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Systems Analysis in Forestry and the Forest Industry: An Overview

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IIASA Working Paper

WP-80-055

April 1980

SYSTEMS ANALYSIS IN FORESTRY AND THE FOREST INDUSTRY: AN OVERVIEW

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April 1980
WP-80-55

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PREFACE

This paper is a survey discussing the use of systems analytical methods in planning and decision making in the forestry and in the forest industry. The number of papers and studies discussing different applications of systems analysis in this sector is wide and rapidly increasing. However the real uses of these methods in practice is hard to predict. So there is clearly a need for detailed state-of-the-art studies at two levels: in research and in practical uses of these methods in the forest.

The paper was presented at the IIASA Forest Industry Workshop, January 8-11, 1980.

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INTRODUCTION

Systems analysis, i.e., modeling, simulation, optimization and planning techniques, etc., has been widely used in separate areas of the forestry sector since the end of the 1950's. If we consider the whole sector, (i.e., from silviculture and timber management to the operation of the mills and marketing of the final products, there are totally different application tasks and therefore the methods and solutions used vary greatly. In the forestry area, for example, the LP-applications are typical but in the mill operation real-time control and optimization systems have wider use.

The development in the whole area of applications has been very rapid. Chappelle (1977), for example, gives statistics concerning the increase of LP-applications in forestry in the US: there were two applications in 1955 and 105 in 1970. The application here means that it is a study of application not necessarily used by foresters or managers. Today, there are hundreds of publications on the application of different methods or systems analysis in the forestry and forest industry. So it is impossible in this kind of overview to list and evaluate all or most of them. This survey is, therefore, designed to take a look at the whole area, i.e., all methods in all applications. The aspects discussed will remain very general and no detailed comments on most individual papers can be made. Some studies mentioned here are merely taken based on the abstract only if the application or method applied is new or of special interest just to show the whole range of possible applications and methods.

The general feature here is that most applications still are on paper, i.e., the researchers are speaking and writing to each other. The number of real applications is still quite low. There are several reasons for this, including:

- -- difficulties in getting all the data needed for the application;
- -- local needs for modification and adoption;
- -- complicated programming and hardware requirements;
- -- need for special staff;
- -- misconceptions and reluctance against new ideas;
- -- lack of practical results, i.e., cost-benefit analysis of these methods; and
- -- difficulties in handling multiple-usage problems and stochastic situations.

Lately there have been several computer program packages constructed for different (mostly timber management) applications, and these packages may promote the practical use of the methods. On the other hand, a "solution package" may have the tendency to modify the problem to fit better with the program package and thus the solution may loose some important local features necessary for decision-makers. The rapid development of computer technology will also ease the usage of systems analysis. One example for stock inventory systems is a microprocessor packed in a backpack for data gathering on the site.

What might be useful in this connection is a study concerning real applications, results, experiences and problems in using systems analysis in forestry and the forest industry. The results of this study could then be used for directing R&D in the area to real problems.

In the following sections, the whole wide area will be divided into: timber management, forest sector economy, planning of industry, land usage, production and operation, and other applications. Each field of application will be briefly discussed with a related Table that indicates the typical tasks and typical methods used. The reference numbers utilized in these Tables refer to the publications, etc., listed in the Reference Section. (Refer to the Notes Section for proper referencing of these numbers.)

TIMBER MANAGEMENT APPLICATIONS

The basic and most important problem to be solved in timber management is the temporal and spatial scheduling of silvicultural and harvesting activities during a planning period (50-100 years) in order to maximize (or minimize) the objective function and fulfill all constraints. The objective function used may be: present net worth of the stock, stock volume, return rate of investment, allowable cut, sustained long-term yield, timber production costs, etc. The constraints include, a.o., allowable annual cut, labor force available, reforestation area, capital available, etc. In order to be able to solve this kind of long-term planning problem a simulation model for timber yield and growth must also be available.

Linear programming is a widely studied method for the solution of this problem. Table 1 shows an overview of selected application studies in the timber management area and we can easily see how dominant the linear programming method is. Many reference numbers will occur twice (or more) because modeling is essential in all methods. Many published studies could also be put in some other area too in this quite arbitral classification. Some modifications of LP, for example goal programming and also non-linear and dynamic programming, have been studied, but so far the practical use of these methods have been very limited. The practical use of LP has been limited to big corporations with enough special staff and forest land, or to public forest owners and organizations, for example in the U.S. and Australia (Australian Forestry Council 1978; Navon 1971).

There are certain limitations in the use of LP in the above problem. First of all, the model, the objective function and the constraints should be linear; how well this is justified in each particular case is dependent on many factors, a.o. silviculture, species, validity of growth model, terrain, etc. Also, in this kind of long-range planning the question of uncertainty and the stochastic nature of the process are rather important. Additionally, more will be discussed about the multiobjective nature of forest management, thus the optimal production of timber will not be the only objective (e.g., recreation, use of forests, wilderness, wildlife, natural watershed, forage, conservation, etc. can be taken as additional contraints or goal programming can be used). This is closely connected with the area of land usage and it will be discussed later.

A major type of problem closly connected with timber production and harvesting activities is the planning of logging and transportation of timber. Here also, as can be seen from Table 1, linear programming is mostly studied and applied. Some very interesting studies concern the use of optimal control theory in timber management (Andersson 1976; McDonough and Park 1975; Mitchell 1976; Newnham 1973). The LP-program packages developed will be very helpful in calculating the outcome and effects of different policies, activities and choices; it does not, however, solve the principal problem: what should be the real objectives, constraints and policies? This question will be especially important in the case of multiuse or product-mix of the forest lands.

Table 1. Timber management

Task Objective \ Method	Modeling & simulation	LP	Network anal.	Goal prog.	Nonlinear prog.	Dynam. prog.	Modif. of LP	Opt. cont. theory	DLP	Syst. dynam.	Time series anal.	Other
Stock inventory, growth, yield	3,6,7,14, 27,30,45											3,14
Present net worth maximation	4,58,86	6,40				58		4				
Sustained yield	36											
Allowable cut	18,37	37			37							
Harvesting planning	6,12,13 25,42,46, 50,51,56, 71,72,73, 79,86	6,12, 13,25, 42,50, 51,56, 79,86		25,73		71		46				72
Harvesting & transportation	9,19,21, 31,57,69, 83	31,53, 83					21					21
Silvicultural and/or transportation planning	30,55	85				55						

FOREST SECTOR ECONOMY APPLICATIONS

Table 2 shows a collection of typical applications in forest sector economy applications. Most of these include modeling and simulation only: this is understandable because, for example, the optimization of a forest sector economy (regional or national) is a very complicated multiobjective task. Some studies are now underway in this direction. The modeling methods used are typical econometric models; input-output modeling (Rafsnider 1975), cost-benefit analysis, and systems dynamics for regional and national sectors, regression models or time series forecasts for global trends and market studies. For industry development and reforestation projects also some LP applications exist.

The main problem here is the long-term forecast for this sector on global, national and also regional levels and how to use these forecasts. They can not be used in individual corporations or mills; possibly their best use can be found in discussions between different interest groups (industry, forest owners, government, labor unions, environmentalists) when the future development or choices concerning the forests usage are explored. Typical examples of these kind of studies on a national level are Jegr (1978), Kallio, et al. (1980), Randers and Lönnstedt (1979), and Randers, et al. (1978).

PLANNING OF INDUSTRY

There are several modeling and simulation studies (regional and national) concerning the planning and evelopment of the forest industry (pulp and paper or sawmills and other mechanical forest industry). These studies are mainly based on forecasts and trend models for demand and supply possibilities and the parameters in these models are estimated based on historical data. These trends are then used in simulation studies for the different locations of mills and the different production mixes and sizes of mills.

The optimal mill location problem has been solved by the LP-technique in some simple cases taking, for example, only the transportation costs into account (Abel 1973). LP technique and investment cycle theory have also been used in some investment policy studies. The possibilities of dynamic programming and systems dynamics have also been studied in this area (Randers, et al. 1978; Ruprich 1974). Table 3 summarizes the studies in these topics.

What was stated in the previous section is also very valid here; the models and solutions are so aggregated on the national and regional level that they are not very useful for real projects; they can serve as implications for future trends and possible investment policies. However, these models assume a constant technology and adhere to the existing pattern and trend in world markets and consumption. This can not be true in the long-term; so what is really needed here is the study of consistent world trade study and the study of technological change in this area.

Table 2. Forest sector economy

Task Objective \ Method	Modeling & simulation	LP	Network anal.	Goal prog.	Nonlinear prog.	Dynam. prog.	Modif. of LP	Opt. cont. theory	DLP	Syst. dynam.	Time series anal.	Other
Global aspects	107											
National sector	3,18,49, 52,72,91, 94,95,106								52	49,52, 94,95		
Regional sector	5,36,47, 96										85	92
Supply & demand	18,85,92, 96,106,107, 110,120,											
Forest industry forecasts	3,61,97						61					
Reforestation & plantation	15											

Table 3. Planning of industry

Method / Task Objective	Modeling & simulation	LP	Network anal.	Goal prog.	Nonlinear prog.	Dynam. prog.	Modif. of LP	Opt. cont. theory	DLP	Syst. dynam.	Time series anal.	Other
Pulp and paper industry	19,32, 37,49,72, 77,91,95, 97,112	19								49,95		37
Saw mills & other mechanical industry	1,38, 44,71	1,38, 44										
Location of mills	1	1										
Investment policy	73,77,95, 97,100, 112,120											

For one corporation and mill, more detailed and technical models have been built, but these naturally include so much proprietary data and information that very little has been published (Zackrisson 1977).

LAND USAGE

As previously mentioned, the multiobjective use of forest land is now becoming a target of many discussions between policy-makers, industry, and forest owners. There will be competition for land between agriculture, timber production, recreation, general conservation, wildlife, forage, etc., on the one hand, and for the timber (i.e., biomass) produced in forests, between the traditional industry (pulp, paper, mechanical), energy production, and the chamical industry, on the other. In this connection, when national and regional multiple-use of forest lands is planned (this concerns especially Public Forests, and also a big corporation), the use of systems analysis can be helpful.

Several studies in this area have already been made as can be seen from Table 4. The most studied method in solving the above described optimal product-mix problem is the LP-technique. The difficulty here is how to formulate the objective function, and how to evaluate the value of non-commodity products; for example, recreation usage or wildlife of forests. One method is to take the production of timber as the objective and the demand on other uses as additional constraints. (This has been done, for example in Timber-RAM; see Navon 1971.) Goal programming is also quite a well studied method in this application. It is believed that the development in multicriteria optimization theory will soon give more powerful methods in the solution of these kinds of problems; however, the main difficulty still remains: how to evaluate and put value on different competitive products?

The problem will become still larger as it is not just the forest owner alone who will be involved here: many different interest groups (government, labor unions, environmentalists, recreation users, etc.) will be interested in this question and so the long-term policy concerning forests will be a target of great interest. Flick (1975) has suggested the use of input-output analysis to solve the value problem in multiple usage of forest land. For this kind of situation the possible use of gaming and value analyses have also been studied (Countryman 1974; Henne 1978).

PRODUCTION AND OPERATION OF MILLS

This area of systems analytical applications in the forest industry is well-developed and it includes the wide range from process control into the planning and investment models for a corporation. Concerning the process control studies and applications, there are so many that only some of the recent surveys

Table 4. Land usage

Method / Task Objective	Modeling & simulation	LP	Network anal.	Goal prog.	Nonlinear prog.	Dynam. prog.	Modif. of LP	Opt. cont. theory	DLP	Syst. dynam.	Time series anal.	Other
Planning of land usage	9,10,12, 22,25, 45,51,56 67,119	12,51, 67		10,25	51	119	56					22,45
Forestry budgeting	22,57	57		57								22
Non-timber products	76,87											
Multiple-usage	21,34, 35,41,46, 48,65,99, 102,104	34,65		102								34,41, 46

have been listed in Table 5 (Gee 1977; Keyes 1975; Uronen and Williams 1978). These applications mostly use quite simple mathematical models of the technological process to be controlled and optimal control theory in a straightforward manner. The use of a digital computer and also special measuring instruments are essential for all of these applications.

In recent years, increased interest in more management type applications in this industry has arisen; the allocation of resources, production planning, coordinated operation of different units and subprocesses, management information systems, etc., are typical examples (Ahlsholm and Pettersson 1970; Edlund and Rigerl 1978; Leiviskä and Uronen 1979a, 1979b; Oliviera, et al. 1977; Uronen and Williams 1978). This, together with rapid development in computer hardware and software, will mean a more increased integration of these tasks and operations into a hierarchical management, information, planning, operation and control system of the mill. This will definitely be the most important topic for further research and development in this area.

OTHER APPLICATIONS

There are a lot of interesting applications of systems analysis in special purposes related to the forestry/forest industry as listed in Table 6. Road planning and transportation planning applications with network analysis or LP-solutions are closely related to timber management and/or industry location problems, as earlier discussed. Fire detection and control systems and tree improvement application of the LP-technique are quite well studied and special cases have been documented.

It is obvious that more and more computerized resource information, data collection and analyzing systems, databanks, and display and mapping systems are needed (e.g., in connection with the satellite surveying of forest resources, etc.).

PROGRAM PACKAGES

Table 7 gives a list of some well-known computer program packages developed for certain application in the forestry/ forest industry area. Most of them are for timber management applications, and the LP-technique is the most common solution method used. In using these programs it is necessary that all relevant data (e.g., yield, growth, prices, labor costs, etc.) is made available. The usefulness of these programs is naturally connected with the limitations and problems discussed earlier, as in connection with timber management applications. The main use is in the rapid calculation of different choices, but the most important part of the problem--the section of objective and the setting of values and constraints--must be solved by the decision-maker himself. It is to be expected that more and more of these kinds of program packages will be developed and used.

Table 5. Production and operation

Method / Task Objective	Modeling & simulation	LP	Network anal.	Goal prog.	Non-linear prog.	Dynam. prog.	Modif. of LP	Opt. cont. theory	DLP	Syst. dynam.	Time series anal.	Other
Resource allocation	13,93, 100					100						
Process control	7,39, 54,113							39,54 113				113
Production planning	4,7,30, 42,63,64, 89,113, 120		30					4,42, 63,64, 89				63,64, 89
MIS	30,63 113		30									63

Table 6. Other applications

Method / Task Objective	Modeling & simulation	LP	Network anal.	Goal prog.	Nonlinear prog.	Dynam. prog.	Modif. of LP	Opt. cont. theory	DLP	Syst. dynam.	Time series anal.	Other
Tree improvement	14,40	14										
Road planning	88,114, 118		88,114									
Transportation planning	13,88, 90	90	88									
Fire control	86,108											
Databanks & information systems	5,20,23, 33,59,66, 79,90, 105	90										5,20

Table 7. Program packages.

Name of package	Reference	Application area
TRES	68	Timer resource growth projection
FOREST	15	Simulation of timber growth
STANDSIM	8	Simulation of timber growth and yield
FORSIM	8	Simulation of timber growth
RADHOP	8	LP program for rationalizing yield flows through time to meet market requirements
MASH	8, 86	Maximizing the present net worth
ADVENT	57	Budgeting in forestry management
PUBLIC	12	Land management planning
Timber RAM	75	Forest management planning
TEVAP 2	74	Forest management planning
ECHO	109	Forest management planning
FOCUS	108	Forest fire control planning
LOGPLAN	81	Logging plan model
SVEN	9	Land usage planning
RAA	67	Resource allocation
INFORM	118	Informations system for management
TRIS	118	Total resource information system
WRIS	118	Wildland resource information system
AUTOMAP	118	Automatic mapper
CISC	118	Continuous inventory of stand conditions
PROGNOSIS	118	Model for stand development
TIMADS	118	Timber management systems
TRAS	118	Timber resource analysis system
WIPS	26	Woodlands information and planning
ECOSIM	118	Ecosystem simulation
RCS	118	Resource system simulation
RDS	118	Road design
OPTLOC	118	Optimal road location
RAM	118	Resource allocation
FRES	118	Forest range environment studies
MULTIPLOY	118	Investment simulation
TAG	118	Transportation analysis

Table 7. (continued)

Name of package	Reference	Application area
WRAP	45	Planning of wildland resources
ECHO	115	Harvesting optimization
GELO	59	Mapping of forested areas

SUMMARY

The number of publications discussing the use of systems analysis in the forestry/forest industry area is large and this survey will not cover all of these. However it can not, based on published reports, be concluded to which extent these methods are really used in everyday decision-making by management. Two dominant application areas can be identified: timber management and process control. Two other growing areas can also be seen: land usage and management information systems in mills. Based on this overview, several questions can be asked:

-- There is a certain theoretical and methodological readiness in using these methods. Why are they not used more widely in forestry or in the forest industry?

-- What are the bottlenecks in the use of these methods and programs?

-- Should cost-benefit analysis be applied to the use of systems analysis?

-- What are the main problems to which R&D should be concentrated?

-- How could the existing models (e.g., in yield and growth of biomass) be improved?

-- Do local circumstances change too much from place to place to enable the development of general models or program packages?

In addition to this, it is evident that technological change, the competition of land and raw materials, changing patterns in world trade and production, etc., will turn the planning of a forest sector into a very dynamic and complicated task. The decision must be made based on models, forecasts and data available: here effective use of systems analysis can be of great help. But even at its best, it will be only a set of tools; the final decision will always lie with the people, the management of the industry, and other decision-makers.

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