives in a multi-objective linear programming model. For instance, suppose the decision maker is working towards the optimisation of two objectives X_1 and X_2 all his activities must be limited to the amount of resources available to him. This may be expressed as $ax_1 + bx_2 \leq R$. a and b are units of target outputs and 'R' is the level of available resources.

The general linear programming equation may be written as:

$$Max.Z = \sum_{j=1}^{n} C_j X_j \qquad \ldots \qquad (1)$$

Where; Z is the objective to be maximised.

X_j is the decision variable for which the problem is being solved.

C_2 is the contribution of a given variable to the objective.

Equation (1) above is subject to a number of constraints and these may be represented as follows:

$$\left(\sum_{j=1}^{n} a_{ij} X_{ij}\right) + \left(\sum_{k=1}^{p} b_{ijk} y_{ijk}\right) \leq R \qquad \ldots \qquad (2)$$

where:

a_{ij} is a measure of the quantity of the resource needed to produce a unit quantity of X and b_{ijk} is the contribution of resource i in the j^{th} cell to the production of an output y; y_{ijk} is the number of units of the k^{th} output that could be produced within the limit of the available resources.

R = the total amount of available resources.

Furthermore, the non-negativity constraint may be represented as:

$X_1 \geq 0$ ... (3)

$X_1, X_2 \geq 0$ ... (4)

Application of Linear Programming in Forestry

As observed by Leuschner (1984), linear programming has a wide application in forestry, and in fact many other programming techniques that have been found useful in forest management are variants of linear programming. Following the general trend of development in management science, linear programming has been widely applied in forestry, initially for maximisation of timber yield and minimisation of costs (Clutter, 1968; Navon, 1971; Thompson and Navon, 1969). In 1975, Leuschner *et al.* applied linear programming to prepare a multiple use plan for the Jefferson National Forest in Virginia. This programme treated multiple use planning as the process of matching a set of production objectives and the resources that could be used to obtain these objectives. The set of objectives were constrained by administrative policies and budgets and by the resources production potential. The objectives included timber, camping, picnicking, swimming, horse-back riding and several other objectives.

Buogiorno and Gilles (1987) expound on the use of linear programming technique in the field of forestry. They demonstrate how linear programming could be used to maximise the revenue from 90ha woodland comprising of 40ha of red pine and 50ha of northern hardwoods. The constraints on the programme include area of land available and the time the owner of the forest land is willing to spend on managing his estate. Of course non-negativity constraint also came into play.

Tarp *et al.* (1987) have extended the use of linear programming further in multiple use forest management planning, by introducing a dynamic linear programming model in which the results are applied in a green account analysis.

Furthermore, Liu-Gao *et al.* (1995) used an interactive method of multiple objective linear programming for supporting the planning problem in the Colorado State forest, using already published data. The problem contained five forest related outputs including non-commercial grazing; commercial grazing, timber, camping and profit. They also used interactive linear programming technique to resolve multi-objective forest planning problems with shadow pricing and parametric analysis.

Using data obtained from the Mt. *Yoomyung* natural recreation forest, in the Korea Republic, Woo and Woo (1996) applied a fuzzy multi-objective linear programming to solve a multiple use forest management problem.

In Japan, Zhang (1996) also used an integer linear programming technique to optimally allocate the spatial layout of a forestland to timber production; soil and water conservation; environmental protection and recreation. This was used to illustrate an integrated management planning for large scale forest land use allocation and multiple use management of regional forests based on an initial forest function evaluation. The foregoing shows that linear programming has been a very useful tool in forest management planning. Generally however, its application is based on certain basic assumptions which make its solution valid.

Strengths of Linear Programming

The wide application of Linear Programming L.P. has been possible because of certain characteristics of the technique which make it very flexible and adaptable to different problem situations. Some of the strong points of L.P. include:

(i) Its capability of handling large data sets with many alternative solutions in a very efficient way using the revised simplex solution technique.

(ii) It high flexibility has made it useful in different fields including management, personnel administration, agriculture, watershed management, etc.

(iii) Another attractive feature of L.P. is the possibility of carrying out sensitivity analysis after an optimum solution has been found. This explains the degree of responsiveness of the objective function to variations in the level of any activity or resource.

(iv) Several computer packages have been developed to solve large linear programming problems within seconds.

(v) Furthermore, in linear programming, production can be specified explicitly by means of production functions. It is thus capable of representing alternative methods of production, joint production, complementarity, competition as well as growth and decay in systems.

Weaknesses of Linear Programming

Despite the usefulness and wide applications of linear programming in solving managerial and other decision-making problems, its application in solving multiple use management problems in forestry has been constrained by a number of shortcomings. These include:

(i) When linear programming is used in solving multiple use management problems, with several objectives, only one objective is often maximised or minimised at a time while the others are set as constraints. But as observed by Chang and Buongiorno (1981), those objectives represented by the constraints are being given infinite weights relative to the goal, which appears as the objective function, as these other goals have to be satisfied completely before the real objective is maximized. The technique also assumes that the objectives stated as constraints have equal relative importance. Chang and Buongiorno (1981) thus conclude that the problem will have no solution, except all the goals expressed as constraints can be met simultaneously.

(ii) Another major drawback of L.P. is the assumption of divisibility. In land management problems, e.g. a fraction of a man day of labour may be recommended by a solution or a fraction of one hectare to be cut. This may not be workable in the management of a biological system such as a forest where all the parts work together harmoniously to maintain a balance, neither is it economical, as it may amount to a waste of resources. For instance, one cannot build a fraction of a dam for irrigation or flood control nor can one use a fraction of a contractor to build the dam.

(iii) Furthermore, not all the benefits and costs of forest management activities can be converted to a single unit of measurement e.g. naira, as required by a L.P. inputs of management activities such as aesthetics, biodiversity conservation, soil protection and environmental amelioration cannot be easily quantified in monetary terms or when they are quantified, they often do not represent the true social value.

Goal Programming (G.P.)

The various lapses identified with the application of linear programming led to widespread use of Goal Programming techniques. According to Leuschner (1984), Goal Programming was first introduced by Charnes and Cooper (1961), while Field (1973) was the first to apply the technique to forestry. Bell (1976) presents a conceptual application to multiple-use planning completed with hypothetical examples. The floodgate of applications continued with the publications by Anholt (1976) -Residue Reduction. Potterfield (1974) -Genetic Improvement; and Rustagi (1976) -Timber Production Planning.

Applications to multiple-use planning include the works of Chang (1975), Bell (1976) and Schuler *et al.* (1977). While Chang (1975) tries to minimise absolute deviations from 52 specified goals, according to ordinal rankings assigned to those deviations, Schuler *et al.* (1977) attempt to minimise the negative deviations from eight goals according to the ordinal ranking of different goals. Owing to the fact that the problem had only four priority levels, he was able to convert the ordinal rankings of different goals while using standard linear programming packages. The works by Bell (1975) and Dane *et al.* (1977) were based on their respective studies on The Bull Run Planning Unit and the Mount Hood Planning Unit of the Mount Hood National Forest. They both used standard linear programming packages because the number of choice variables was much higher than the capacity of the then available Goal Programming Packages. They also used cardinal weights for different goals such that the ratio of two weights reflected the subjective judgement of relative importance by the planning team.

Schuler and Meadows (1975) used Goal Programming to allocate 1,064 acres to eight alternative uses to meet, as best as possible, a set of goals in a unit of Mark Twain National Forest in Missouri. The study by Field (1973) on the same area was used to develop alternative plans for various levels of contribution of the goals of the management area; with parametric variation of the goals and weights to analyse the tradeoffs among the various goals for a 10,000 acre plot of the forest. The major lapse in this application was its inability to state the feasibility and rationale of the specified goals.

Although the application of goal programming began in the mid 70s many of the multi-objective programming techniques were applied in the second half of the 80s. Since then, there has been a great increase in the number of applications of goal programming in planning multiple-use forest management and a wide variety of solution methodologies have been utilised in these applications. However, Ignizio (1981) points out that despite the many algorithms and approaches so far in use, there is no best approach for all types of multi-objective programming problems. Evaluative studies of several interactive multi-objective programming methods have also concluded similarly that, no single method can be regarded as the best (Wallenius, 1975; Gibson *et al.*, 1987). The 1990s witnessed further development of goal programming application in forestry related activities. Sano *et al.* (1996) used goal programming to formulate management plan for a national forest near Sapororo, Hokkaido, Japan. Information was gathered using a geographical information system. Logging areas were selected based on forest types. Sets of constraints on land-use and erosion control were formulated, and the goal functions of benefits and water resources were included. The method satisfied all goal functions, although, the balance between coniferous and broadleaved trees was biased towards coniferous trees. When a goal function for volume of broad-leafed trees was added, it resulted in an improvement in the rate of harvesting but not without a corresponding increase in the logging area.

Furthermore, Lundwin and Chamberlain (1989) tested the application of goal programming as a wildlife management decision tool on the Pigeon River fish and wildlife Area of N.E. Indiana. The resultant model showed the number of hectares of each habitat type to be converted to another habitat type. Yin *et al.* (1995) also applied a multi-sectorial goal programming model to the Peace River Region in British Columbia, Canada, to illustrate the application procedure of the analytical system in land conversion impact assessment. It is an integrated approach which provides a research framework for land use assessment, studying the interrelations among biophysical, social and economic factors in agriculture, forestry and wetland management. In the application, three scenarios were designed for the impact assessment of land use conversion.

The first is the base scenario for comparison which represents the current land use position. Scenarios 2 and 3 reflected the conditions of land use conversion from forestlands and wetlands to farmlands for 10 years. Under scenario 2, there were no significant changes in achieving net return and grain production goals compared with scenario 1. A significant increase in land devoted to hay helped the region to reach its hay production goal. Land use conversion on the other hand, results in a moderate reduction in the attainment of timber production, a moderate decline of forest cover, and a loss in the waterfowl habitat value of about 2,895 birds. The goal achievement situation in scenario 3 conditions did not cause the same habitat loss problem and the habitat value goal was attained in this scenario. Goal programming model can thus be used for policy analysis to estimate the likely consequence of changes in policy on regional development and goals achievement.

Sano (1998) gave an analysis of forested watershed management methods using mathematical programming and the landscape concept. The different management viewpoints (interests) were separated into two types of data, that is, quantitative data such as timber production and qualitative data such as wildlife habitat. Quantitative data was analysed by goal programming while the qualitative data was analysed using the landscape concept. In the report, timber production, water conservation, land conservation, habitat of *Bubo Blackistonii* (*Ketupa blackistonii*) as components of forest management in Shiretoko Peninsula, Hokaido, northern Japan, were analysed. The result showed a conflict between the habitat of *Ketupa blackistonii* and cutting area. Finally, a watershed management plan was successfully prepared.

Structure of Goal Programming

Goal programming is a variant of linear programming. The major differences are contained in the formulation of the objective function and the use of deviational variables in the goal constraint equations (Schuler and Meadows, 1975). Also, unlike linear programming, G.P. does not require the conversion of all measures of achievement to a common unit of measurement such of Dollar, Naira or Pounds contribution to profit. Also, while linear programming identifies the optimal level of an input or activity that maximises or minimises a single objective such as profit or cost respectively through summation of the contributions of various activities to a common measure, goal programming identifies the optimal level of the one that minimises the sum of the weighted deviations (positive or negative or both) from the goals set by the decision maker. Goal programming provides a way of striving towards all objectives simultaneously by treating all goals in the same manner while giving different weights to the various goals if need be. In goal programming, deviations from goals are minimized as much as possible within the limit of the institutional and resource constraints.

As pointed out above, goal programming is essentially a modified form of linear programming.

In equation (1), the general linear programming is expressed as:

$$\text{Max. } Z = \sum_{j=1}^{n} CjXj \; .... \qquad (5)$$

S.t. eqn (2) which is the resource constraint written as

$$\sum_{j=1}^{n} a_{ij}X_{ij} + \sum_{k=1}^{p} b_{ijk}\, Y_{ijk} \leq R \qquad (6)$$

and; $X_i \geq 0$.

Z_i X_i; C_j; ri; a_{ij} and R are all as earlier defined.

n= number of variables

Also the non-negativity constraints

In goal programming, the general model is similar to the above, the only difference is that the objective function is altered to address deviations from the stated goals while the multiple objectives are added as a set of equality constraints with deviations and some changes are made in the non-negativity constraints. Hence, the structure of a general goal programming model may be pressed as:

$$\text{Minimize } Z = \sum_{k=1}^{n} Pkd\text{-}k + Pkdk+ \ldots \qquad (7)$$

Subject to:

$$\sum a_{ij} X_j \leq R \; .... \qquad (8)$$

$$\sum_{k}^{i} b_{kj} X_j + d\text{-}k - d\text{+}k = gk \qquad (9)$$

$$\text{and } X_j,\ dk,\ d\text{-}k,\ d\text{+}k \geq 0 \ldots \qquad (10)$$

where:

d-k = the negative deviation from or, under- achievement of goal ‘k’

$d+k$= the positive deviation from or, over-achievement of goal 'k'

Wk = the ordinal or cardinal weight for the deviation variable.

R = the constraint or restriction placed on the problem

X_j = the choice variable for which the problem is solved

a_{ij}= the coefficients that quantify the amount of constraint i for each unit of the choice variable j.

g = the multiple objectives or goals to be attained

bk_j = Coefficients that quantify the contribution of the jth choice variable to the achievement of goal 'k'

j = the choice variable

The objective function may be expressed in any particular combination of units as appropriate. The problem of commensurability between objectives is handled by stating each objective as a separate equality in the constraints whereby the negative and positive deviations from goals (d-k and d+k) are included in the left hand-side of the equation and the same is added to the actual achievement $(b_{kj}\ X_j)$ to maintain the equilibrium. What the objective function now does is to minimise the deviations (d-k and d+k) from the object (gk). Thus, goal programing takes care of multiple objectives not by including them in the objective function to form multiple objectives but by expressing only one objective in the objective function while minimising deviations from the other goals. This differs from L.P., which continues to satisfy the constraints at the expense of the main goal even after a feasible solution is already found. Goal programming strives to approach all goals as closely as possible.

Preemptive ordinal or cardinal weight may be used to assign priority to the goals. According to Leuschner (1984), cardinal weight will minimise the weighted sum of absolute deviations from the objectives whereas the preemptive ordinal weight first minimises deviations from the first ranked objective, then to the second, etc.

The negative deviation d-k and the positive d+k are constrained and so cannot be negative (non-negativity constraint). Therefore, the addition and subtraction of these to and from the actual achievement in eq (9) affords a balanced level of achievement.

Strengths of Goal Programming

Given its flexibility and potentials for further development, goal programming is no doubt a promising and reliable tool for multiple use forest management planning. As observed by Leuschner (1984), when goal programming technique is used in planning, the multiple goals are accommodated, since incommensurable goals may be stated in the constraints. Furthermore, goal programming will advance to completion if one or more of the goals cannot be achieved simply by assigning an under-achievement (d-k).

Weaknesses of Goal Programming

Despite the various attractive points of the technique, goal programming does have its own shortcomings. For instance, Buongiorno and Gilles (1982) observed that assigning appropriate weights to each goal variable might be a difficult task as it involves considerable judgement as well as trial and error. This predisposes it to some level of arbitrariness in goal ranking.

Furthermore, when applied in forestry planning, it has a weakness in its failure to recognize the fact that several forest management activities are interdependent and in fact the output of a particular activity may serve as input for other activities, for example, road construction and maintenance activities are vital inputs in the timber harvesting activity. But both of them are outputs of forest management activities. In order to take care of these lapses, foresters have used another model which treats the entire forestry sector as a system within which the various activities are interrelated and complement one another in the processes of trying to achieve the management objectives. Input-output models have been found very useful in various aspects of forestry. It is particularly useful in situations when output from a given management activity serves as input for other activities within the system. The next section takes a look at the input-output models as it applies to the forestry sector.

Input-output Models (I.O)

Input-output analysis is said to have originated from a French economist, Quensnay when he published his book *Tableau Economiqu'* (Aruofor (1990) quoting Newman (1952) and Todaro (1971). In the publication, he demonstrated the successive rounds of economic activities related to a given increase in output in a particular form. According to Aruofor (1990), the production functions in input-output analysis were analogous to the linear programming production function and akin to the input-output analysis coefficients in use today. They measure specifically the level of input required to produce one unit of output of a given activity. The U.S Bureau of Statistics and Leonteif had continued to further develop the technique and had backed it up by statistical expressions and by measurements and tabulations. Since the development of the technique, it has received international patronage as an invaluable tool for production planning, forecasting, structural analysis and multiplier analysis among others.

Structure of Input-Output Model

Since the main purpose of the input-output model is to explain the magnitudes of the inter-industry flow, its mathematical frameworks are closely related to certain basic assumptions which makes its empirical application possible (Olayide and Heady (1982). These assumptions are in three categories including the general assumption, the Leontief assumptions and the computational convenience assumption.

The general assumption states that it must be possible to form the productive sectors in such a way that a single production function can be assumed for each one. This assumption is usually made in all general equilibrium models. The Leontief assumptions are many, but the most relevant ones to the present study include:

(i) A given product is only supplied by one sector

(ii) The quantity of each input used in production by any determined entirely by the level of output in that secto

The computational convenience assumption is that input functions should be linear over a given range of outputs for purposes of statistical and computational convenience. This assumption of linearity between input and output function can be expressed mathematically as follows:

$$X_{ij} = C_{ij} + A_{ij} X_j \ldots \qquad (11)$$

Where:

A_{ij} = marginal input coefficient

C_{ij} = is an element of a fixed cost which does not vary with the level of production/output.

X_{ij} = Input 'i' required to produce an output 'j'

X_j = is a measure of the jth output

When $C_{ij} = 0$, then equation becomes

$$X_{ij} = A_{ij} X_j \quad \ldots \qquad (12)$$

Thus, the basis of the input-output model application in forest resources management is the assumption that it is possible to divide all production activities into sectors whose interrelations can be meaningfully expressed in a set of simple input functions. Also the output of a particular activity may serve as input for another activity, for example, road construction for management supervision may be an input to timber harvesting.

In presenting the mathematical function for input-output model, Olayide and Heady (1982) also made an assumption of Nigerian economy being grouped into four sectors for the purpose of convenience only. These sectors include agricultural, manufacturing, services and others. In their presentation, the flow table of the various sectors was rendered mathematically as follows:

(i) $X1 = X11 + X12 + X13 + X14 + Y1 \quad \ldots \qquad (14)$

(ii) $X2 = X21 + X22 + X23 + X24 + Y2 \quad \ldots \qquad (15)$

(iii) $X3 = X31 + X32 + X33 + X34 + Y3$ … (16)

(iv) $X4 = X41 + X42 + X43 + X44 + Y4$ … (17)

(v) $Ro = ro1 + ro2 + ro3 + r04 + Yo$ … (18)

Where Xi (for i = 1,2,3,4) is the gross output of the ith sector, R is the primary input (value added) ; X_{ij} (for i = 1,2,3,4and j = 1,2,3,4) is the purchase from ith sector by sector 'j' as an input needed to produce X_j .Y_i (for i = 1,2,3,4) is the final demand for products of sector I and Yo is the final demand for primary inputs.

From equation (13), A_{ij} is the ratio between X_{ij} and X_j and is measured for a single observation. Thus, we may express the relationship as

$$A_{ij} = \frac{X_{ij}}{X_j} \quad \ldots \quad (19)$$

In the same manner, we get :

$$Foj = \frac{R_{oj}}{X_j} \quad (20)$$

for primary coefficients

Substituting equations (19) and (20) into equations (14) to (18) a set of structural equations relating output to final demand is obtained as follows:

$X1 – a11X1 – a12X2 – a13X3\text{-}a14X4 = Y1$ … (21)

$X2 – A21X1 – a22\ X2 – 23\ X3 – a24\ X4 = Y2$ … (22)

$X3– a31X1 – a32X2 – a33X3 – a34X4 = Y3$ … (23)

$X4 – a41X1 – a42X2 – a43X3 – a44X4 = Y4$ … (24)

$Ro – fo1X1 – fo2X2 – fo3X3 – fo4X4 = Yo$ …. (25)

Applications of Input-Output Models in Forest Resources Management

Input-output models have frequently been used to describe the role of forestry activities in regional economies (Elrod *et al* 1972;

Troutman and Porterfield, 1974). Input-output models have also been used to evaluate forest policies and programmes (Schallau *et al* 1969; Connaughton and Mckillop, 1979). Almond and Palmer (1983) quoting Palmer and Keaton, (1978) and Alward and Stewart, 1978) have emphasised the usefulness and applicability of input-output analysis to forestry planning. Many applications of input-output models have utilised primary data obtained through direct surveys. Consequently, the cost in terms of money and manpower for these studies has been substantial (Bourque and Hansen, 1967). Various techniques for constructing models using secondary data have been proposed (Czmanski and Walizia, 1969; Richardson, 1972) and applied, significantly reducing the cost of obtaining a useable model. As observed by Chang and Buongiorno (1981), applications of input-output models to forestry in the past have concentrated mostly on the contribution of the forestry sector to a local economy (Hughes, 1970), and the economic structure of the forest product industries (Kaiser, 1968; 1969). Flick (1975, 1976a; 1976b) has applied the input-output method to problems in forest management. In these applications, Flick described the input-output relationships between various forest management activities as if they were separate economic activities in a general economy. Furthermore, Jones and Stokes (1987) observed that input-output method could be applied to analyse the travel cost estimates of forest-user expenditure associated with using the forest resource within a regional economy. They opined that such costs can be allocated as part of final demand in an input-output model which makes it possible to estimate output, income and employment impacts resulting from forest user spending. They concluded that though there are various problems encountered when input-output method is applied to forestry sector, it is still useful particularly when the role forestry and agriculture play in the general rural development of a country or a region is considered.

Strengths of Input-Output Model in Forest Resources Management
Chang and Buongiorno (1981) while commenting on the usefulness of input-output analysis to multiple use forest planning observed that other analytical tools such as linear programming and goal programming though have been very useful in minimising or maximising objectives and minimizing deviation from set goals

respectively have failed to realise the fact that management activities often require not only primary inputs such as labour and budget but also inputs from other management activities. They concluded that input-output analysis is a technique well-suited to handle relationship between management activities. Aruofor (1990) is of the opinion that the main strength of input-output technique lies in its mathematical flexibility which explains its operational characteristics.

Limitations of Input-Output Analysis Application in Forest Resources Management

Recent development in forestry has placed much emphasis on non-timber forest products including wildlife, medicinal plants, recreation, water catchment protection, biodiversity conservation and carbon fixing. The applicability of input-output analysis which models explicitly physical and financial flows within the market economy is not well suited as a technique to address these problems.

The application of input-output analysis to the forestry sector has encountered a number of problems which are based partly on the nature of the model itself and partly on the characteristics of forestry business. The first problem associated with the nature of this model is the problem relating to standardised methods for constructing the model. According to Aruofor (1990), there is considerable level of arbitrariness which defeats the purpose of the model. Furthermore, construction of input-output tables requires tremendous effort and financial outlay especially as national accounts figures report only data not suitable for such exercise (Soyode, 1982).

The original assumptions on which the application of input-output technique is based also constitute a weakness in its application to forestry. For instance, the assumption of homogeneity does not apply in the forestry sector in the real world because many outputs are jointly produced by different sectors of the economy while some sectors may produce several goods and the production processes of a particular output may vary from one sector to the other. Similarly, the assumptions of linearity of input and output functions may not hold. There is no assurance in forestry that a given increase in the level of input will result in a corresponding increase in the level of output. Externalities such as the climate, pests and diseases and outbreak of forest fires are also a reality in forestry business which makes the assumption of no externality in input-output analysis rather subjective.

There are a number of other problems relating to the nature of forestry business itself. For instance, a common problem with the application of I.0. technique in the forestry sector is the fact that forestry activities are not separately identified in national input-output tables. Mcgregor and McNicol (1992) citing the example of the Irish input-output table observed that forestry development was aggregated to include establishment, planting, maintenance, building and construction. Hence the total output of the forestry development sector is accounted as Gross Capital formation. Mcgregor and McNicol (1992) suggest two alternative ways of addressing this problem. They are:

(i) to approach the appropriate statistics office for detailed information.

(ii) to develop superior information through sectoral survey which, may then be used to separate the forestry sector's sales and purchases from the aggregated accounts presented in the original table.

Another data-related difficulty in the application of input-output modelling to forestry problems is the meaningful estimation of the change in value of standing timber, necessary for the definition of the industry's output which includes timber and other production which is sold, or used for recreational services and the value of the physical harvesting stocks.

Availability of employment and self employment data both at national and state levels is another major problem. On a national level, employees in employment as well as self employment data are not available on a forest planting-harvesting breakdown basis. Also self-employment statistics are subject to relatively high sampling error (up to 10 percent); are aggregated together in the composite forestry and fishing classification and provide no information about part time self-employment .

The residence of the forest labour force is another consideration. On a regional scale, inter-regional mobility of workers on individual projects and contracts for considerable periods of time is a problem, in the sense that a significant part of wages and salaries paid to forest workers, many of whom do not reside locally, may be spent outside the study area. Matter and Murray (1988) observes that high level of labour mobility is common in forestry. To ignore this will imply an over-estimation of regional multipliers but to make appropriate adjustments in the income from employment, country information about the workers' residence is necessary. Obviously, despite the ability of input-output model to analyse the relationship of different forest management activities in terms of the contribution of one activity to the achievement of other(s); it does have its own peculiar shortcomings some of which are discussed above.

Having gone through a review of the viewpoints of several authors as presented in this chapter it can be deduced that though there are many algorithms and several approaches have been advanced for multiple use planning, no single approach of programme can be said to be the "best" for all types of multi-objective programming problems. The realisation of this fact is probably one of the forces that propelled Chang and Buongiorno (1981) when they combined both the Goal programming and input-output models to proffer a solution to the problem of multiple use planning on public forests.

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