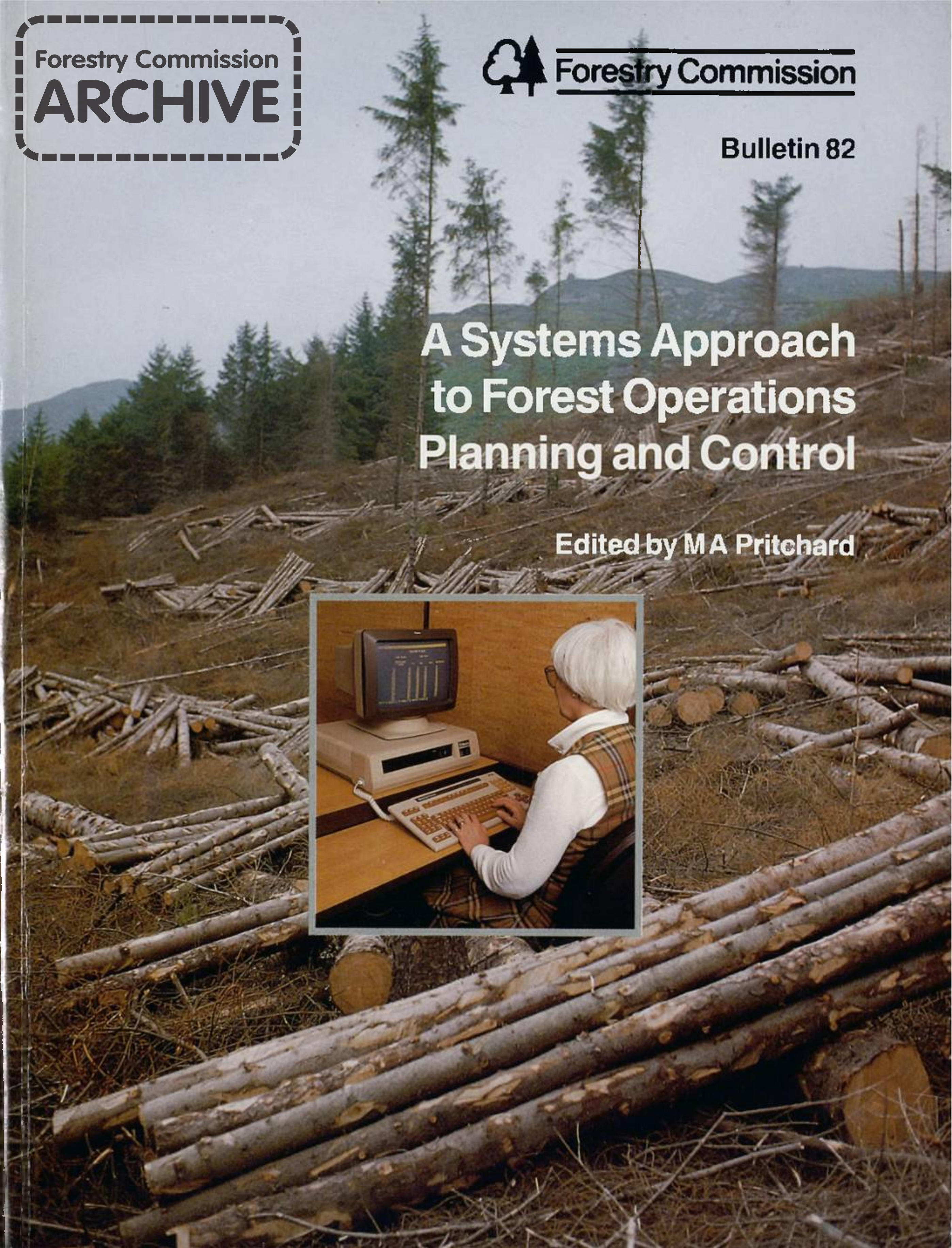
Forestry Commission

Bulletin 82

A Systems Approach to Forest Operations Planning and Control

Edited by M A Pritchard



FORESTRY COMMISSION BULLETIN 82

A Systems Approach to Forest Operations Planning and Control

Proceedings of a IUFRO Working Group S3.04.01 (Forest Operations Planning and Control) Symposium held at Heriot Watt University, Edinburgh 25-29 July 1988

Edited by M.A. Pritchard
Forest Officer, Forestry Commission

LONDON: HER MAJESTY'S STATIONERY OFFICE

ISBN 0 11 710272 5
ODC 62
UDC 681.3

Keywords: Information systems, Forest management, Forestry

Enquiries relating to this publication should be addressed to the Technical Publications Officer, Forestry Commission, Forest Research Station, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH.

Contents

Foreword

Computer-based systems are now commonplace in most forestry operating environments. One of the inherent features of forestry everywhere is the amount of data collected over long periods of time. Information technology has made the storage and analysis of these data a cost-effective reality. Never before has the forest manager been better placed to call upon these data, analyse them and turn them into meaningful information. Furthermore, the opportunities for testing the likely effects of different courses of action are now extensive. This analysis and interpretation, coupled with an understanding of past events, is an essential prerequisite of good forest planning.

As the major body linking forest scientists, IUFRO provides the ideal forum for exchanging information and stimulating new ideas and concepts. This Bulletin is a record of the exchanges shared by forest scientists within IUFRO at the symposium held in Edinburgh in July 1988.

M.A. Pritchard

Paper 1

Development of the Information System in Forestry

*S. **Tomanić**, Faculty of Forestry, University of Zagreb and N. **Novak**, ROŠ 'Slavonska šuma', Osijek, Yugoslavia*

Summary

This paper considers the characteristics of the information system (IS) in forestry; its structure, development methods and effects are considered. The characteristics of the IS in forestry and its use depend on the extent of the evolution of information science and its application to forestry, together with the natural laws of forestry. The development of the forestry IS has been slow to start when compared to other activities; this is a common phenomenon in most countries. The reason for the lag is a relatively low level of education in information science for forestry staff, and resistance to innovation.

The organised development of the IS in forestry is a complex and long-term task requiring experts in information science and forestry who are the immediate users of the system they create. It is necessary to make a conceptual and realisable project whose aims, development concept, tasks and financial resources are well-defined, realistic and harmonised with the requirements of forestry. In the development of the information system it is possible to use centralised, decentralised or distributed data processing techniques. The integrity of the forestry IS is achieved through standardised databases, hardware network and programme support.

The effects of using a developed forestry IS can be direct, indirect, measurable and unmeasurable. The most significant directly measurable effects are increased production and better quality, together with greater opportunities for predicting, planning and controlling processes within forestry.

Introduction

The acceptance of developing and using modern information technology is one of the most significant issues forestry has dealt with for the last 20 years. Internal relations in forestry have largely influenced the conditions and assumptions for the efficient use of information. This efficiency is expressed in terms of an integral information system comprising production, business and operations functions, all supported by automatic data processing. This method of controlling the development of information, ranging from the complete negation of any positive influence, to allowing for an efficient development of distributed data processing within the last 20 years, is the topic of this paper.

Attention is focused on the development of the information system in a forestry enterprise where forests and forest land are social property. Great attention is paid to the main forest products, by-products and general benefits of forestry. This paper considers the development of the information system in forestry only in terms of organisation, staff and hardware.

Such an approach to the topic has both good and bad aspects. The good aspects are that each subject of discussion may offer the possibility of pointing to things that ensure further progress in the development of forestry, by using information through any available means. The bad aspects of such a choice are diverse, as we do not consider other ways of introducing the information system. Primarily, the problem is the general social situation, in particular problems related to computer literacy of professional staff in the forestry enterprise, a situation that has existed since the very beginnings of the information system development.

This paper is an attempt to give a global view on the development and application of the information system by using the author's knowledge of the method of forecasting, within a distributed data processing network, on the forest management area of 250 000 ha of valuable bay oak, ash and hornbeam forests.

Development of the forestry information system

A method of information system project

The necessity of using information systems to replace routine clerical work by computer-aided data processing has emerged in forestry rather late when compared with other branches of the economy, considering the availability of computer facilities.

The reasons are many. Some of them have been investigated, others only assumed. They are primarily a consequence of the traditional, introvert behaviour of foresters related to the lack of readiness by managerial staff to accept and use new knowledge and skills.

Unusual methods of development need to be applied under such conditions during the initial application of the information system. This means that the present limitations ought to be overcome by strategies which will readily yield attractive solutions to the issues in major activities. They should, in a short time, accurately substitute a great number of routine operations to the staff who would logically be the first to support and thus encourage the development of the information system. The principles of the preliminary discussion among the information professionals and other staff in the production and business process will enable a systematic development of the general information system by one of the known methods.

Needless to say, such an approach to the development should initially be supported by a small group of enthusiasts or even an individual (Rupnik, 1988). By overcoming their own limitations and avoiding the resistance of their environment, they will produce the first information results and in this way qualify to make the initial report independently or supported by the now convinced management, for the development of the conceptual project of the information system based on computer data processing. The development of the information system should, under such conditions, at first completely satisfy the demands of the project task, which is complex and long term.

The aims of the project should be well defined, current and reconciled with other purposes of forestry, or they should indirectly result from them. Work at higher levels of abstraction should be ensured here. The goals should be understandable and known to everyone. It is particularly important that they are quantified as completely as possible. The aims that are not measurable are probably abstract and hard to realise.

Functional and operative characteristics of the information system

These are defined as a system of information and co-information processes (Figure 1.1). An information process is any form of transforming information. This comprises creating, processing, transferring, storing and using information. The basic characteristic of any of these transformations is the algorithmic transformation and connection of input and output.

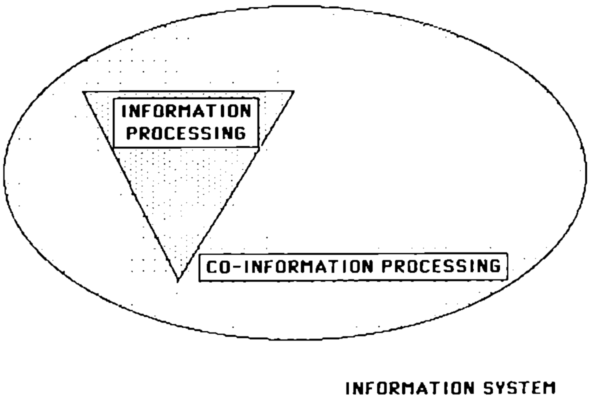


Figure 1.1 Characteristics of the information system.

Co-information processes enable the functioning of the information processes in the real world. They refer primarily to the material, staff, management and organisation, and to the financial, biological, technological, chronological, spatial and climatic processes. Due to the considerable number of co-information factors, we usually say that the forestry information system is complex.

The complexity of this system is significant in its interaction with the short-term and long-term aims of forestry. This particularly refers to the overall field of planning together with the various ecological impacts and profits from forestry, which cannot be defined by the usual economic factors without difficulty.

The methods of using the information system in forestry are closely connected with the natural laws of this science. These methods are especially interesting for users at different levels of management according to the spatial and chronological distribution of the production and business events in forestry. An illustration of this traditional approach can be seen in Figure 1.2.

It is obvious that time gives another essential dimension to this scheme, if we enrich the system with strategy, tactics, operation and routine (Figure 1.3), which are understood as systemically connected input, processing and output data.

Like any other biological system, the forestry information system defines the links between the elements within biology by random values; while the complexity of the total system is increased repeatedly through the existence of the functional segmentation at input, processing and output. This means that the border line between forestry as an activity and its environment is clearly defined at every level of the system.

One thing is certain today - managing and controlling such a big and complex system can be successful only by means of a dimension information system as a function of information and co-information processes (Novak, 1987).

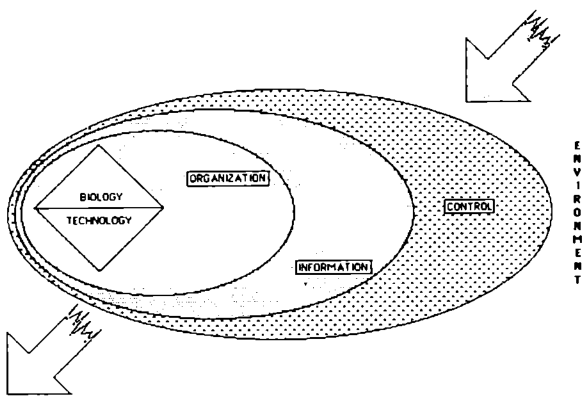


Figure 1.2 Natural laws and the forestry information system.

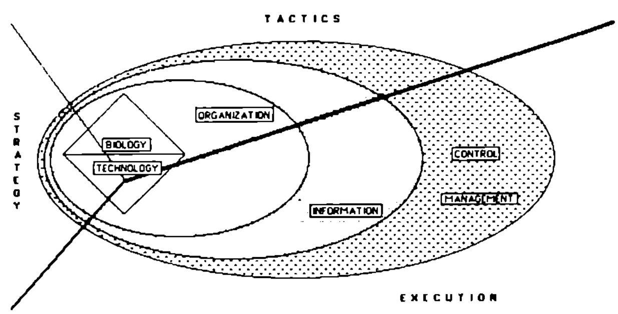


Figure 1.3 Complexities of the forestry information system.

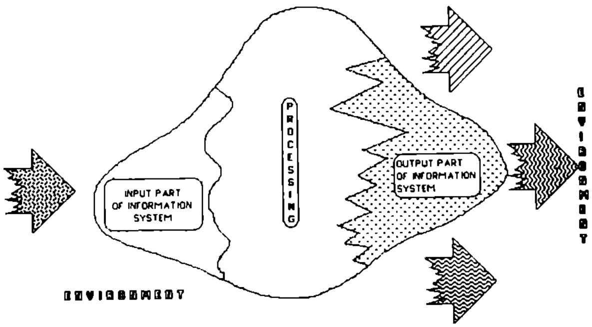


Figure 1.4 Dynamics of the forestry information system.

Parts of the information system

Among the aims of the forestry information system, those of production, transport and forest management are particularly significant:

- profit increase,
- increase of production,
- reduction of production and management costs,
- improved mechanisation,
- generally better information.

In order to realise effectively the tasks and functions, the information subsystems are being projected spontaneously for every economic and production system, taking into consideration the details of computerised work methods. The following organisation of data processing is being applied (Novak, 1984):

- centralised data processing,
- decentralised data processing,
- distributed data processing.

The development stage of a forest enterprise and the technical characteristics of computer equipment, together with the organisation level and local requirements, are the conditions directing the method of data processing. It is very important to ensure the possibility of direct communication between computers, locally or at a distance. The integrity of the subsystems in the production and business aims is achieved by designing and creating a data bank consisting of production and business databases.

To meet the needs of forestry operations, one part of the data processing system should be carried out within a real time span. This requirement presents a special challenge for the project team working on the information system. In spite of the data processing being performed at the time and place of the observed event, the costs of exploitation of the equipment and communication channels should be minimised. Meeting the needs of forestry information requirements is achieved by the following information subsystems and their lower units:

- forest management,
- forest resources,
- forest production,
- trade and turnover of forest products,
- forest research,
- forest-aimed education,
- literature and other sources of information.

Benefits resulting from use of the computerised system

Presenting and explaining the direct and indirect use, that is, the efficiency of information, should primarily be based on satisfying some of the assumptions which have been referred to in the introduction. However, these assumptions are not ensured by the information system itself or independently. This is the task of the management staff (Perović-Jovanović, 1987).

The management effects of using the information system are commonly divided into measurable and unmeasurable. Both effects can be direct and indirect. Under the economic conditions it is understood that the measurable sides of the information system's efficiency are those whose financial equivalent is evident.

Our intention is to classify and describe those uses of the information system that can be simply and exactly expressed. Subjectivity with such an approach is certainly hard to avoid, especially as investigations in the field of forestry have not been systematically

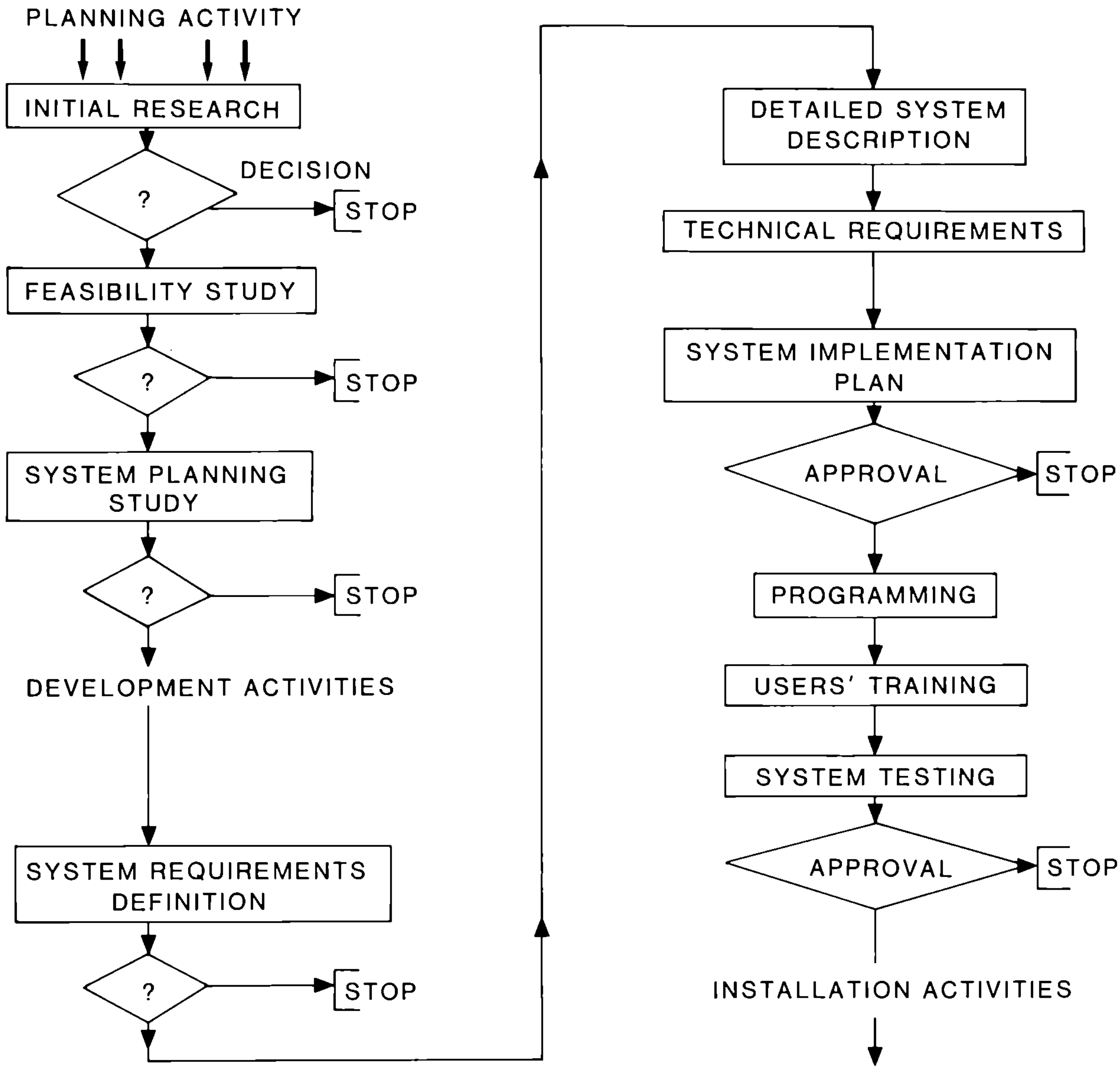


Figure 1.5 *Diagram of information system development.*

carried out. However, we think that this is the right time and place to develop an agreement for establishing the unification of methods and aims for future research. We shall refer to three index groups of a forestry enterprise, which can be improved by using the information system.

Measurable reduction of production and management costs

The question here is primarily of savings in labour and materials. These effects are the easiest to measure and the quantification is evident. The reduction on total administration and routine work is the first result of developing and applying the information system supported by computer. With routine office work, the application of a computer enables an increase in productivity, together with lower administration costs.

Developing a computer-aided information system in forestry resulted in a saving of space and equipment in terms of reducing investments and the costs of maintaining unnecessary space for staff, equipment, archives and storage. Improved conditions connected with space also result from the trend of equipment miniaturisation, so that the effects within this subgroup have been doubled. Technological progress in installing modern equipment no longer requires strict conditions in terms of temperature, moisture, cleanliness, vibration, electric discharge, etc., which therefore simplifies and reduces the cost of hardware.

Introducing the computer into management has eliminated conventional documentation. Savings on paper are evident and considerable. They are partly connected with the reduced demands on paper used for storing data and information. Secondly, there is the elimination of copying and duplication costs of all kinds. The costs of filing and circulating documents are also reduced.

Data redundancy is also reduced by developing the computer-aided information system. This is partly connected with the above mentioned benefits but also and most significantly, the multiple input and processing of one and the same information in different dimensions of time and space is avoided.

Regulating the process using computer systems results in reductions of stock costs in terms of material reserves, semi-products and final products. This group of management benefits is affected, besides other factors by the quality of the information and interpretation.

Computer data processing (by means of programs, systems analysis, processing) can, with simple algorithms, generate various reports so that multiple savings of time and quality increases can also be achieved. In other words, standardisation is enabled without unnecessary information noise.

Increasing the degree of information availability

The value of information is connected with its relation to time and space, i.e. information is aimed at a particular subject and linked with the dimension of time. This means getting information today or now, and not in the future when the information is no longer of the same importance or is indeed of no importance at all. It should also be borne in mind that the information should cause a reaction as soon as it has been received. Examples are numerous. We all experience the disadvantages of late information or of receiving someone else's information. The efficiency of a faster reaction in terms of production manifests itself in two ways:

1. complete utilisation of the opportunities presented by different situations in the course of production and business processes;
2. avoiding the situations that do not guarantee the desired effects so that the factors and information suggesting such situations are detected in time.

These effects cannot normally be expressed immediately and simply through quantity so they are classified as unmeasurable benefits, which does not mean that they cannot be recognised or that they do not exist. They can be expressed to a greater or lesser degree successfully by using description and abstraction.

Increasing the chances of opportune and correct reaction to the stimuli of the environment is of significant importance. Since the environment of the production and economic system of forestry acts dynamically, these changes directly reflect themselves on the observed system. To observe and understand the character of the change in the system's environment ensures timely reaction and enables adequate adjustment. Without the information on any change we lose the opportunity to react correctly. The consequence is uncontrolled system operation.

Assumption and planning of economic events by means of a computer becomes easier, more accurate and faster because a faster reception of a great amount of information is ensured. In this way we avoid the triple bridge of planning because our base is comprised of the most recent and necessary information.

Fast detection of marginal events is the base of any production system. It consists of a good plan, which should encompass the limitations of something tolerant, that is, of the time when intervention is necessary. Breaking the limitations entails practical production and economic consequences.

Computer data processing within real time reaction to the disturbances of the production and economy is instantaneous. In this way losses are reduced or eliminated; other methods would lead to considerable losses caused by the slowness of the system.

Savings on time in the computer-controlled production process (still not a robot-controlled one) are evident through the great speed of computer processing. This also refers to business. The minimisation of the production and business cycle usually results in additional benefits of rationalisation, as the production system is especially followed in all its phases, so that a synergistic effect will occur.

A faster use of alternative methods is evidently one of the efficient benefits of a computer. Here we understand the existence of algorithmic processing and behaviour conventions so that in any situation there will be the fastest method of finding the optimal variety of behaviour and achievement of the expected (always higher) effects than by other processing methods.

The techniques of systemic analysis and operation research would be significantly aggravated under the conditions of traditional processing. Computers offer significant opportunities.

Increased precision of information

This group includes similar effects to the computerised information system though it is more difficult to quantify them. Their presence results in higher correctness of the consequential action as there are built-in defence mechanisms that eliminate the objective and subjective errors.

Every system is trying to eliminate errors at any of the stages: at input, processing and output. Computer processing offers great opportunities and additional benefits by way of permanent control of data input and processing. Well set algorithms for formal, though often logical control, ensure great accuracy of data input. The output side of the system is another control of the data input and processing itself. A further control is achieved by comparing the output values with the expected ones. Besides fully automatic corrections we thus eliminate the errors and purify the process from the undeserved diversion.

Controlling electronic data processing offers two important advantages. A secret (authorised) manipulation of the data is enabled, which in these times is a not insignificant advantage. Besides which, the simultaneous availability of information free from errors is provided for every user. Together with the built-in control, telecommunications transfer of data is itself reliable and economic.

Computerised data processing ensures, unlike other methods, an analysis of the total number of available data. The traditional methods use a sample analysis that may and need not be representative of the total population, while the computer ensures a fast processing of all data. Such a way of modelling and simulating at a scale of 1:1 is difficult to evaluate financially in an adequate way. However, it is more than clear that the input fund is very large and the possibility of modification considerable with elimination of undesirable errors. This is what we have always wanted to achieve and it is the computer that has made this wish come true.

Sophisticated facilities for simulating the behaviour of particular subsystems offer possibilities for interventions from the outside so that they are observed integrally at different levels of the total system. This possibility is ensured not only under modern data processing conditions in a system but also in its environment which can give its own professional level through operations, or in the course of operating the computer, or by way of developed program tools in preparatory phase.

Conclusions

The following conclusions are based on the general perceptions of the information system, as well as on the authors' experience with their development. There is a large application potential for information science achievements in forestry. There are also significant demands for a developed integral forestry information system, aided by computers in all subsystems of forestry.

The development of the computer-aided forestry information system is unfortunately late when compared with other activities. The reasons for the slow development are primarily the relatively low educational levels in the field of information of the people working in forestry, the inaccessibility to other experts of forestry, and resistance against innovations caused by inertia.

The organised development of an integrated information system requires experts in information science and forestry who will mostly use the system to simplify and improve their own work. In the beginning attractive solutions should be chosen for major activities, which would accurately substitute the routine work done by the people who decide on the development of the information system.

An organised development of an integrated information system in forestry is a complex and a long-term job. The development of an information system requires a conceptual and realisable project. The aims of the project - developing concept, tasks, participating staff, and financial resources - should all be well defined, real and harmonised with the requirements of forestry and its subsystems. The most significant aims are the increase of both production and income, lower costs, humanisation of work and the improvement of information for all the people who decide and work on solving problems in forestry.

The forms of using the information system depend on the natural laws in forestry. Spatial and time distribution of production and other events are conditions on the specific forms of development and use of the information system in forestry. The border lines between forestry and its environment are not always sufficiently defined. They are often amorphous. This particularly refers to the general functions of the forests and its uses. In these cases, many ideas are difficult to quantify.

In the development of an information system it is possible to apply centralised, decentralised and distributed data processing. One part of the data is being processed in the place and time in which it occurs. The processing costs should thus be minimised. This requirement is a great challenge to the designers of the information system.

The forestry information system comprises the following subsystems: forest resources, forest management, forest production, trade, forest research, education, and the subsystem of forestry literature and other sources of information. The subsystem integrity is achieved by designing standardised databases, hardware network and programme support, enabling an undisturbed flow of information in all directions.

The effects of using a developed forestry information system can be direct and indirect, measurable and unmeasurable. The direct and measurable effects are:

less administrative and routine work,
saving on space and equipment,
elimination of conventional documentation,
less data redundancy,
lower stock costs,
shorter time and increased quality of data and information processing.

The development of the information system enables timely and correct decisions, avoiding slowness of process rate regulation, avoiding uncontrolled operation of the system, prediction and planning of business and other events, and a higher precision of information. This provides an opportunity to formulate an agreement on international conventions for an integral forestry information system which would involve development concepts, international forestry standards, communication, and exchange of forestry information and knowledge.

REFERENCES AND FURTHER READING

BOSS, D.E. and CORCORAN, T.J. (1986). *Local enterprisal strategic forest planning as assisted by computerised cartographic modelling.* ECE/ILO Joint Committee on Forest Workers; TIM/EFC/WP.1/SEM. 21/R.1.

DYKSTRA, D.P. (1984). *Mathematical programming for natural resource management.* McGraw-Hill, New York, USA.

HARPER, L. (n.d.). *Data processing documentation: standards, procedures and application.* Prentice-Hall, New Jersey, USA.

MARJANOVIĆ, S. (1982). Primena kibernetike u rukovodenju radnim organizacijama, četvrto izdanje. *Informator,* Zagreb.

NAKAJIMA, I. (1982). Satellite and computer-aided forest resources survey. *Japan Agricultural Research Quarterly,* 15 April 1982, 272-278.

NOVAK, N. (1984). Distribuirana obrada podataka pomoću opreme PDT 150 - Kopa 1500. Rukopis na savjetovanju: Godišnje srećanje uporabnikov '84. *TOZD Kopa terminali, Slovenj Gradec.*

NOVAK, N. (1987). Proizvodni informacijski sustav u šumarstvu. *IV Savjetovanje SITH* o informacijskim sustavima u tehnološkom razvoju. Programska oprema, zbornik radova, 57-75. *Cavtat.*

PEROVIĆ-JOVANOVIĆ, M. (1987). Analiza efikasnosti funkcioni-sanja automatizovanih informacijskih sistema. *Zavod za organizaciju poslovanja i obrazovanja kadrova,* 1-153. *Beograd.*

PRIESOL, A. (1986). Forest management and planning in forestry. In *Proceedings of a UN/ECE seminar on the preparation and implementation of forest management plans,* 1-14. Costerbeek, The Netherlands.

PRITCHARD, M.A. (1986). *Computers for forest management: asset or liability?* ECE/FAO/ILO Joint Committee on Forest Working Techniques and Training of Forest Workers; TIM/EFC/WP.1/SEM.21/R.4.

RUPNIK, V. (1988). Razvoj, izgradnja i optimalno upravljanje velikim informacijskim sistemima. Workshop - Letna šola, *Iskra-Delta, Ljubljana.*

SOUČEK, B. (1982). Od mikrokompjutera do superkomputera u narednih deset godina. *Zavod za informatičku djelatnost Hrvatske,* Zagreb.

TOMANIĆ, S. (1985). The role of computers in the forestry information system. *Proceedings of the 7th International Symposium CAD/CAM,* Zagreb, Yugoslavia.

Paper 2

Planning and Control of Forest Operations in New Zealand Plantations

A.G.D. White, School of Forestry, University of Canterbury, Christchurch, New Zealand

Abstract

This paper outlines some of the planning systems currently being employed in plantation forestry in New Zealand. Their historical evolution is briefly described and their strengths and weaknesses reviewed. An example from that country is examined to show the dangers of emphasising planning too much and neglecting implementation and control of chosen operational plans. Some of the difficulties managers experience in using research planning tools in practice are then explained and discussed. A possible way to monitor operational plans for a range of forest plantation activities in order to improve managerial efficiency is suggested, in which the dominant role that management *per se* should play is stressed, and not the technology that managers may choose to utilise to assist them in the managerial process. Researchers should be more aware of the normal managerial process, and design planning tools which cater for feedback mechanisms, particularly those that are crucial to effective management.

Introduction

Researchers, particularly those in the field of modelling, have recently been providing useful means of gaining valuable insights into interactions among the many elements needed to characterise plantation forestry systems. Their contributions have, however, concentrated on indicative planning models and not into ways of allowing managers and decision makers to employ the research tools effectively in practice. Researchers develop these planning tools using a limited amount of data, and, perforce, are able to conduct only a restricted validation of their results. Managers experience difficulty in conforming with the conditions under which research results are strictly applicable, and so misunderstandings and misapplications often occur. The purpose of this paper is to examine, by way of example, one environment in which this kind of situation arises, to show how the systems approach may fail in practice, and how both researchers and managers, but particularly the former, can improve this lack of liaison and co-ordinating capability for planning and control of plantation forest operations.

Historical perspectives

New Zealand today has a plantation estate of about 1.2 million hectares with an estimated total stem volume in excess of 200 million m^3 that is currently growing at more than 20 million m^3 per year (Collins *et al.,* 1988). This resource is based entirely on introduced species: 89 per cent is radiata pine (*Pinus radiata* D.Don), 5 per cent Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), 4 per cent other conifers and 2 per cent hardwoods. The State owns slightly more than half the total area, while about 80 per cent overall is in the hands of a dozen or so owners.

The annual log harvest has been running around 10 million m^3, with domestic consumption accounting for about 60 per cent of the figure (Ministry of Forestry, 1988). Only 5 per cent of this comes from the native forest. The national annual allowable cut from the plantation resource alone should rise to about 30 million m^3 by the year 2020 without any further increase in the planted area (Burrows *et al.*, 1987). A further indication of past and likely future developments is shown in Table 2.1.

Table 2.1 Trends in forest areas and roundwood production

Year	Area of forest (M ha) Native	Area of forest (M ha) Plantation	Roundwood production (Mm^3 yr^{-1}) Native	Roundwood production (Mm^3 yr^{-1}) Plantation
1920	6.0	0.075	1.4	0.1
1940	6.0	0.327	1.4	0.3
1960	6.2	0.350	1.7	3.0
1980	6.2	0.850	0.6	9.4
2000	6.4	1.150*	0.2	14.2*
2020	6.5	1.200*	0.4	29.5*

* Forecasts made and reported by Burrows *et al.* (1987).

The nature of this forest resource did not eventuate without considerable forethought and planning: in fact, a systems approach was clearly adopted from the inception of large-scale planting during the 1920s. MacIntosh Ellis, on becoming the first New Zealand Director of Forestry in 1920, inherited a small area of plantation crops grown under elaborate and costly methods. He was greatly concerned at the excessively high costs of establishing plantations and so initially, he placed little faith in the long-term worth of plantation forestry in New Zealand. Indeed, he closed down 12 of the 19 plantations then in existence, reduced the annual new planting to a mere 1600 ha and allocated substantial funds for research into more efficient nursery techniques, wider initial spacings and better organisation of planting operations. He then concerned himself with studying domestic and overseas wood supply availabilities, with travelling throughout the country to observe forestry practices and with becoming familiar with legislative matters. Subsequently he produced a report by the end of the year (Ellis, 1920) which clearly demonstrated the use of a systems approach to national forest planning.

One of the most valuable parts of it was an analysis of New Zealand's wood supply needs for the following 30 years in terms of both quantity and quality. Later, in 1923, when the results of a national forest inventory clearly showed that those demands could not be met through sustained yield management of the native forests, his clear presentation of the situation and associated recommendation to plant 120 000 ha of introduced species between 1925 and 1935, so that the country's wood needs could be met, was adopted by the then government with remarkable alacrity. The targets were achieved by 1931 and a resource of very high quality had been established mainly as a consequence of clear objectives having been set, a good groundwork of practical research having been prepared and a dedication to careful implementation of the establishment prescriptions by the workforce and its supervisors. There was a noticeable deterioration in the quality of establishment in the latter few years of the planting boom which lasted until 1936. This deterioration could be ascribed to the introduction of too many short-cuts and a decline in implementation standards from a less able workforce and less keen supervision. The good balance between operational planning and control of plantation establishment, the very essence of sound management, was lost temporarily, and has never been fully restored, as will be discussed later.

Ellis, in characterising the system of plantation forestry in New Zealand, had the very clear purpose of growing crops to satisfy the country's long-term needs for a wide range of forest products. He recruited an engineer to oversee the accumulation of a vast quantity of technical knowledge on the wood properties of introduced and native species and to evaluate the utilisation possibilities for each of them. This concern for end-use capabilities is documented in an article entitled *Quality vs. quantity* (Entrican, 1950).

Concern for wood quality as well as quantity is a philosophy which has continued to this day as is evident, for example, from examining the content of the silvicultural research programme at the Forest Research Institute, Rotorua, for the past 25 years or so. Its silviculturalists have aimed to improve wood quality, develop economic cropping strategies and assess potential end-use value of logs, in preference to limiting study to purely biological factors of improved growth performance. Sawing studies and economic returns have always featured prominently in silvicultural research and have had a profound influence on silvicultural thinking. Bunn (1979; 1981) provided useful insights into the underlying concepts for silvicultural practices in New Zealand.

At the same time, the role of the Treasury since the 1960s also transformed the face of New Zealand plantation forestry. The Forest Service, from 1968, was required to earn at least a 10 per cent real rate of return on any plantation investment. While researchers became pre-occupied with overcoming the limitations imposed by such a decree, forest planners and managers were obsessed with the need to manipulate the evidence on paper to satisfy this criterion for financial support, to the apparent exclusion of adequate managerial and periodic review of progress. This latter theme is further developed later. Neglect of adequate control and feedback mechanisms, which led to a lack of transparency and accountability, was the main reason for the dissolution in March 1987 of the New Zealand Forest Service, an organisation which had provided invaluable substantial net benefit to the nation over a period of 65 years. To some extent, the final result was inevitable, because of that lack of commitment to control and its consequential effect on financial accountability.

People in the Forest Service were well aware of the problems, but the department was politically found out before matters could be rectified. Examples of this awareness had earlier been made regularly in public by the then Director General of Forests (e.g. Kirkland, 1982; 1984; 1985). In the first of these he examined the crucial importance of maintaining and utilising resource and financial management information systems; in the second, he attempted to persuade wood users of the need for co-operating on the pricing of wood for sale in relation to its potential marketability and the associated growing costs; and in the third, he summarised the evolution of plantation management and supporting research, then discussed the consequential data needs. The four stages he identified in the last example were as follows:

1. choosing suitable species, with little prior research;
2. unco-ordinated collecting, analysing and interpreting of individual aspects of plantation forestry;
3. adopting a systems approach and integrating available research in a co-ordinated way as far down the system as primary processing;
4. extending the integration of growing, harvesting, processing, utilising and marketing, and also including the incorporation of financial management control.

Nevertheless, in spite of this recognition, the Forest Service, when dissolved, still did not possess an integrated resource and financial management information system that could provide managers with the ability to effect proper financial management control and be adequately accountable to Parliament. This deficiency is undoubtedly not a problem restricted just to New Zealand, and probably has implications for the design and conduct of future planning research to provide decision-support capabilities applicable to routine management in many countries. The New Zealand record is again examined further to illustrate the extent of the problem so that researchers can learn from the experience there.

Planning techniques in New Zealand plantations

Models for a wide range of forest planning functions abound in New Zealand. In a 1983 survey by a sub-committee of the New Zealand Forestry Council, over 100 distinct forms were identified. This sub-committee and the full Council were attempting to co-ordinate and rationalise the various efforts of organisations and individuals, when the Government announced the re-structuring of State land management agencies. The Council was dissolved in 1986 and its role subsumed within an arm of the newly created Ministry of Forestry which, in addition to its policy and planning role, was made responsible also for research and extension.

Two of the modelling systems developed by staff at the Forest Research Institute, now an arm of the Ministry of Forestry, are described briefly here to illustrate the kind of capabilities available for plantation planning in New Zealand and to examine some of the technical difficulties managers experience in trying to utilise the models researchers have devised. In 1976, the New Zealand Forest Service set up a Mensuration Project Team of researchers and managers to devise and promulgate a mensurational and forecasting capability to assist in the planning process needed to manage the burgeoning plantation resource. The team provided an overall system for collecting and processing data pertaining to various stages in plantation cropping, a means of forecasting the available quantities of log assortments, and mathematical programming models for devising forest harvesting strategies at the forest estate level. The work, together with other similar developments in the Oceania region, was presented in the form of an edited proceedings (Elliott, 1979). This team effort was continued with the formation of the Radiata Pine Task Force (1979-82) which produced SILMOD, a series of sub-models aggregated to provide an economic stand model for tracing the interactions of silvicultural operations from time of planting through to delivery of harvested wood supplies at utilisation plants, so that the quality and value of the wood supply could be predicted. An outline of this modelling capability is provided by Williams (1986) and an illustration of one of its major uses by Whiteside and Sutton (1983).

The successor to the Radiata Pine Task Force was the FRI Conversion Planning Project Team, the work of which was published in a bulletin compiled by Kininmonth (1987). The aim of this group was to develop a stand modelling capability to link production aspects with processing options and market outlets, so that decision-makers might choose silvicultural operations which would be better directed at meeting the demands for various forest products. Within this expanded system, however, updating of sub-models in SILMOD pertaining to forest-related operations was carried out, and it is with these that the following review is concerned. A broad overview of the overall system to be so analysed is depicted in Figures 2.1 and 2.2.

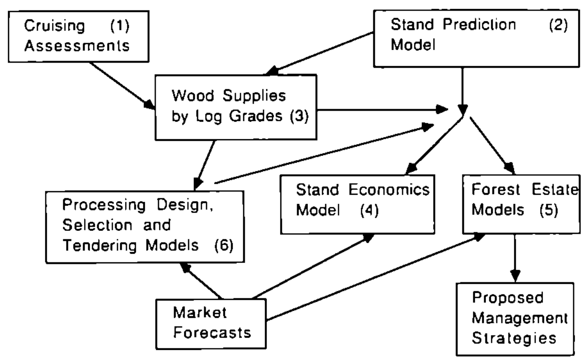


***Figure 2.1** Broad overview of conversion planning model system (adapted from Manley, 1987).*

Field cruising assessments, (1), provide indices of tree size and defect, from which current estimates of wood supply can be obtained for a stand or stands. Stand prediction, (2), allows modelling to be conducted for either actual or notional stands from age 0 or later up to final harvest. From either mode of entry, estimates of potential wood supply aggregations by log grade, (3), can be derived.

Economic analysis, (4), can then be conducted, with or without consideration of processing, by single time periods. The estate models, (5), output multiple time period strategies for planting, silvicultural tending, harvesting and transporting logs to processing plants that have set demands. Processing options, (6), can only be analysed in single time periods. A more detailed outline of some of the constituent components of the stand prediction model (STANDMOD) is shown in Figure 2.2.

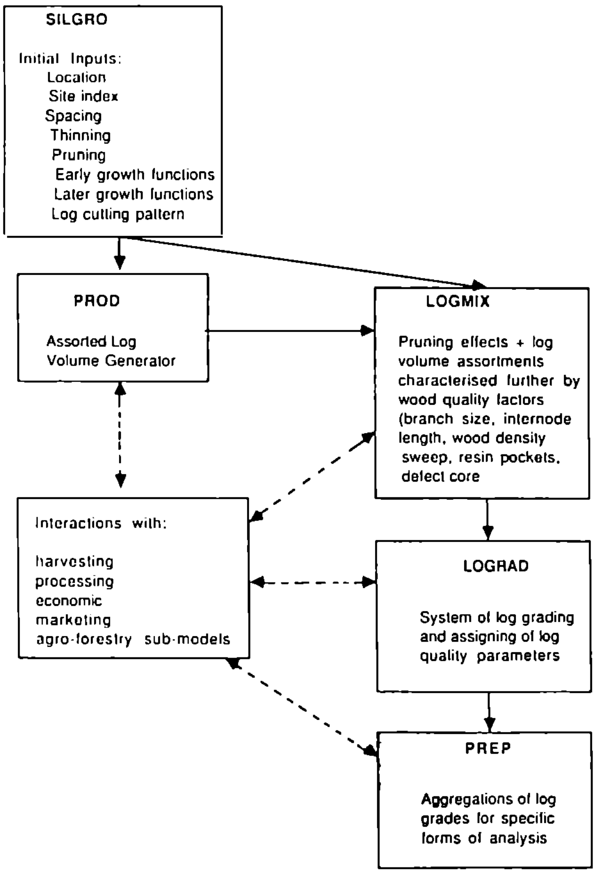


Figure 2.2 *Overview of STANDMOD, a model for predicting stand out-turn (adapted from Whiteside et al., 1987).*

SILGRO simulates growth of radiata pine to maturity and outputs an appropriate yield table together with internal quality of pruned logs. PROD takes SILGRO output and generates the quantities of various log assortments by size classes. LOGMIX adds quality factors to PROD output so that stand tables of assorted logs and their associated inherent qualities can be derived. LOGRAD classifies the estimated out-turn by standard log grades and PREP simply rearranges these into the classification needed for a particular purpose in hand.

Independent tests of the predictive capability of STANDMOD have been shown to produce reasonably satisfactory forecasts of stand out-turn, but these examples were able to be chosen because of the detailed historical knowledge about those crops that was available, and that sort of knowledge is not routinely obtained by managers, and not easy to apply even if it were available. Herein lies the problem of accurate implementation of such tools. Lesser knowledge of stand characteristics and lesser attention to control aspects that presently characterise reality may well negate the claims made by Williams (1988) that foresters can safely use these modelling procedures for:

> *"evaluation of alternative management options, land purchases, log sales, scheduling of operations to optimise profitability, and . . . facilitat[ing] medium to long term planning".*

The main reason for such concern arises from the likely ways in which the modelling capability can be routinely utilised, which aspect is discussed later. There are also, however, dangers within the construct of the model itself. For example, the growth modelling from time of planting to time of harvest is not path-invariant; there is one model for early growth and another for later growth, the final yield forecast from which depends not only on an appropriate choice for each of the two functions but also on the choice of year to switch from one to the other. Another example of likely imprecision lies in the large number of interacting predictive functions; the statistical errors arising from combining them all and moving through time become enormous. There is, moreover, often a lack of balance throughout the system in that some equations such as those for predicting branch size, defect core diameters and sweep are based on data which display widely dispersed residual error patterns, which, when combined with regional stand growth and yield models, are hardly likely to permit sensitive enough analysis of 'optimum stocking' far less 'optimum pruning schedules' stand by stand. This lack of balance is also evident in the single time period applicability of most of the sub-models against the multiple time period capability of IFS & FOLPI, the forest estate model options. As a research tool applied to carefully controlled research investigations, STANDMOD is excellent, but it does have major limitations in the hands of managers of large-scale operations.

Manley (1987) has certainly made it plain that the whole modelling tool *"is not a decision-making system but rather a decision-support system"*. Nevertheless, other proponents, in selling their research, have not always heeded this warning and have sometimes advocated that this and that management practice is 'totally wrong'. Such assertions could well rebound on the researchers because of the inappropriateness of the model mechanisms. Consider how the planning capabilities are used in practice.

A manager, in conducting a review of appropriate silvicultural regimes to practise using SILGRO will be asked to input site index, initial stocking, final stocking, early basal area growth functions, height/age and volume/age relationships, as well as nominated thinning and pruning instructions. He will also be asked to check the reasonableness of supplied functions such as mean branch index by log height. In some, if not the majority, of situations much of this information will be unavailable to the manager, and so guesses are made. At the same time, the chosen specific combination of all the input variables is unlikely to be totally representative, as at least one or two can be expected to vary considerably over even a small population. Even if the assumed conditions could be made truly representative through very intensive efforts to strive for complete uniformity in a crop, the evidence is that such an attainment is never actually achieved in practice.

When silvicultural operations are being scheduled, there is usually genuine effort to target them on average, but it is not feasible to schedule on a large scale without having some parts of the crop treated too late and others too early. For some prescriptions, there may well be a difficulty in having an acceptable number of individuals available for selection, at least in the required distribution on the ground. Consider, for example, the evidence from a thinning trial in a Central North Island plantation, in which very careful selection of trees in each of four replicates of the following stockings was made in a uniform stand. Despite the care taken, there was an apparent removal of some of the more vigorous stems to regulate spacing at age 8 years, when the trial was established, as shown by the average diameter of the largest 100 trees per hectare. By age 22 years, the mean top height statistics showed a trend clearly associated with the negative selection intensities for lower stockings (Table 2.2):

Table 2.2

	Stocking class ha^{-1}						
	200	300	400	500	600	700	1500
d_{100} (mm) at age 8	121	117	128	120	127	135	165
h_{100} (m) at age 22	32.5	33.2	33.7	33.0	33.8	33.8	35.0

Routine management is likely to show even more coarse implementation: undergraduate student exercises in various parts of New Zealand, for example, have shown that prescriptions aiming to reduce stockings to 225-240 stems per hectare may be 15 to 20 per cent below those targets, which will further contribute to reduced yields over and above the size loss effects of negative size selection. There is a clear need to reject stands that are too variable for intensive silviculture.

Operations in New Zealand plantations are subject to regular quality control checks but the information, after being applied to the one current operation, is rarely used to indicate the advisability of pursuing one of several optional subsequent actions. Management information systems, moreover, are not utilised to any degree to characterise crop variations and thus allow appropriate choices to be made. Routine inventories too are far from detailed enough: for example, a large firm in the Central North Island collects information to decide whether or not crops should be thinned (generally down to one fixed stocking): the stand statistics assessed are stems ha^{-1}, basal area ha^{-1} and mean top height. Nothing is collected in the way of data on the size class distribution of pruned or defective stems, nor of their arrangement on the ground. It is not possible, therefore, to assess carefully whether or not a stand should be thinned, what the implications are of thinning to different stockings and with different selection criteria, nor, consequently, will the final harvest yield be able to be forecast from both residual basal area and stocking per hectare. Stocking is usually the variable specified, and so, since there is no means of relating it to an inventoried basal area, far less to dbhob distribution, there has to be an assumption built into the growth and yield model as to what the corresponding basal area ha^{-1} figure is. There is, moreover, no calibration of whether or not the stand is on the assumed course in terms of branch index, internode length, sweep, resin pockets, etc., far less stem defects, even though STANDMOD allows the default assumptions to be altered.

In other words, the research tool is not geared to easy routine management implementation. Research planning can be effectively done, but there is no managerial feedback system in place to calibrate progress and no reviewing of how much more or less to produce of each log grade. There is now a move, however, for managers to conduct cruising inventories in mid-rotation, but that is a little late if one of the main planning objectives is to choose the best mix of early silvicultural strategies. There are examples, admittedly at a much lower level of internal log defect and processing sophistication, where that feedback mechanism is operated and the opportunity is given to plantation managers to change directions to suit medium term wood supply needs. Accounts are given in Whyte (1979; 1983; 1987); briefly, the yield forecasts are derived from continuous routine inventories which not only calibrate the progress of crop development and drive the yield forecasts, but allow the manager to monitor the reliability of various predictive functions provided by independent research. That is, there was a deliberate attempt to allow and encourage the manager to control the crop management system, as well as plan for the future. It is also possible to build in a better co-ordination of forest and stand management evaluation either with whole sector models (e.g. Whyte and Baird, 1983; Baird and Whyte, 1987) or with multi-stage iterative modelling (as outlined by de Kluyver *et al.*, 1980). What appears to be 'best' for a single stand may not be 'best' for various stand aggregations making up more than one forest, and so properly coherent levels of modelling need to be fully integrated.

There is, of course, not just one way, but several viable planning tool options. Nevertheless, what should have become clear is that researchers in designing their planning models ought to think more of how managers are likely to be able to utilise them effectively, spell out what crucial data to collect, store and retrieve, when to review decision processes, how to react to changing circumstances and how to maintain a good managerial balance between control and planning of forest operations.

Conclusions

Planning of plantation forestry operations in New Zealand has been evolving steadily since the 1920s using a systems approach from the outset. There has always been a conscious aim to address the options for utilisation of assorted products in any plantation planning. With the passage of time, more and more of the many interactions in plantation systems have been modelled in greater and greater detail at the stand level, through harnessing the capabilities of a range of computer systems. Recent modelling has become more transparent, but there are still major uncertainties at all planning levels, too much reliance on default indices and not enough direct co-ordination among short-, medium- and long-term planning mechanisms. There has not been a comparable research effort to improve the means of controlling operations: quality control assessment is carried out regularly, but the objectives for that are restricted too much to aspects of paying contract labour for each operation and not enough with using the information to (1) identify prescriptions that match supply with demand, (2) choose more discerningly where and with what intensity to conduct certain operations, particularly thinning and pruning, and (3) use MIS properly and cost-effectively.

A framework which allows managers to evaluate, implement, monitor and review the conduct of various plantation forest operations, is required. Such a framework should contain a recognition of stages of development that require decisions and how to establish and utilise comprehensive database systems effectively. Researchers need to specify feedback mechanisms that managers ought to apply to their individual circumstances, document the data implications and provide them as part and parcel of their research effort.

REFERENCES

BAIRD, F.T. and WHYTE, A.G.D. (1987). *Flexibility in harvesting.* New Zealand Forestry Council Working Paper No. 10. (27 pp.).

BUNN, E.H. (1979). The consequences of the past planting programme. *New Zealand Journal of Forestry* **24** (2), 152-158.

BUNN, E.H. (1981). The nature of the resource. *New Zealand Journal of Forestry* **26** (2), 162-199.

BURROWS, G.D., LEVACK, H.H. and NOVIS, J.B. (1987). A national forest planning model for New Zealand. In *Proceedings of the 56th ANZAAS Congress,* Palmerston North, New Zealand, January 1987, 231-236, eds. M.M. Roche and R. Hodder.

COLLINS, J., McGREGOR, F. and NOVIS, J. (1988). *A national exotic forest description system.* New Zealand Forestry Council Working Paper 3.3. (92 pp.).

DE KLUYVER, L.A., DAELLENBACH, H.G. and WHYTE, A.G.D. (1980). A two-stage, multiple objective mathematical programming approach to optimal thinning and harvesting. *Forest Science* **26** (4), 674-686.

ELLIOTT, D.A. (compiler). (1979). *Mensuration and management planning of exotic forest plantations.* F.R.I. Symposium No. 20, Rotorua; 2-13 October 1978. (530 pp.).

ELLIS, L.M. (1920). *Forest conditions in New Zealand and the proposal for a New Zealand forest policy.* Director of Forestry's Report, Wellington, New Zealand. (48 pp.).

ENTRICAN, A.R. (1950). Quality versus quantity in New Zealand forestry and forest industry. *New Zealand Journal of Forestry* **6** (2), 100-111.

KININMONTH, J.A. (compiler). (1987). *Proceedings of the Conversion Planning Conference, Rotorua, 8-11 April 1986.* F.R.I. Bulletin No. 128. (382 pp.).

KIRKLAND, A.D. (1982). *Financial management in the New Zealand Forest Service.* Financial Management Seminar, Wellington, New Zealand, Sept. 1982.

KIRKLAND, A.D. (1984). *The pricing and allocation of State wood - a discussion paper.* New Zealand Forestry Council Working Paper No. 2. (15 pp.).

KIRKLAND, A.D. (1985). Data needs and recent developments in resource management and planning. In *Proceedings of the 10th Commonwealth Forestry Conference,* Session C, Victoria, B.C., Canada. (16 pp.).

MANLEY, B.R. (1987). Model system of the Conversion Planning Project Team. In, Kininmonth, J.A. (compiler). F.R.I. Bulletin No. 128, 12-26.

MINISTRY OF FORESTRY (1988). *Statistics in New Zealand forests and forest industry to 1987.* Ministry of Forestry, Wellington, New Zealand.

WHITESIDE. I.D. and SUTTON, W.R.J. (1983). A silvicultural stand model: implications for radiata pine management. *New Zealand Journal of Forestry* **28** (3), 300-313.

WHITESIDE, I.D., McGREGOR, M.J. and MANLEY, B.R. (1987). A prediction of radiata pine log grades. In, Kininmonth, J.A. (compiler). F.R.I. Bulletin No. 128, 55-69.

WHYTE, A.G.D. (1978). Inventory and yield forecasting systems for Caribbean pine in Fiji. In, Elliott, D.A. (compiler). Proceedings of F.R.I. Symposium No. 20, 41-47.

WHYTE, A.G.D. (1983). Development of the Fiji Pine Commission. *New Zealand Journal of Forestry* **28** (3), 412-422.

WHYTE, A.G.D. (1987). A resource planning and management system for pine plantations in Fiji. Paper at 13th IFIP Conference on *System modelling and optimisation,* Tokyo, Japan, 31 August to 4 Sept. 1987. (15 pp.). Proceedings to be published by Springer-Verlag.

WHYTE, A.G.D. and BAIRD, F.T. (1983). Modelling forest industry development. *New Zealand Journal of Forestry* **28** (3), 275-283.

WILLIAMS, F.J.N. (1986). Evaluation with the silvicultural stand model (SILMOD). *New Zealand Institute of Foresters Handbook,* 96-97, ed. H.M. Levack.

WILLIAMS, F.J.N. (1988). The F.R.I. radiata pine modelling system: STAND, PAK, FOLPI. Ministry of Forestry, Forest Research Institute, Rotorua, March, 1988. (19 pp.).

Paper 3

Preliminary Trials of the Forest Management Model, FIRFOR

R.M. Newnham, Petawawa National Forestry Institute, Chalk River, Ontario, K0J 1J0, Canada

Abstract

The results of seven tests of the forest management simulation model, FIRFOR (Newnham, 1988), in the jack pine working circle (31 541 ha) of a forest management unit in northern Ontario, are described. The tests illustrate the long-term (300 years) effects on the annual harvest of different management options. The annual cut may be prescribed by stand age, or may be controlled by volume (with an area check) or area (with a volume check). A proportion of any fire-damaged wood may be salvaged. The model may be used as an aid to the forest manager in developing forest management plans.

Introduction

With the advent of more intensive forest management and greater emphasis on short and long-term planning in Canada, a need has arisen for computerised forest management, or wood supply, models. Such models have to function within the guidelines for forest management laid down by each provincial government. For maximum efficiency, the models should be linked with geographic information systems (GIS), database management systems (DBM), and other forest resource models (wildlife, recreation, etc.) to form an integrated planning system.

There are two broad categories of forest management model: optimisation models and simulation models. Optimisation models are designed to maximise production or profits, or to minimise costs, for a given set of conditions and constraints. They use accepted and well documented mathematical methods (e.g. linear, integer, and dynamic programming). One of the first such models, and one that is still widely used with various modifications, was Timber RAM (Navon, 1971; Johnson *et al.*, 1977; Armstrong *et al.*, 1984). Linear programming was also used by Newnham (1975) to optimise logging plans. Dynamic programming was used by Brodie and Haight (1985) to optimise silvicultural investment for several stand projection systems, and by Tait (1986) to determine optimum financial rotations in coppice stands. To solve real-life problems, these models may require considerable expensive CPU time on a mainframe computer and may also be difficult to modify or adapt to changing conditions.

Simulation models do not provide optimum solutions, although output from several simulation runs may be used as input to an optimising program. Rather, they are designed to answer 'what if. . .' questions: what effect will a 10 per cent increase in mill demand have on long term timber supply or, what happens if fire destroys 25 per cent of the forest management unit in one year? Simulation has been widely used in stand growth modelling for a number of years (Newnham, 1964; Bella, 1971; Arney 1972; 1985; Ek and Monserud, 1974; Hegyi, 1974). The STEMS model (Belcher, 1981; Belcher *et al.*, 1982; Miner and Walters, 1984) is currently one of the most widely used growth models. An example of a forest management simulation model is WOSFOP (Hall, 1977) that is used in New Brunswick (and, with modifications, in Ontario) for forecasting timber supply. This, and similar models, although based on simple principles, can become quite complex as more and more factors are taken into consideration. Van Wagner (1983) used a relatively simple model to demonstrate the long-term effects of fire on timber supply. Reed and Errico (1985) achieved results similar to those of Van Wagner using graphical methods and a matrix method (Reed and Errico, 1987).

The forest management model FIRFOR is a simulation model that has been developed in recent years to aid in long-term planning. It has been described in detail (including a full listing of the Fortran programs) by Newnham (1988). There are a number of options, or rules, for selecting stands for harvesting each year. As with the Ontario version of WOSFOP (with which FIRFOR has many features in common), stands may be cut at a specified rotation age but, among the special features of the model, are the abilities to:

1. control the allowable annual cut (AAC) by area (within specified limits and with a volume check), or by volume with an area check;
2. simulate the irregular occurrence of fire in a realistic way by allocating the area burnt each year from a specified Weibull distribution (that should be based on the local fire history);
3. salvage a specified proportion of the burnt wood if, in any year, the area burnt exceeds a specified percentage of the total area;
4. simulate 'non-compliance' with any of the harvesting rules (in practice, it is usually never possible to follow any computer-generated plan exactly because of lack of access, the need to concentrate operations, etc.).

The object of the study described in this paper was to illustrate some features of the model with a series of tests that were made using data based on the current inventory of the jack pine (*Pinus banksiana* Lamb.) working group on a forest management unit in northern Ontario. These tests were in no way exhaustive: a complete evaluation of the model would require many more tests in which different combinations of options and input parameter values would be examined.

Data

The summary inventory data for the working group, obtained from the Ontario Ministry of Natural Resources, gave the areas and total volumes for each 20-year age class for each site class. Within a 20-year age class, the area assigned to each one-year class was obtained by dividing the area by the number of years in the class. A histogram, showing the distribution by site class and 10-year age class, is given in Figure 3.1. The area of the working circle was 31 541 ha and the total merchantable volume was 3 860 379 m^3.

For the purposes of the model, Plonski's jack pine yield tables for gross merchantable volume (Plonski, 1974) were 'formulated'. In doing so, the yield curves were projected past 100 years (the upper limit of the published tables) and modified so that, after about 100 years, the yield declined noticeably (Figure 3.2) as the stands were assumed to break up due to mortality.

Fire, that could be considered to burn either a constant area each year or an area drawn at random from a specified distribution, was allocated equally to each age class in the present study. However, FIRFOR does have the option of allocating fire among age classes in proportion to the relative risk where these risks are known (or can be estimated).

Method

FIRFOR is an interactive model. The user sits at a terminal, selects the options he or she wishes to test from a series of menus, and responds to questions and requests for data. Newnham (1988) gives a full description of the input requirements and an example of the screen menus. Figure 3.3 shows a screen menu for the section on harvesting. For the purposes of the present limited series of tests, the following factors were kept constant for all of the tests, except where noted:

1. the initial forest was that provided by the inventory data (Figure 3.1);
2. the gross merchantable volume yield curves for jack pine were used (no allowance was made for the presence of other species);
3. fire was considered to burn 0.1 per cent of the area each year (except Test 6 where the area burnt was drawn from a Weibull distribution with an average of 0.095 per cent);
4. when the area burnt in any year exceeded one per cent of the total area, 15 per cent of the volume of burnt wood could be salvaged over the following 3 years;
5. the compliance factor was 100 per cent (except Test 7 where it was 10 per cent);
6. no stands younger than 40 years were harvested (see Figure 3.2);
7. no stands with a volume of less than 90 m^3 ha^{-1} were harvested (see Figure 3.2);
8. the tests were each run for a period of 300 years.

Results

The model was used to provide answers to seven hypothetical 'what if. . .' questions. The options selected, and the values of the input parameters for these tests, are shown in Table 3.1, together with average areas and volumes harvested over a period of 300 years and the final inventories.

Test 1

"What if we fell all stands as they reach rotation age and gradually eliminate overmature stands during the first 20-30 years?"

For this test, management option 3 was selected. In year 1, all 'overmature' stands (i.e. site class 1 stands greater than 90 years, site class 2 stands greater than 95 years, and site class 3 stands greater than 100 years) were felled. In addition, stands reaching rotation age were also felled. The rotation was selected at the age at which the mean annual increment (MAI) is approximately maximum for each site class (ages 50, 55, and 70 for site classes 1, 2, and 3 respectively). In the second and succeeding years, stands were harvested either as they reached rotation age or the upper age limit. Thus, after 30-40 years all the 'overmature' stands had been eliminated and all stands were harvested as they reached their respective rotation ages.

As there was no attempt to control the annual harvest, there was considerable variation in both the area (219-1731 ha) and volume (33 307-34[illegible]11 m^3) cut each year (Figure 3.4). The area burnt each year was constant (0.1 per cent) so that, after the 'overmature' wood had been eliminated, the harvesting pattern 'cycled'. The reason that the harvesting patterns illustrated in Figure 3.4 vary slightly is because the cycles for each site class had a different period, equal to the respective rotation age. The inventory fell rapidly over the first 30-40 years as the 'overmature' stands were harvested and then fluctuated about a fairly constant level (Figure 3.5). The average area harvested each year was 577 ha and the average merchantable volume 96 208 m^3 (Table 3.1). However, the wild fluctuations in annual harvest would be completely unacceptable in practice so that some form of control is required to stabilise the timber supply.

Test 2

"What if we prescribe an area to be harvested each year and harvest the stands with the highest volume first?"

For this test, management option 4, with area control of AAC, was chosen. Stands were selected for harvesting in order of declining volume per hectare. In effect, stands were 'queued' in order of declining volume and the model began harvesting at the top and continued down the queue until the specified area, in this case 600 ha, was reached. At this point, the model checked to see whether the accumulated volume fell within the limits (90 000-110 000 m^3) that had been set by the user. If the volume was outside these limits, the area to be harvested was adjusted in an attempt to bring the volume harvested up to the minimum or down to the maximum. However, if either the lower (500 ha) or upper (700 ha) area limit was reached, no further adjustment was made and the volume harvested would fall outside the limits. The only time that the area limits would not be satisfied would be if there were insufficient stands available for harvesting that were greater than the minimum volume (90 m^3 ha^{-1}) and the minimum age (40 years).

The effects of these constraints on the annual harvest is demonstrated in Figure 3.6. For the first 20 years, the minimum area was harvested as the highest volume stands were cleared. During this period, the upper limit on volume was exceeded. For the next 20 years, the maximum allowable volume was harvested as the area increased to the prescribed 600 ha. That level was then maintained for the next 20-25 years while the volume cut fluctuated within the prescribed limits. After about 70 years, the volume harvested remained at, or very close to, the lower limit while the area harvested often exceeded 600 ha in order to maintain volume at the minimum. The inventory of the residual forest fell rapidly during the first 100 years and then slowly increased from about 1.35 to about 1.65 million m^3 at the end of the test (Figure 3.7). The block of stands in the 145-year age class at year 100 (Figure 3.8) may at first appear incongruous. It can be explained by the fact that the stands in the two site classes represented in the block were never sufficiently high in the 'queue' to be selected for harvesting and eventually, with age, would have fallen below the minimum volume limit.

The average area harvested (607 ha) was only a little above the specified amount and the average volume was 94 605 m^3 yr^{-1} (Table 3.1).

Test 3

"What if, instead of prescribing an area to be cut, we prescribe a volume to be harvested each year?"

This test was similar to the previous test except that the AAC was controlled by volume, with an area check, rather than by area, with a volume check. The area and volume limits were the same but the prescribed annual cut was set at 95 000 m^3 rather than 600 ha as in Test 2. As a result of this change, the annual harvest was reduced during the first 20 years to the maximum volume permitted (Figure 3.9B) and the area cut was less than the 500 ha lower limit (Figure 3.9A). For the next 30 years, the annual cut was maintained at 500 ha while the volume harvested drops to the prescribed 95 000 m^3. A comparison of Figures 3.9B and 3.6A shows that, to this point, the volume trend for Test 3 is the mirror image of the area trend for Test 2. Between years 50 and 120, the annual harvest was maintained at the prescribed 95 000 m^3 while the area cut increased to the upper limit. After 120, there was a further decline in the volume harvested until year 180, after which the annual harvest often failed to reach even the lower limit while the area cut exceeded the upper limit in an attempt to satisfy the minimum volume requirement. This shortfall was caused by a lack of stands greater than the minimum permissible age (40 years) for felling (Figure 3.10B). The shortage was also reflected in a considerably lower residual inventory (approximately 1 million m^3 - Table 3.1). Note also the approximately 1800 ha of forest in the >140-year age class at 100 years (Figure 3.10A). Because selection of stands for harvesting was in order of declining volume per hectare, these stands were missed and the volume they contained was wasted by natural mortality.

The average area cut each year was 666 ha while the average volume was 92 234 m^3 (Table 3.1).

Test 4

"What if we prescribe an area to be harvested each year but, instead of harvesting first the stands with the greatest volume, we harvest the stands that are declining the fastest or growing the slowest?"

The input parameters for this test were the same as those for Test 2, except that the stands were selected in order of increasing growth rate. The 'queue' of stands for harvesting then had the stands with the greatest negative growth, if any, at the top of the queue (instead of the stands with the greatest volume per hectare), and the stands with the greatest (positive) growth at the bottom. The prescribed annual cut was again 600 ha and the limits remained unaltered.

The pattern of annual harvesting for both area and volume (Figure 3.11) was similar to that for Test 2, except that there appeared to be more fluctuation from year to year, for which it is difficult to find a logical explanation. For one year (approximately 155) the minimum volume was not attained. The inventory in the residual forest stabilised after 100 years but at a level some 50 000 m^3 lower than in Test 2. However, the average annual harvest at 96 105 m^3 was 1500 m^3 greater. After 100 years, the stands were concentrated in the younger age classes (<60 years - Figure 3.12), thus avoiding the losses due to natural mortality found in the two previous tests (see Figures 3.8 and 3.10).

Test 5

"What if we harvest a prescribed volume and harvest the slowest growing stands first?"

This test was identical to Test 3 except that, as in the previous test, selection of stands for harvesting was in order of increasing growth rate. When comparing the harvesting patterns of these tests (Figures 3.9 and 3.13), two things are apparent: there was, as in Test 4, considerable fluctuation in the annual areas cut, and, for the most part, both the area and volume cut each year stayed within the prescribed limits. For a large part of the test, there was a uniform harvest of the prescribed 95 000 m^3 each year but, towards the end, the harvest fluctuated between that amount and the lower limit of 90 000 m^3. This trend suggested that, if the test had continued further, there might have been a problem in maintaining even the minimum level. Figure 3.14 adds credence to this possibility as the inventory of the residual forest had not stabilised by the end of the test. It also appears that, by the end of the test (Figure 3.13B), nearly all the stands were either less than the minimum age or minimum volume per hectare for harvesting (see Figure 3.2), another indication that harvestable wood was in short supply.

Because of these suspicions, Test 5 was continued for a further 300 years and it was found that the minimum level of harvest could only be maintained, or occasionally exceeded, for the first 70 years. Thereafter, the minimum level of harvest frequently fell five or six thousand m^3 below the lower limit. The average annual harvest fell from 96 585 m^3 during the first 300 years to 87 258 m^3, while the average area increased from 585 to 752 ha.

Test 6

"What if, instead of assuming a constant area is burnt each year, we assume that a variable area is burnt each year and that the distribution of these areas reflects the fire history in the region?"

In all the tests so far, fire was considered to burn 0.1 per cent of the forest area each year. Although the salvage option was specified in each instance, no wood could be salvaged because the area burnt never exceeded the minimum area (1 per cent) considered necessary for salvaging to be a feasible operation. Test 6, however, considers fire not to be uniformly distributed over time but to be drawn at random from a Weibull distribution (Bailey and Dell, 1973):

$$F_X(x) = 1 - e^{-(x/b)^c}$$

where x = the proportion of the total area that is burnt in any year, and b and c are parameters ($b > 0$, $c > 0$). For this test, b was set equal to 0.0002 and c set equal to 0.35, to give a distribution with extreme positive skewness (Figure 3.15) and a mean of 0.095 per cent. In over 80 per cent of the years, the area burnt was 0.1 per cent or less. In a distribution of 1000 observations generated at random, the largest value was 4.94 per cent. The remaining input parameters were the same as those for Test 5.

The results of this test (Figure 3.16) were similar to those obtained for the first 300 years of Test 5. The solid 'spikes' in Figure 3.16 represent the 3 years following a fire in which salvaging took place. The 'worst' fire period was years 61 to 65, when nearly 5.5 per cent of the forest area was burnt, but even this was not sufficiently serious to affect later harvests. Previous FIRFOR tests (Newnham, 1988), with a Weibull distribution having a mean of 0.477 per cent, produced years in which as much as 25 per cent of the area could be burnt. This was found, of course, to seriously affect subsequent harvest levels.

Test 7

"What if, instead of assuming that the manager complies exactly with what the computer prescribes, we assume that, because of operational constraints (not considered in the model), he is unable to comply fully with these prescriptions?"

In this test, the effect of 'non-compliance' with the harvesting rules was simulated using a compliance factor of 10 per cent. What this means is that when the stands have been 'queued' for harvesting, only 10 per cent of each stand, or stand type, is actually harvested that year. To satisfy the annual cut requirements, the model will thus have to go further down the queue. A compliance factor of 10 per cent may, at first, appear very low. However, assuming only minor changes in the order of the stands in the queue, of the 90 per cent of each stand that was 'missed' in the first year, 10 per cent will be harvested in the second year, and so on. Thus, after 5 years, 41 per cent of the stands originally identified for harvesting will have been actually harvested. This simulation gives the manager a choice of stands that can be harvested each year, so that he or she can concentrate the annual cut in particular areas or avoid inaccessible areas. However, it is realised that the manager is unlikely to take exactly 10 per cent of each stand type. Thus, the results can only give an indication of the effects of such 'non-compliance' on the harvesting pattern.

Apart from the 10 per cent compliance factor, Test 7 used the same input parameters as Test 5. There are some interesting differences in the harvesting patterns that were produced. First, the noticeable year-to-year fluctuations have been largely smoothed out (compare Figure 3.17 with Figure 3.13). Second, the annual cut dropped to the lower limit of 90 000 m^3 at about 150 years instead of about 260 years. However, the forest inventory appeared to have stabilised at about the same time and, although not tested further, could probably have maintained that level of harvest in the future. Lastly, the age-class distribution covered a broader range (Figure 3.18). The average area harvested (587 ha) was about the same but the average volume (93 715 m^3) was nearly 3000 m^3 lower (Table 3.1).

Conclusions

The tests described here give some idea of the types of question to which FIRFOR can provide answers. Not all input variables have been studied and those that have been, have only been tested over a narrow range of values and conditions. For the jack pine working circle used in this study, many more tests would have to be undertaken before the optimal management strategy, i.e. the combination of management options and input values that maximise long-term sustainable yield, could be selected with any degree of confidence.

The model in its present form is simple, easy to understand, and well suited to rapid policy analysis. It is valuable because it allows several management options to be compared, with all other factors being held constant. However, modifications would be required in order to simulate a more realistic and complex forest management situation. The forest that is used in the tests can contain only one forest type in up to three site classes. The growth function that is used to drive the model is derived from empirical yield tables for unmanaged stands. It is assumed that stands that are harvested or which die from natural mortality, regenerate immediately to the same species. We know, of course, that this often is not the case. Silvicultural treatments, such as planting with genetically improved growing stock, thinning, or fertilisation, are not included in the model. This is largely because of a lack of supportive data. Neither are the effects of attacks by insects and disease considered.

As the demand for these improvements becomes apparent and as more information becomes available, FIRFOR will be modified to accommodate these needs. Ultimately, FIRFOR (or a similar model) will be an important component of the integrated forest management planning system that is being developed at the Petawawa National Forestry Institute.

REFERENCES

ARMSTRONG, G.W., BECK Jr., J.A. and PHILLIPS, B.L. (1984). Relaxing even-flow constraints to avoid infeasibility with the Timber Resource Allocation Method (RAM). *Canadian Journal of Forest Research* **14**, 860-863.

ARNEY, J.D. (1972). *Computer simulation of Douglas-fir tree and stand growth.* Ph.D. thesis, School of Forestry, Oregon State University, Corvallis, Oregon, USA.

ARNEY, J.D. (1985). A modelling strategy for the growth projection of managed stands. *Canadian Journal of Forest Research* **15**, 511-518.

BAILEY, R.L. and DELL, T.R. (1973). Quantifying diameter distributions with the Weibull function. *Forest Science* **19**, 97-103.

BELCHER, D.W. (1981). *The user's guide to STEMS (Stand and Tree Evaluation and Modelling System).* USDA Forest Service, North Central Forest Experiment Station, General Technical Report NC-70.

BELCHER, D.W., HOLDAWAY, M.R. and BRAND, G.J. (1982). *A description of STEMS - the stand and tree evaluation and modelling system.* USDA Forest Service, North Central Forest Experiment Station, General Technical Report NC-79.

BELLA, I.E. (1971). A new competition model for individual trees. *Forest Science* **17**, 364-372.

BRODIE, J.D. and HAIGHT, R.G. (1985). Optimisation of silvicultural investment for several types of stand projection systems. *Canadian Journal of Forest Research* **15**, 188-191.

EK, A.R. and MONSERUD, R.A. (1974). Trials with program FOREST: growth and reproduction simulation of mixed species forest stands. In *Growth models for tree and stand simulation*, ed. J. Fries, 56-73. Department of Forestry and Yield Research, Royal College of Forestry, Stockholm, Research Note 30.

HALL, T.H. (1977). *Stand response following harvest.* M.Sc.F. thesis, Faculty of Forestry, University of New Brunswick, Fredericton, New Brunswick, Canada.

HEGYI, F. (1974). A simulation model for managing jack pine stands. In *Growth models for tree and stand simulation*, ed. J. Fries, 74-90. Department of Forestry and Yield Research, Royal College of Forestry, Stockholm, Research Note 30.

JOHNSON, K.N., BELL, E.F. and BURKHARDT Jr., A.F. (1977). Rotation flexibility and allowable cut. *Journal of Forestry* **75**, 699-700.

MINER, C.L. and WALTERS, N.R. (1984). *STEMS: a nontechnical description for foresters.* USDA Forest Service, North Central Forest Experiment Station, Research Report NC-252.

NAVON, D.I. (1971). *Timber RAM ... a long range planning method for commercial timber lands under multiple-use management.* USDA Forest Service, Pacific Forest and Range Experiment Station, Research Paper PSW-70.

NEWNHAM, R.M. (1964). *The development of a stand model for Douglas fir.* Ph.D. thesis, Faculty of Forestry, University of British Columbia, Vancouver, B.C., Canada.

NEWNHAM, R.M. (1975). *LOGPLAN - a model for planning logging operations.* Canadian Department of Environment, Forest Management Institute, Information Report FMR-X-77.

NEWNHAM, R.M. (1988). *FIRFOR - a simple forest management model.* Canadian Forest Service, Petawawa National Forestry Institute, Information Report PI-X-72.

PLONSKI, W.L. (1974). *Normal yield tables (metric) for major forest species of Ontario.* Ontario Ministry of Natural Resources.

REED, W.J. and ERRICO, D. (1985). Assessing the long-run yield of a forest stand subject to the risk of fire. *Canadian Journal of Forest Research* **15**, 680-687.

REED, W.J. and ERRICO, D. (1987). Techniques for assessing the effects of pest hazards on long-run timber supply. *Canadian Journal of Forest Research* **17**, 1455-1465.

TAIT, D.E. (1986). A dynamic programming solution of financial rotation ages for coppicing tree species. *Canadian Journal of Forest Research* **16**, 799-801.

VAN WAGNER, C.E. (1983). Simulating the effect of forest fire on long-term annual timber supply. *Canadian Journal of Forest Research* **13**, 451-457.

Table 3.1 Summary of selected options, values of input parameters, and results for Tests 1–7.

Test number	Management option	Area harvested (ha/year)				Merchantable volume harvested ('000 m/year)				Final inventory (million m³)
		Prescribed	Lower limit	Upper limit	Actual (mean)	Prescribed	Lower limit	Upper limit	Actual (mean)	
1	3	–	–	–	577	–	–	–	96.2	1.878
2	4Av	600	500	700	607	–	90.0	110.0	94.6	1.712
3	4Vv	–	500	700	666	95.0	90.0	110.0	92.2	1.500
4	5Ag	600	500	700	598	–	90.0	110.0	96.1	1.817
5	5Vg	–	500	700	585	95.0	90.0	110.0	96.6	1.935
6	5Vg	–	500	700	582	95.0	90.0	110.0	96.6	1.963
7	5Vg	–	500	700	587	95.0	90.0	110.0	93.7	1.943

Notes:

A – annual harvest is controlled by area (with a volume check).
V – annual harvest is controlled by volume (with an area check).
g – stands are selected for harvesting in order of increasing annual growth.
v – stands are selected for harvesting in order of decreasing volume per year.

Test 1: stands are selected for harvesting based on age with no control of the annual harvest.
Test 6: annual area burnt is drawn at random from a specified Weibull distribution.
Test 7: compliance factor is 10 per cent.

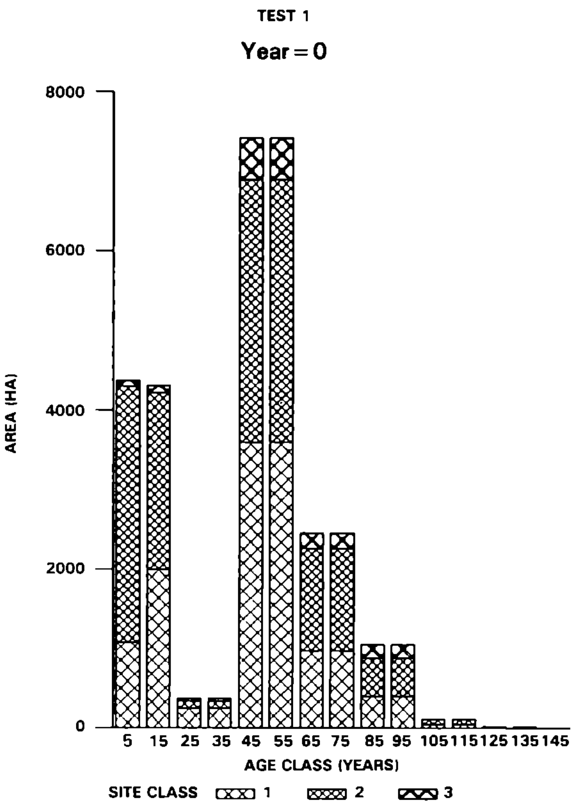


Figure 3.1 *Age-class distribution, by area, for the initial forest.*

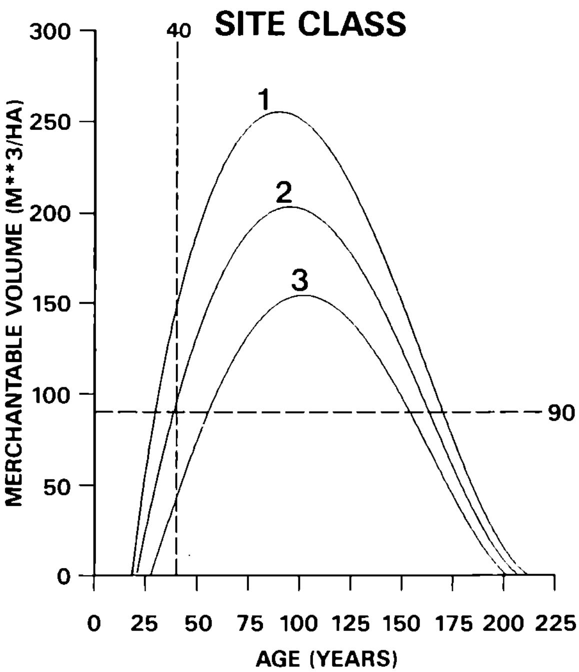


Figure 3.2 *Merchantable volume yield curves for jack pine (after Plonski, 1974).*

FOREST MANAGEMENT OPTIONS:

1. No management.
2. Harvest the 'overmature' stands in each site class as they reach a specified age.
3. Harvest the 'overmature' stands plus other stands as they become mature (at a rotation age specified for each site class).
4. Harvest a specified annual area or volume. Salvageable wood is harvested first followed by stands in order of declining volume per hectare with optional constraints on minimum volume per hectare or minimum age.
5. As for 4 except that stands are selected in order of increasing annual growth.

With any of the options there is the option of salvaging a specified percentage of the annual volume loss due to fire within a specified period (< 5 years) if the area burnt exceeds a specified percentage of the total area.

ENTER your management option (1 - 5):

4

ANNUAL HARVEST:

For management options 4 and 5, the annual harvest may be regulated by:

1. AREA, with constraints on the volume that should be harvested each year (IAV = 1), or
2. VOLUME, with constraints on the area that should be harvested each year (IAV = 2).

The user must enter the prescribed area or volume to be cut each year and the range within which each of these will be allowed to vary. If the harvest is controlled by area, the prescribed area will be cut each year, except when the associated volume cut falls outside the prescribed volume range. When this happens, the area that is cut will be adjusted (within its range) until either the volume cut comes within the prescribed range or an area limit is reached. A similar procedure is used when the harvest is controlled by volume.

ENTER the appropriate value for IAV (1 or 2):

1

ENTER area (ha) to be harvested each year and lower and upper limits (e.g. 1200,800,2000):

600,500,700

ENTER lower and upper limits on volume (m**3) to be harvested each year (e.g. 100000, 125000):

90000,110000

Figure 3.3 *Menu of forest management and harvesting options.*

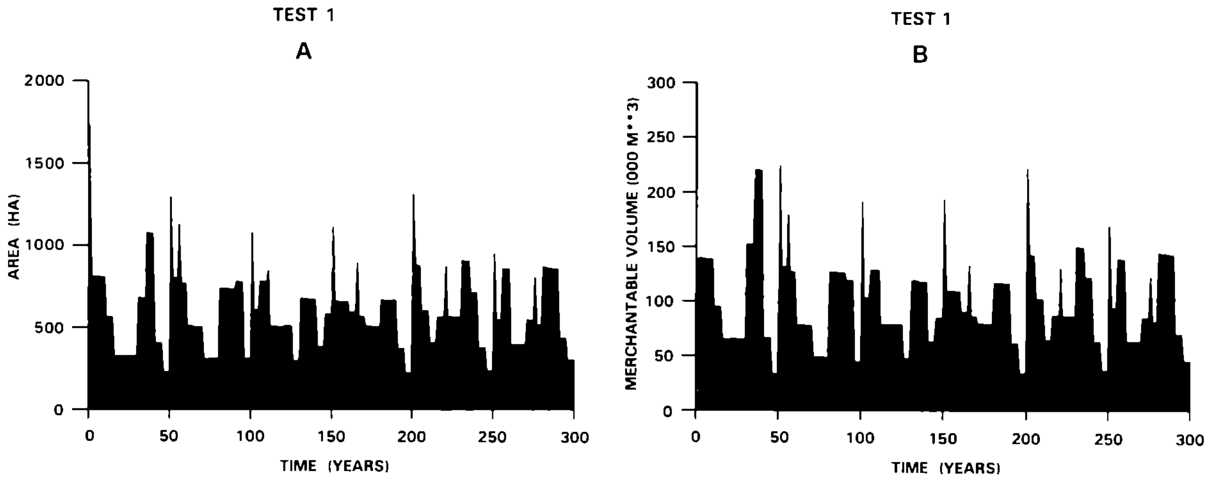


Figure 3.4 Test 1: annual harvest by area (A) and by merchantable volume (B).

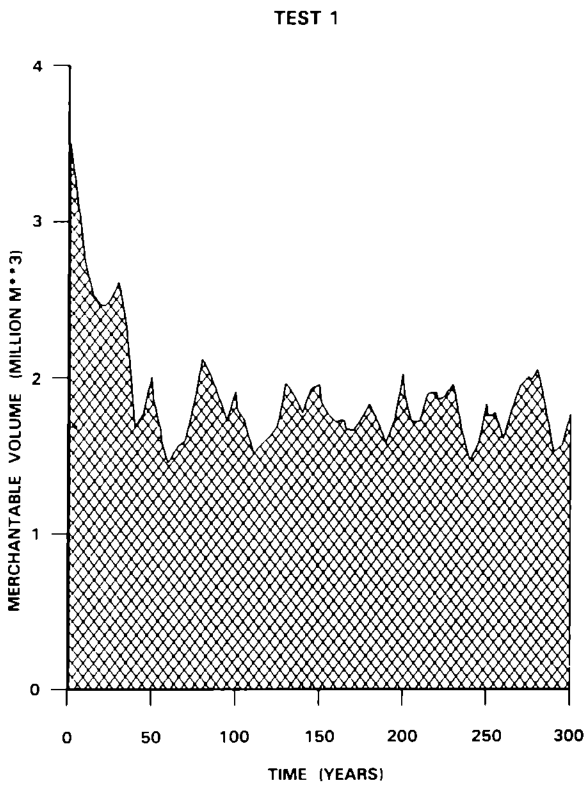


Figure 3.5 Test 1: residual forest inventory.

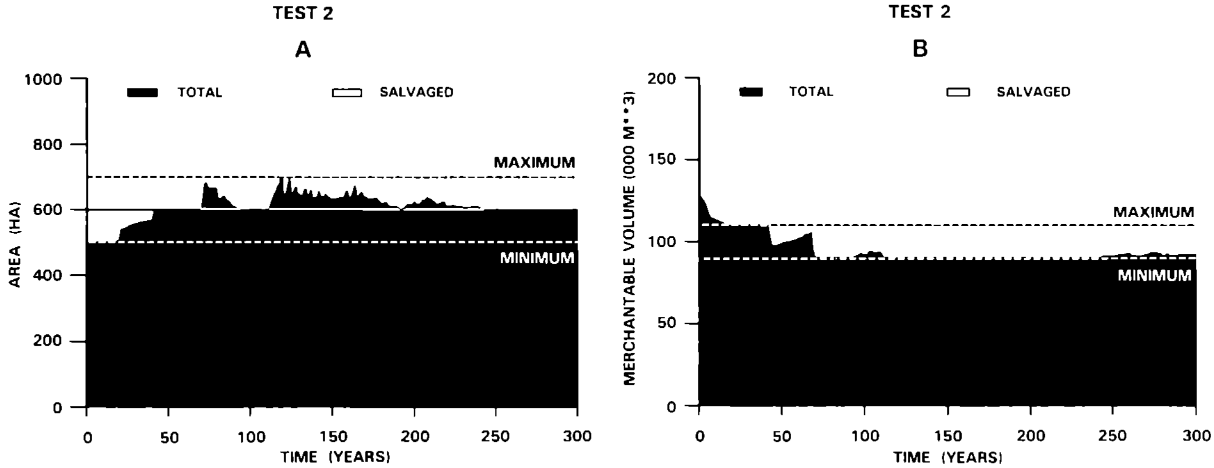


Figure 3.6 Test 2: annual harvest by area (A) and merchantable volume (B).

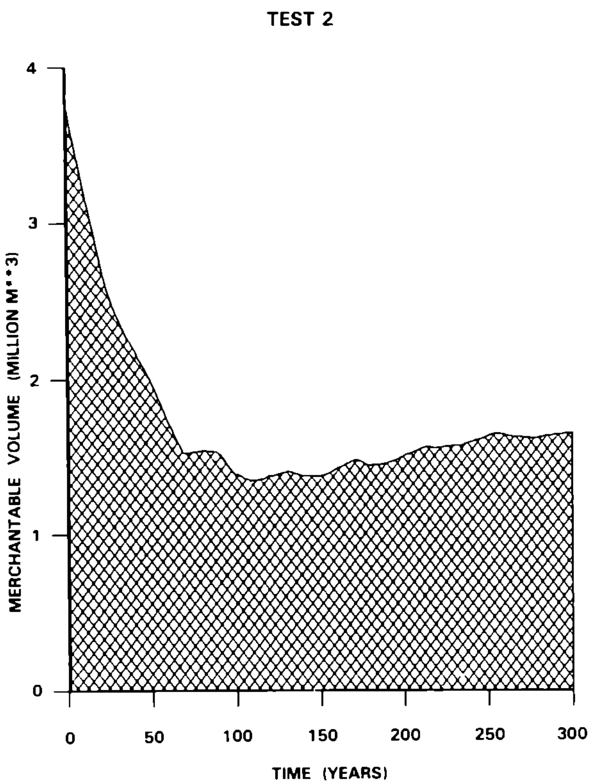


Figure 3.7 Test 2: residual forest inventory.

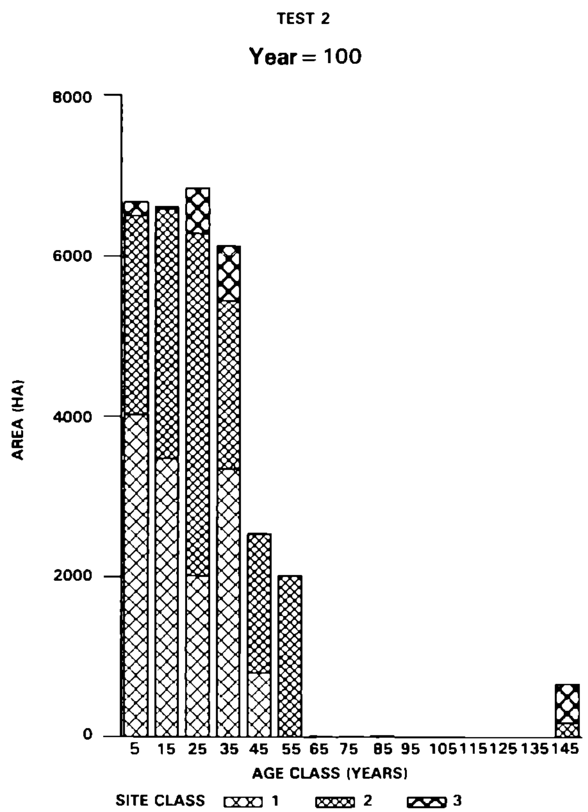


Figure 3.8 Test 2: age-class distribution after 100 years.

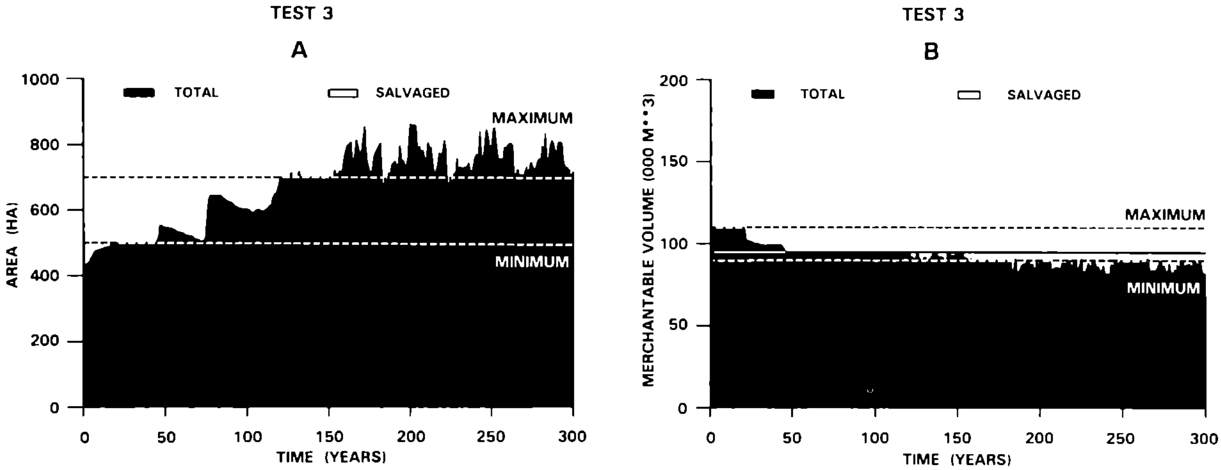


Figure 3.9 *Test 3: annual harvest by area (A) and merchantable volume (B).*

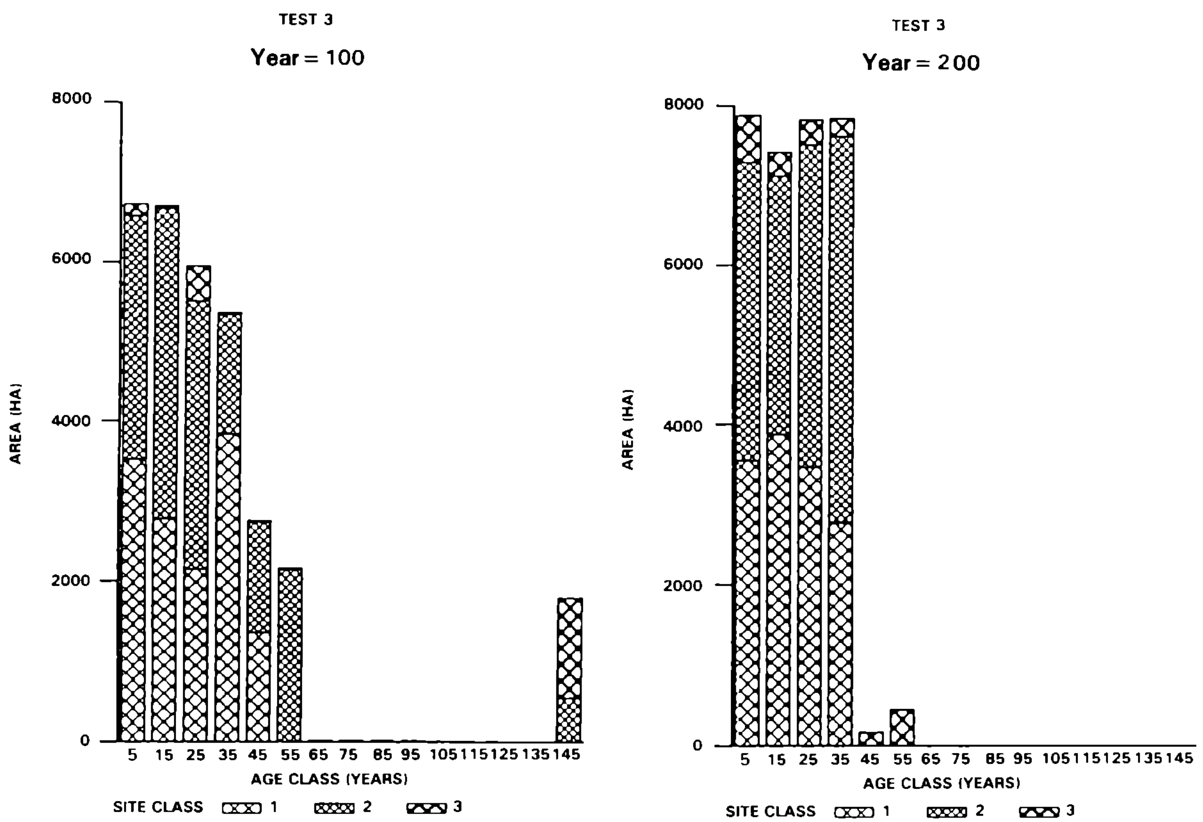


Figure 3.10 *Test 3: age-class distribution after 100 years (A) and after 200 years (B).*

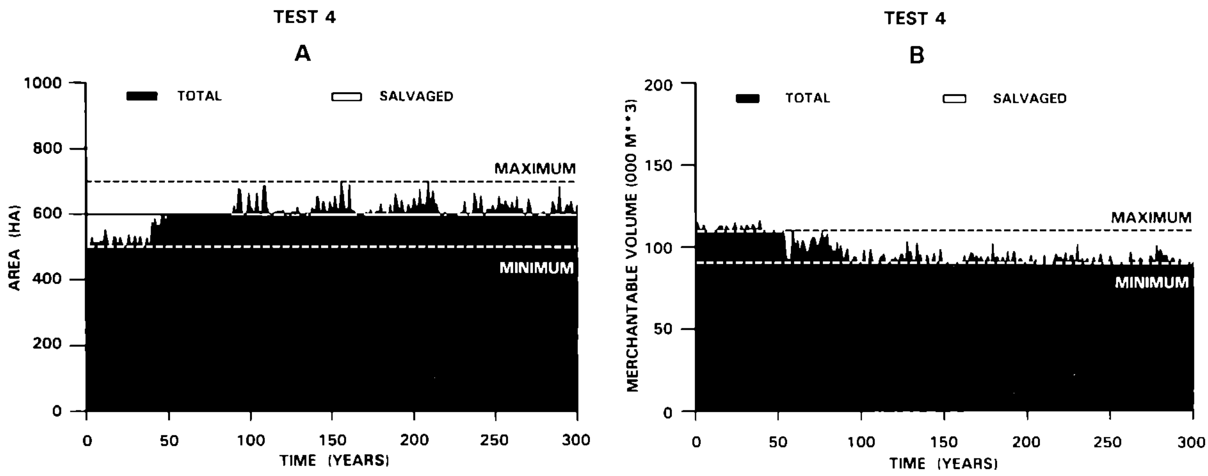


Figure 3.11 *Test 4: annual harvest by area (A) and merchantable volume (B).*

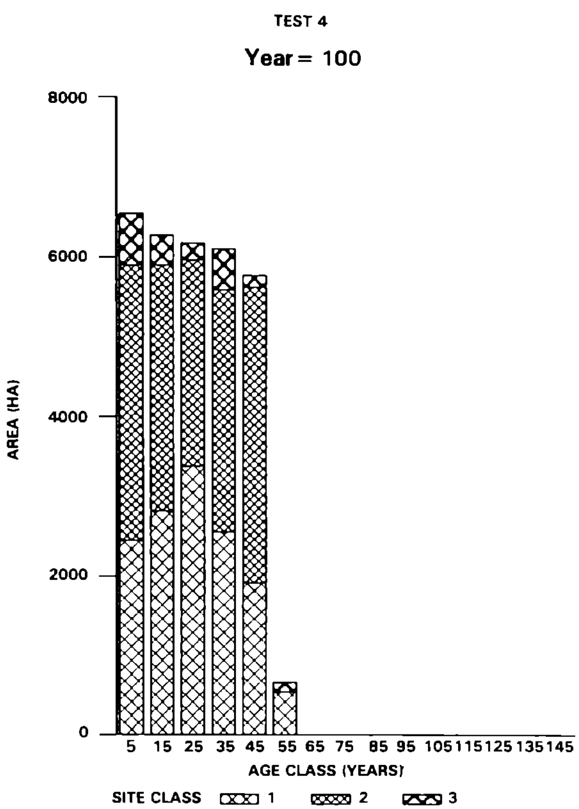
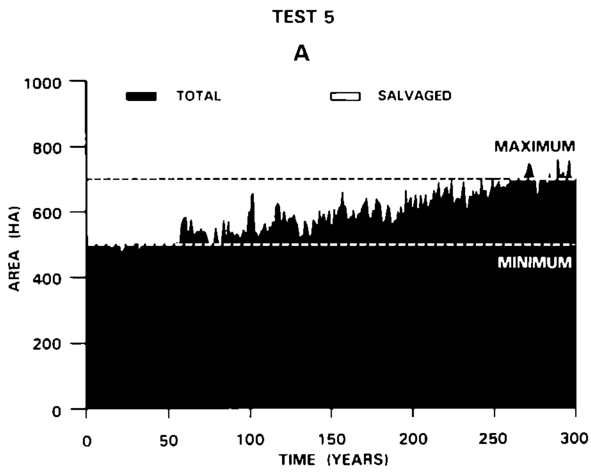


Figure 3.12 *Test 4: age-class distribution after 100 years.*



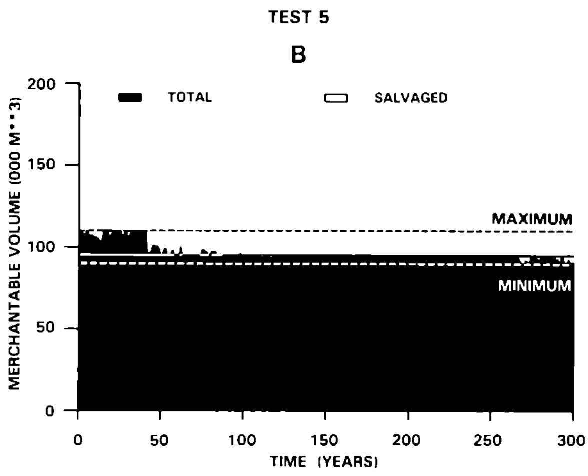


Figure 3.13 *Test 5: annual harvest by area (A) and merchantable volume (B).*

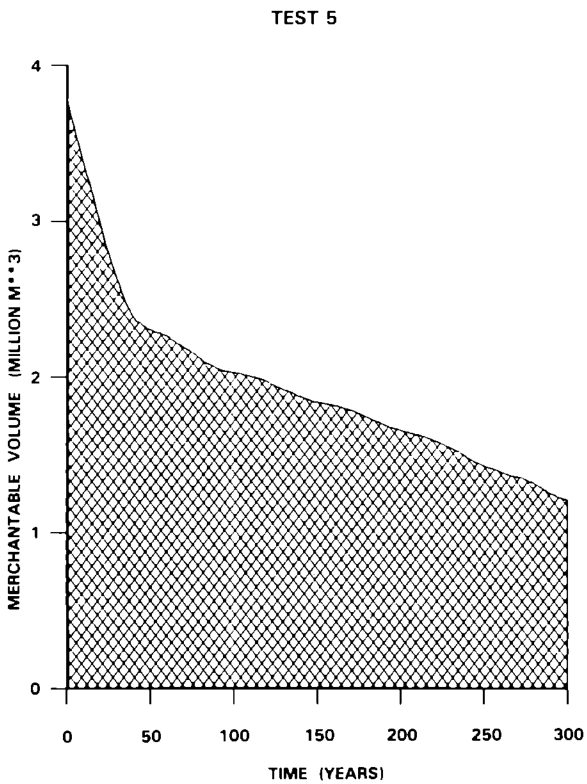


Figure 3.14 *Test 5: residual forest inventory.*

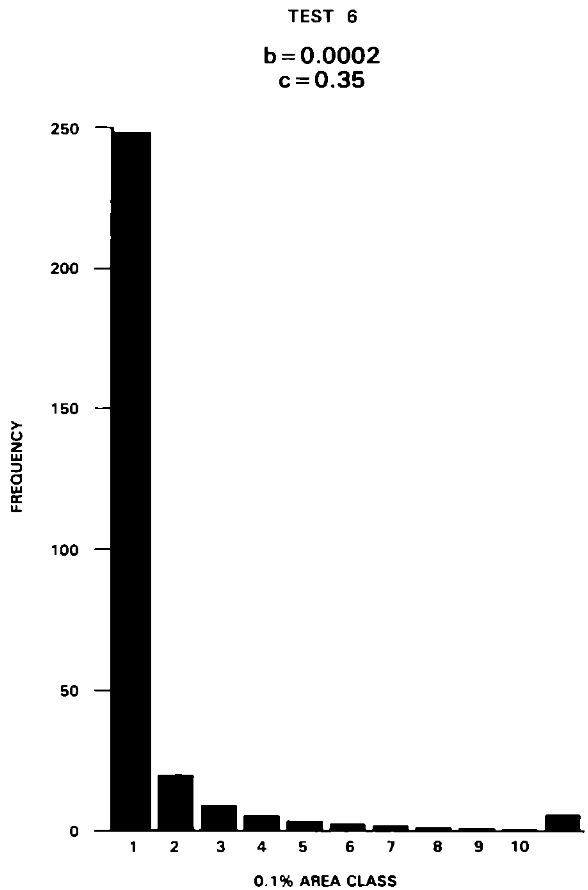


Figure 3.15 *Distribution of annual areas burnt, by 0.1 per cent area classes, for a Weibull distribution with parameters b = 0.0002 and c = 0.35. Mean area burnt = 0.095 per cent.*

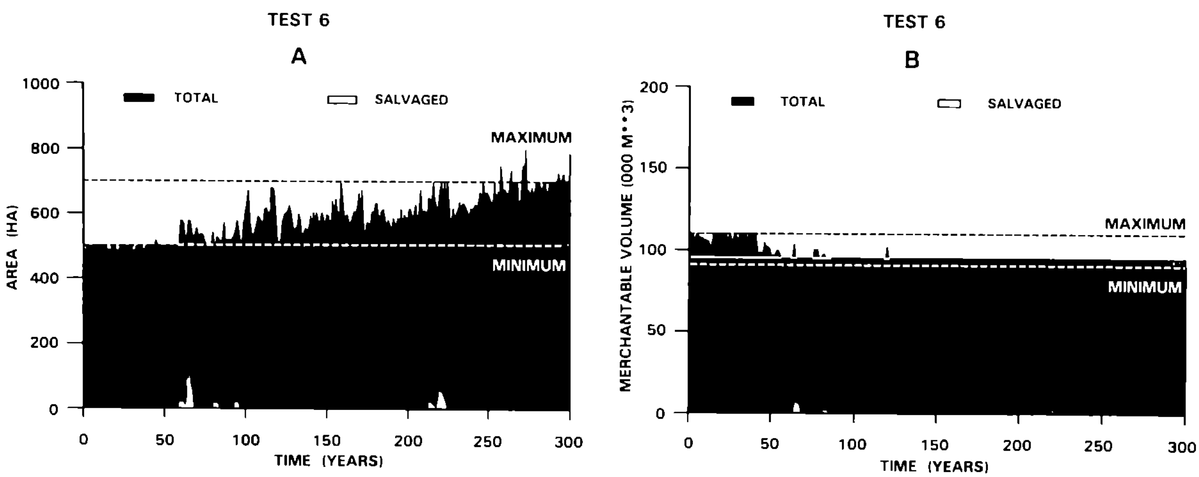


Figure 3.16 *Test 6: annual harvest by area (A) and merchantable volume (B).*

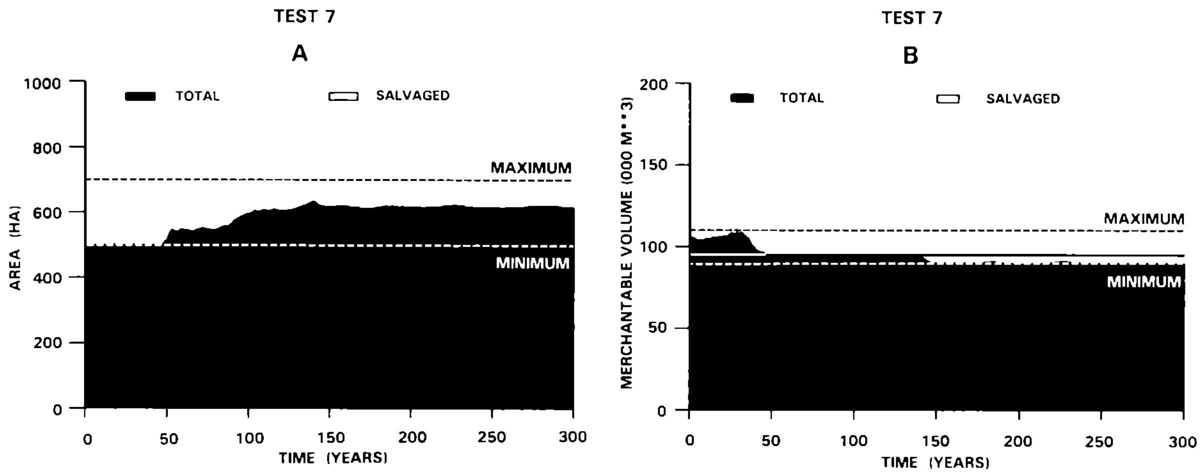


Figure 3.17 *Test 7: annual harvest by area (A) and merchantable volume (B).*

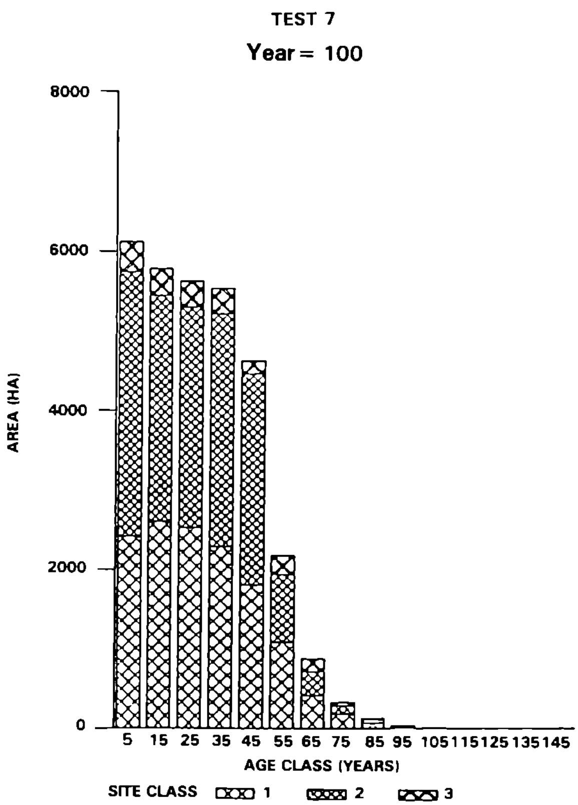


Figure 3.18 *Test 7: age class distribution after 100 years.*

Paper 4

FIAP, The Forestry Commission's Forest Investment Appraisal Package: An Aid to Decision Making for the Forest Manager

*W.C.G. **Harper**, Economic Planning Branch, Development Division, Forestry Commission, 231 Corstorphine Road, Edinburgh, EH12 7AT, U.K.*

Abstract

Investment appraisal is a term used to describe the evaluation of different options, in order to meet a specified objective. In forestry appraisals the costs of different operations are considered together with the likely volume production of revenue from the crop. Cash flows are discounted in order to allow for differences in timing.

Investment appraisal used to be done by calculators and ready-reckoners. This was complicated, time-consuming, prone to errors and difficult to verify. The Forestry Commission recognised that a computerised system of investment appraisal for forest management would allow staff to appraise their decisions without needing to get involved in the detail of the calculations. The package which was produced is called FIAP, the Forest Investment Appraisal Package, and is available on all Forestry Commission microcomputers as part of the Forest District computer system.

This paper describes how FIAP was developed and discusses the experience of making a complex and flexible system available as a management tool. The user must understand what the package is designed to do, learn how to use it and be confident that support is available from the documentation and from the developers of the package.

Introduction

Foresters have used the technique of discounted cash flow in investment appraisal since the 19th century (Gane and Linnard, 1968). In discounting, the value of sums of money spent or received in the future is reduced to give a present value. There are two main reasons for this:

1. individuals prefer to receive benefit now rather than later;
2. individuals can save or invest money to earn some rate of return.

In most forestry projects, expenditure is concentrated in the early years, but the first revenue may not be generated until over 20 years later. Thus, discounting offers a means of allowing for differences in the timing of cash flows when comparing options.

The Forestry Commission uses the technique of discounted cash flows to carry out investment appraisal (Insley, Harper and Whiteman, 1987). An investment may be considered worthwhile if the net present value (NPV), that is discounted revenue (DR) minus discounted expenditure (DE), is increased as a result. Often maximising NPV is secondary to other objectives, for example, increasing the conservation value of a particular area. Discounted cash flow provides a method whereby the opportunity cost of such decisions can be considered.

In the United Kingdom, the Government emphasised the need to evaluate the economic return from public sector investments in a policy known as the Financial Management Initiative or FMI (HM Treasury, 1984). This policy has reinforced the need for the Forestry

Commission, as a Government body, to examine its investment strategy. The Treasury specified that discounted cash flow was the appropriate technique to use and set the discount rate to be used by public sector bodies at 5 per cent in real terms (i.e. after taking account of inflation).

The techniques of investment appraisal and discounting are relatively easy to apply to a simple investment with a few cash flows and a fairly short timespan. With a forest investment, identifying the cash flows can be more difficult. Judgements must be made, for example, on the yield and value of timber which will be produced, 20 years or more in the future, from a crop about to be planted. Costs and benefits can occur as single payments or annually over a range of years, so calculations of net present value may prove complicated. Before 1985 calculations had to be done by hand with the help of a few ready-reckoners, for example tables of discounted revenue. In that year a computer program called FIAP, the Forest Investment Appraisal Package, was produced to assist with such calculations. It was written in FORTRAN to run on a VAX computer and was accessed by users through a dial-up network. However, experience showed that there were problems running a modelling package requiring fairly long interactive sessions on the network. In 1988 a version was produced which could run on the Forest District microcomputers and is referred to as 'MicroFIAP'.

Advantages of a computer based forest investment appraisal system

Although forest managers were expected to consider the options available and appraise alternate courses of action, the problems associated with a manual system were such that appraisals were done infrequently and mistakes in calculations were common. A computerised system provided the opportunity to give managers a tool to allow them to do appraisals whenever required. Some of the limitations of the manual system and the advantages of a computer package are outlined below.

1. The calculations required in discounting are relatively complex

Some people are so intimidated by algebraic formulae that they decide to abandon the appraisal altogether. Only those very familiar with discounting could be expected to understand the full implications of each formula and the adjustments which have to be made in some cases. Unless the calculations were set out in full, checking required recalculation and tended not to be done.

With a computer based system, the calculations are part of the program. Once the information to be used is specified, the program will do all the calculations. Details of calculation such as adjusting for inflation or stocking percentage are taken care of automatically. The emphasis on checking a calculation thus changes from deciding if the correct discount factor is used, to considering if the assumptions used to describe the forestry are appropriate.

2. Performing each calculation by hand takes a long time

To calculate the net present value for a simple forestry investment option might take an hour or so using a calculator. The same calculation can be done by computer in less than 5 minutes. The person doing the appraisal by hand therefore had to find a comparatively uninterrupted hour to do the calculations. Checking a calculation required much the same time. The range of assumptions considered in an appraisal was restricted as changes need recalculation and the time was not available to consider more than one or two options. The speed of calculations on the computer means that simple appraisals can be done in a short time and more complex appraisals can be explored fully.

3. Computers allow a wide range of data to be used

Before computers were made widely available, assistance was provided in the form of ready-reckoners. The commonest of these in forest use were tables of discounted revenue. To keep the tables to a manageable size only a limited range of options could be included. For example, microFIAP allows over 900 yield models to be used whereas the DR tables usually were produced for around 200 models. The range of possible crop ages and felling ages is enormous, but this had to be restricted in providing tables. A computer allows all available data to be stored and easily accessed. The user can select the model and felling age appropriate to the particular case. The use of the wrong model of felling age can in some cases alter discounted revenue by over 10 per cent.

4. FIAP allows local problems to be considered using local information

In the past, papers were issued which contained economic appraisals of particular forest investment problems. The general approach was for Headquarters staff to look at a problem and using the best available information produce an appraisal and recommendations. Only major national problems were considered and problems of local importance only tended to be left. The information used was based on national averages and these were not necessarily applicable in all districts. With FIAP it is possible for each Forest District to appraise the problems of most relevance to them and to use local information on costs and crop types. Appraisals can thus be directly applied to management decisions.

Development of FIAP

Having identified the problems of the manual system and the potential advantages of a computer package, staff in Economic Planning Branch developed a computer package in FORTRAN to run on a VAX 11/750 using VMS operating system (Harper, 1986a). The initial specification for this system was fairly general. Once this was achieved the system was used by Economic Planning Branch staff and made available through the network. Users were given a short introduction to the system, and support was provided by telephone whenever required. Experience using the system showed:

1. areas where more fexibility was required;
2. additional features which were asked for by users;
3. presentational changes needed to make the system easier to use and understand.

These modifications were evaluated and implemented if necessary. In addition, changes were made to take account of a substantial revision of the Forestry Commission accounting system and the conventions used in plantations' valuation.

The development and testing of FIAP had been done using terminals directly linked to the computer. The use of the system by field staff through a network revealed problems which had not been anticipated. These problems were largely due to the inadequacies of the network at that time, but users also felt that FIAP was not meeting their needs. Initially, the network was not complete and time had to be allocated to each Forest District. This meant that the manager was not free to use FIAP as and when he wished. Sometimes establishing a link to the computer was very difficult and often the telephone line would disconnect during a session. Although the facilities were provided to allow the user to save work at regular intervals during a session, many users found it difficult to understand how computer files should be used and often lost considerable amounts of work. The speed of response had been extremely good on directly linked terminals, however the network slowed this down unacceptably.

With hindsight some of the problems could have been predicted, but they illustrate the difficulties of developing a package which is one of the first to be made available on a new system. It is only with experience that the inadequacies of the system are revealed. In the meantime the user can become very disenchanted with computers in general.

FIAP is a modelling tool and tends to be used in occasional long sessions. It is only rarely used in conjunction with other packages or other users. It was therefore decided that a version which ran on the Forest District microcomputers without using the network would allow more flexibility for the user and also reduce demand on the network.

The Forest District microcomputers run under the BOS operating system and are programmed in BOS MicroCobol. Packages were available which could be used for menus and screen input, but the ability to do calculations was very limited. The systems analysis and programming was done by data processing professionals in the Forestry Commission. An extremely detailed specification had to be drawn up by the forest economist working with the systems analyst. FIAP is an extremely complex and flexible system and a considerable input was needed from the person commissioning the work to ensure that the program met the specification.

The microcomputer version of FIAP was tested against the VAX version and also checked by manual calculations. The system was evaluated by two field staff to ensure that it was clearly presented and met their needs and also by someone with expertise in forest economics to check the calculations and presentation from that point of view. Our experience developing MicroFIAP has been that even with a prototype system already available and a very clear idea of the desired end-product, a considerable amount of time and effort is needed when commissioning data processing professionals to produce technical systems.

Making FIAP available to the field staff

The FIAP user is typically a forest manager who wishes to evaluate a number of different options for managing the crop. The package assumes a knowledge of forestry and forest economics. In parallel with the development of FIAP, Economic Planning Branch has run three or four courses each year on forest economics. These cover the basic principles of forest economics, particularly investment appraisal of forest operations, and show how FIAP can be used to assist in such appraisals. Courses on economics had been part of our management training for many years, the introduction of FIAP meant that the emphasis could change from teaching the mechanics of calculations to understanding the principles involved and identifying the factors which were likely to prove most significant.

Guidance to field staff was also provided in the *Investment appraisal handbook* (Insley, Harper and Whiteman, 1987). This describes the techniques of investment appraisal and discusses specific forestry applications. Examples are included throughout the handbook of how FIAP can be used in investment appraisal.

MicroFIAP was written and completed by December 1987. The introduction of the system to the field was scheduled for April and May 1988. This allowed time for checking of the system, writing a user guide and developing a programme for training users. The user guide gives a comprehensive description of how the system works and hints on how to use it effectively. The effort required to provide a high standard of user documentation is well justified as it is repaid by reducing the amount of support needed.

Training courses were run to introduce the users to MicroFIAP. These were aimed at forest managers and land agents who understood the economics and had some experience of the VAX version of FIAP. People without that background attended the economics courses. The MicroFIAP training courses were run for groups of no more than nine people, each using a keyboard and screen. Two tutors were used, one from Education and Training Branch with experience of teaching forest staff to use computers and the other from Economic Planning Branch. Participants were guided through the package pressing keys themselves as instructed by the tutors. This was followed by a series of exercises, starting with simple practice using menus and input screens and increasing in complexity to real problems in forest economics which had to be analysed before the calculations could be done. In training people to use a computer package, it is essential that each person has their own terminal and can work at their own pace so that they can understand and become confident with the system. Questions arise on both the mechanics of how to use the system and the underlying philosophy, so the course tutors should be able to cover both these areas and spend time with each person.

Our experience with MicroFIAP suggests that almost as much work is required in implementing the system as in the initial design and production. If a package is to be used by field staff, they must:

1. understand what it is trying to achieve;
2. be shown how it works and learn to use it themselves; and
3. be confident of support from the documentation and the developers of the package.

The structure of FIAP

FIAP is a menu driven package with a main menu and sub-menus, input forms and questions at lower levels. Information is assembled and can then be used for calculations or displayed on the screen or sent to be printed. A house-keeping facility to manage the files created by FIAP is provided within the system.

The information used by FIAP is presented using forestry terminology familiar to the user. All the yield models (Edwards and Christie, 1981) are available stored as tables. Selection is made from menus for species, thinning type, yield class and spacing. The yield models provide information on the timing of each thinning and of clear felling, the volume produced per hectare and the mean tree size. Mean tree size is used in conjunction with a price size curve to relate the standing value per cublic metre to the mean volume per tree (Mitlin, 1987). Generally, larger trees are worth more per cubic metre. The price per cubic metre from the price size curve and the volume per hectare from the yield model are combined to give a value per hectare at each harvesting operation. The cash flow from each harvesting operation is then discounted and cumulated to give a total discounted revenue per hectare.

Expenditure cash flows for a typical hectare are set out in a summary known as a planting model. For valuation purposes this would include all operations required during the life of the crop and might contain over 30 entries. A planting model can also be used in an appraisal of a particular operation and might in that case only need a single line which is altered for each option. Each line in the model describes an operation by the account code and name used in the financial system. The cost per hectare is given and the percentage of the area which will receive that treatment. Operations can take place in a single year or annually for several consecutive years. In order to calculate discounted expenditure (DE), each cost per hectare is multiplied by the percentage treated, discounted over the length of time specified and the result summed to give a total DE for the model.

A number of so called 'miscellaneous parameters' can be set which can alter the detail of the calculation. Some of these such as rotation age are used in virtually all calculations, whereas others only apply in special cases.

The main economic calculations done by FIAP are discounted revenue, discounted expenditure and net present value. The annuitised value of each of these is also calculated for use when comparing projects of very different timespans. Internal rate of return (IRR) can be calculated to give the discount rate at which discounted revenue exactly equals discounted expenditure.

In addition FIAP will also calculate the age at which discounted revenue reaches a maximum. This is the felling age which would normally be adopted for crops on stable sites. Many of our crops must be felled before they reach that height because of the effects of windblow and in these cases it is possible to set rotation age by the likely final top height.

Information used by FIAP can be displayed on the screen. It therefore provides a convenient way to access yield model information for other purposes. FIAP uses an inflation index to adjust cost and revenues automatically to current prices and this can also be accessed and manipulated for other purposes.

Each time a calculation is done on FIAP, the information used is recorded together with the answer. Prints of yield models, price size curves, planting models and the inflation index can also be produced. A printed record can thus be obtained of all the work done on a particular run of FIAP and this can be kept for reference and checking.

FIAP allows the user to build up expenditure profiles in planting models and save these for future use. It is also possible to save all the settings in use at the end of a particular run and restart from these later. Facilities for saving, deleting and archiving data are provided within FIAP so that a knowledge of the system utilities is not required. Even so, the concepts of file handling are the most difficult to convey to users unfamiliar with computers and the flexibility provided is often not fully used.

Use of FIAP

Forest District staff use FIAP to appraise investments in forest operations. For example, new options for ground preparation of restocking areas by scarifying or mounding can be evaluated against existing techniques by comparing the costs of the operation and subsequent treatments such as weeding, and the likely revenues based on the potential growth and stability of the crop. Local staff can use their experience of costs and crop types and so decide which is the most appropriate technique in that area.

The largest single use of FIAP has been the 1986/87 Financial Review (Forestry Commission, 1988). This review valued the existing plantations on the basis of projected future costs and revenues. The expected rate of return for all new planting and restocking to be done during the next 3 years was also calculated. Forest Districts used FIAP to evaluate their proposed investments and had to justify regimes which produced low rates of return.

Examples of subjects where FIAP was used in the investment appraisal include thinning policy (Harper, 1986b); assessing the most appropriate use of improved Sitka spruce cuttings (Mason and Harper, 1987); comparing the effects of change by *Heterobasidion annosum* (*Fomes*) with the cost of stump treatment (Harper, 1987); evaluating the economic return from farm woodlands (Insley, 1988).

FIAP was developed to take the drudgery out of the calculations needed for investment appraisal and so encourage more appraisals to be done and greater consideration given to investment decisions. The intelligent use of FIAP relies on the forest manager applying his knowledge of forestry and forest economics to the assumptions used and the answers produced by the computer package. It must be used to assist and enhance his professional expertise, not as a substitute for it.

REFERENCES

EDWARDS, P.N. and CHRISTIE, J.M. (1981). *Yield models for forest management.* Forestry Commission Booklet 48. Forestry Commission, Edinburgh.

FORESTRY COMMISSION (1988). *67th annual report and accounts 1986–1987.* HMSO, London.

GANE, M. and LINNARD, W. (1968). *Martin Faustmann and the evolution of discounted cash flow.* Institute Paper 42. Commonwealth Forestry Institute, Oxford.

HARPER, W.C.G. (1986a). Forest Investment Appraisal Package (FIAP). *Report on Forest Research 1986*, 56. HMSO, London.

HARPER, W.C.G. (1986b). To thin or not to thin - optimising present and future returns to the grower. *Forestry and British Timber* **15**, 22-27.

HARPER, W.C.G. (1987). Economic evaluation of damage by *Heterobasidion annosum* and the benefits of stump treatment. In *Proceedings of the IUFRO Project Group P4.02 and Subject Group S1.05-05*. Scandinavia, June 1987.

HM TREASURY (1984). *Investment appraisal in the public sector: a technical guide for Government Departments.* HMSO, London.

INSLEY, H. (ed). (1988). *Farm woodland planning*. Forestry Commission Bulletin 80. HMSO, London.

INSLEY, H., HARPER, W.C.G. and WHITEMAN, A. (1987). *Investment appraisal handbook.* Forestry Commission, Edinburgh.

MASON, W.L. and HARPER, W.C.G. (1987). *Forest use of improved Sitka spruce cuttings.* Forestry Commission Research Information Note 119/87/SILN.

MITLIN, D.C. (1987). *Price-size curves for conifers.* Forestry Commission Bulletin 68. HMSO, London.

Paper 5

A Feedback Mechanism for Planning and Control of Forest Operations

P.A. Harou, University of Massachusetts, Amherst, MA 01003, U.S.A.

Summary

Any forest operation could be subdivided into different components probably linked to a major piece of equipment. Each sub-operation/equipment can then be monitored separately in an overall computer-based system. A feedback mechanism needs to be put in place to monitor productivity and costs on a continual basis. The computer algorithm of a feedback mechanism, The Alternative Test, is presented in this paper. This simple algorithm could be appended easily to any existing computer-based system of a forest operation Management Information System. It will provide information on when to abandon an existing piece of equipment based not only on costs data but also on benefits and abandonment values.

Introduction

The planning of forestry activities is important, for the plan established will serve as a basis for controlling these activities. The plan serves as a standard against which accomplishment will be reported. This is true for forest operations planning and control as well. As Ericson (1986) said "simple logging plans have been used for many years but it was not until 15 or 20 years ago that formalised plans, in which the objectives and results are expressed in economic terms made their breakthrough. At the same time many of the major forest enterprises also constructed computer-based systems and routines for planning, data-processing and follow-up." However, the author recognised several weaknesses in those systems.

These systems have often become cumbersome, complex and difficult to update. The approach we recognise would use a simple cash flow monitoring for each component of a logging system in conjunction with a simple feed-back mechanism called 'Alternative Test'. This feedback mechanism flashes out the excessive discrepancies between plan and actual outcomes and by comparing the ongoing logging operations with other alternatives. Using this subroutine in any forest operations systems would ensure maximum vigilance over time and hence improve productivity and enhance profitability.

Monitoring of system components

Any forest operation system can be decomposed in a number of components which often have their own routine in computer based systems. Whatever the intricacies of these systems, components may in most cases be reduced to a schedule of inputs and outputs over the time of the operations. Such scheduling can be translated in a cash flow table when these inputs and outputs are priced.

Once the activities of a component are related to a schedule of inputs and costs, outputs and benefits, many programs existed to summarise the profitability of these activities. The program CASH is an example (Blinn and Rose, 1987). However, no particular software is needed if one is familiar with the different types of spreadsheet available in the software market. The advantage of using a general spreadsheet for monitoring the productivity and profitability of ongoing forestry operations is that a system can be built easily for any type of activities comprising that system. Furthermore, in a spreadsheet columns can be added for every year of the schedule so that in addition to the initial estimates, actual figures during the project implementation can be recorded and maintained in the database also. Favourable or unfavourable deviations between estimates and actual figures will catch the manager's eyes and call for appropriate actions. Either maintaining the favourable situations which have caused lower costs or higher benefits or remediating a situation of cost overruns, is the forest manager task.

While negative discrepancies between estimated and actual figures can require some management actions it may be that some uncontrollable variables, such as a real price increase of important inputs, are at work. In such a case not much can be done. But is the activity still worth pursuing in that case?

Feedback in the monitoring process

Two types of feedback are useful when controlling forest operation systems or components of one system. We alluded to the first type in the previous section. A cost overrun or underrun under a certain benchmark, e.g. deviations of 10 or 20 per cent from the estimates, will induce a printed message to attract the manager's attention. This will not necessarily cause a rethinking of the activity itself but an improved organisation of that activity.

Now assuming that nothing can be undertaken to counteract a negative discrepancy between estimates and real values, a reassessment of the activity itself is at order. This second type of feedback will induce some important change in the initial plan of operations. In a forest operation system, most of the systems' components include a major piece of equipment being a skidder, a truck, a chainsaw or else. These pieces of equipment condition most of the skidding, transport or cutting activities. The abandonment of this equipment, i.e. the major investment along manpower in that component, is the most crucial managerial decision to be made.

The financial principle behind the replacement of a piece of equipment is straightforward. An equipment should be replaced when the marginal costs of operating it are not compensated by proportional marginal revenues. As a piece of harvesting equipment grows older, there is a tendency for maintenance and other operating costs to increase. This leads to reduced usage which in turn raises the cost per unit of output. Meanwhile, new models of more performant equipment are being developed. These tend to have still smaller operating costs and greater output capacity. The combination of higher operation costs and increased opportunity cost may cause the equipment to be replaced well before the end of its physical life (Smith, 1979).

A key principle in replacement analyses is that sunk costs in old asset should be disregarded in the determination of the investment when comparision is made with other alternatives. Thus, rules for determining the investment in alternative equipment are (Canada, 1981):

1. investment in old asset = present realisable (salvage value) + any capital expenditure necessary to make it perform the needed function during the expected future life;
2. investment in new asset = total money to be tied up in a new asset if acquired.

Combining the two above principles one can postulate that a piece of equipment should be replaced when the cash flow net present worth (NPW) of the ongoing equipment at the ongoing cost of capital is lower than the mutually exclusive new alternative NPW calculated with the new (and probably higher if it is an expensive equipment such as a skidder) cost of capital.

However, the management decision can be improved if one considers not only the abandonment value of the present equipment now but also its abandonment value at a later time before the final year of the physical life of the old equipment. A test encompassing the comparison of the present value of the future cash flows of an equipment with different abandonment values for the remaining years of equipment life has been proposed by Harou (1980): the Alternative Test. This test will provide an immediate feedback for deciding to keep or not a forest operation equipment taking into consideration all the possible alternatives mutually exclusive of the ongoing one.

Alternative Test

The recommended decision rule to decide when to replace equipment is called the Alternative Test. It is adapted from a decision mechanism proposed by Robicheck and Van Horne (1969) which is further modified here following a discounted tree decision model. Briefly, replacement becomes the best alternative at the point when abandonment value exceeds discounted present value of the equipment remaining net cash flow. Abandonment value (AV) is the relevant opportunity cost of continuing to hold a piece of logging equipment. Sometimes this opportunity cost will simply be the resale value of the equipment. But most often it will represent the NPW of an alternative investment mutually exclusive of the ongoing project, a new, more efficient piece of equipment.

An illustration of the Alternative Test is shown succinctly in Table 5.1. Consider a 10-year logging equipment in its fifth year. Cash flow forecast for the remaining years of the project, after updating the appraisal figures based on past data and the information available at that time about the future, is found in the table together with possible future abandonment value of the equipment. The Alternative Test is explained in the figure. Calculations are similar to those made for a discounted decision tree. First, one must discount cash flow in the final year back one period. The rate of discount, or the cost of capital, used is 10 per cent. The $1363 discounted value resulting from project continuation at end of year 4 (remaining years) must be compared with the AV at that time. The longer of the two must then be rolled back for analysis to the previous period. Here, since the $1363 discounted value resulting from project continuation in year 5, exceeds the $1000 AV at end of year 4, $1363 is discounted back to the end of year 3, (beginning of year 4) along with the project's $2000 earning in year 4. The NPW at beginning of year 4 ($1239 + $1818 = $3057) is higher than the AV ($3000) at that time and is thus discounted with the cash flow in year 3 ($3000) back to the beginning of

Table 5.1 Alternative Test for a logging operation

Remaining years	*5* *(0)*	*6* *(1)*	*7* *(2)*	*8* *(3)*	*9* *(4)*	*10* *(5)*
Revised cash flows		10,000	8,000	3,000	2,000	1,500
Abandonment value	20,000	12,000	6,000	3,000	1,000	zero
NPW with testing	9,090	7,272	2,272	1,818	1,363	
Test	11,569	5,454	2,799	1,239		
	20,659	12,726	5,508	3,057		

FLOWCHART

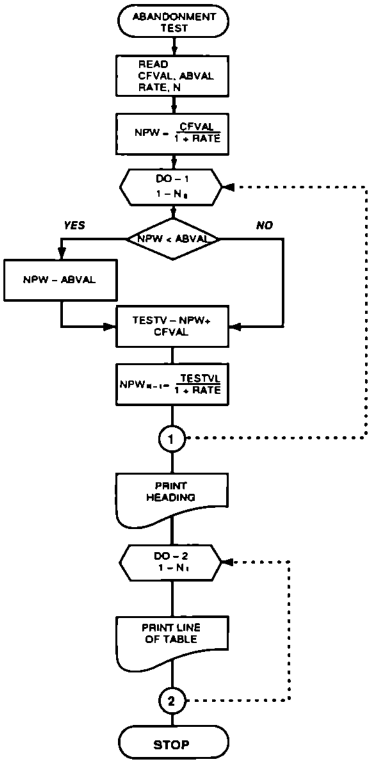


Figure 5.1 The flowchart and algorithm of the Alternative Test (AT).

THE 'AT' PROGRAMMED

```
C*      ABANDONMENT TEST PROGRAMMED                                  *****
C*                                                                   *****
C*THIS PROGRAM RESOLVES THE ABANDONMENT TEST ACCORDING TO             *****
C*  THE ALGORITHM OF ROBICHECK AND VAN HORNE                         *****
C*                                                                   *****
C*      AUTHOR:  PATRICE  HAROU ,JANUARY 1988                        *****
C*                                                                   *****
C*********************************************************************
C
C
C*********************************************************************
C*          LIST OF VARIABLES NAMES                                  *****
C*  CFVAL=CASH FLOW VALUES                                           *****
C*   ABVAL=ABANDONMENT VALUES
C*  RATE=ALTERNATIVE RATE OF RETURN
C*  N=NO. OF YEARS IN THE CASH FLOW TABLE LESS ONE
C*  NPW=NET PRESENT WORTH OF TESTV ONE YEAR BACK
C*  TESTV=CFVAL+NPW OR ABVAL WHICHEVER IS HIGHER                     *****
C*                                                                   *****
C********************************************************************
C*
C
C*********************************************************************
C*          DIMENSION AND INITIALIZE                                 *****
C*********************************************************************
C
 REAL NPW(151),RATE,CFVAL(151),ABVAL(151),TESTV(151)
C
C
C*********************************************************************
C*          INPUT AND VALIDATION                                     *****
C*********************************************************************
 READ(5,100)N
 100 FORMAT(I3)
 N1=N+1
 READ(5,101) (CFVAL(I),I=1,N1),(ABVAL(I),I=1,N1
 101 FORMAT(51(6F10.2/))
 READ(5,110)RATE
 110 FORMAT(4.3)
C
C
C*********************************************************************
C*          DESCRIPTION OF PROCESSING                                *****
C*********************************************************************
 N2=N-1
 NPW(N1)=0
 NPW(N)=CFVAL(N1)/(1+RATE)
 DO 1 I=1,N2
 IF (NPW(N1-I).LT.ZABVAL(N1-I))NPW(N1-I)=ABVAL(N1-I)
 TESTV(N1-I)=CFVAL(N1-I)+NPW(N1-I)
 NPW(N-I)=TESTV(N1-I)/(1+RATE)
 1 CONTINUE
 TESTV(1)=NPW(1)
 IF (NPW(1).LT.ABVAL(1))TESTV(1)=ABVAL(1)
 TESTV(N1)=0
 NPW(N1)=CFVAL(N1)
C
C
C*********************************************************************
C*          OUTPUT AND CLOSING                                       *****
C*********************************************************************
 WRITE(5,120)
 120 FORMAT(/////,5X,'THE ABANDONMENT  TEST'///
+      ,5X,'THE ABANDONMENT OF THE PROJECT IS REQUIRED NOW'/
+          ,5X,'IF THE ABANDONMENT VALUE IS GREATER THAN NPW IN'/
+          ,5X,'YEAR ZERO'/)
 WRITE(5,125)
 125 FORMAT(5X,'THE ABANDONMENT OF THE PROJECT WILL PROBABLY'/
+        ,5X,'BE REQUIRED IN THE FUTURE YEARS IN WHICH THE '/
+        ,5X,'ABANDONMENT VALUE IS PRINTED IN COLUMN 4'/////)
 WRITE(5,130)
 130 FORMAT(1X,'YEAR',5X,'CASH FLOWS',5X,'ABANDONMENT',4X,'TESTVALUES'
+,4X,'NPW OR ABVAL')
 DO 2 I=1,N1
 WRITE(5,140)I-1,CFVAL (I),ABVAL(I),TESTV(I),NPW(I)
 140 FORMAT(1X,I3,4(5X,F10.2))
 2 CONTINUE
 STOP
 END
```

year 3 or \$2781 + \$2727 = \$5508. In year 2, two alternatives must again be analysed. The \$6000 AV must then be entered into the discounting procedure and the rollback process must continue.

The result of the test is that the project should be continued, based on today's expectation, since in year zero the NPW of continuing to hold the logging equipment asset is \$659 (\$20 659-\$20 000). Had the NPW been negative, the optional solution would have been to abandon the project. This NPW value is based on assumptions that the equipment will be replaced in year 2 considering today's forecast of future costs and benefits.

This procedure, beginning at the end of the project economic life and discounting cash flows back one year at a time with annual or periodical comparisons with the current AV, forces the manager to consider alternatives for the running equipment. The NPW calculated this way will be higher than the NPW calculated without considering AV. The NPW will be \$659 v. \$252. This results from substituting AV for future cash flow stream whenever AV exceeds maximum possible discounted cash flow of keeping the logging equipment. The flow chart and the programmed Alternative Test are given in Figure 5.1.

This Alternative Test is rerun each year after updating the cash flow table. Rerunning annually, or semestrally, or any other period judged appropriate for the type of activities monitored, permits dealing with future uncertainties related to cash flows and AV.

Conclusions

Any forest operation system can be partitioned in different components each of them having an important piece of equipment or series of equipment. Then replacement is of considerable managerial interest since it influences both the costs and benefits of the system component more than any other input except maybe for labour. Yet the labour input is directly linked with the type of equipment used in forest operations and hence the equipment used is crucial to establish the labour input also.

The Alternative Test proposed is the best way to control the maximum efficiency of a piece of equipment both in terms of cost minimisation and opportunity cost of the capital invested compared to other possible mutually exclusive alternatives. The test is superior to many other feedback mechanisms such as the full cost analysis, the marginal cost analysis, the abandonment test, the optimal abandonment test and the abandonment test under uncertainty (Harou and Massey, 1982). The Alternative Test is specially appropriate for deciding on equipment replacement since the abandonment values are easier to forecast than for forestry investments in general. Such test diminished also the perceived risk of the forestry investments (Harou, 1986).

On practical ground the Alternative Test can easily be appended to any computer system already existing. The components of a forest operation system can incorporate easily the new programming statements of the proposed algorithm. While the outcome of such an algorithm, should not be used blindly to direct management actions, it should be an important feedback mechanism indicating to the manager areas of concern needing possible further investigation.

REFERENCES

BLINN, D. and ROSE, D. (1987). *CASH.* Staff Paper Series no. 54, p. 35. University of Minnesota, USA.

CANADA, J.R. (1981). *Intermediate economic analysis for management and engineering.* Prentice-Hall, New Jersey, USA. (430pp.)

ERICSON, O. (1986). A modern approach to planning of logging operation. In *Proceedings of the 18th IUFRO World Congress,* Yugoslavia, Sept. 1986, M. Bol (compiler), IUFRO Division 3, Forest Operations and Techniques, 78-89

HAROU, P.A. (1980). How to decide when to replace equipment. *Forest Industries* **107**(2), 56-58.

HAROU, P.A. (1986). Incorporating feedback mechanisms into forestry decision making. *Canadian Journal of Forest Research* **16**(3), 580-584.

HAROU, P.A. and MASSEY, J. (1982). Monitoring forestry projects: the Alternative Test. *Journal of Agricultural Administration, London,* **9**(2), 139-146.

ROBICHECK, A. and VAN HORNE, J. (1969). Abandonment value and capital budgeting: reply. *Journal of Finance* **24**, 96-97.

SMITH, G.W. (1979). *Engineering economy,* 3rd edtn. Iowa State University Press, Ames, Iowa, USA. (579pp.)

Paper 6

Animated Simulation and Computer-assisted Graphics

T.J. Corcoran and H.B. Metcalf, Professor of Forest Engineering, and Professor of General Engineering, University of Maine, Orono, Maine 04469, U.S.A.

Abstract

GPSSR/PC, GPSS/PC, SIMAN, TESS, SIMFACTORY, and SIMSCRIPT II.5 are high in popularity amongst the many commercially available microcomputer-based simulation software packages. All the forenamed offer true animation to complement the execution of a simulated system. This means that a high level of visualisation of and interaction with running simulation is afforded to the designer of a simulated environment as well as its ultimate user, thus enhancing realism and accuracy in both a research and a production management sense.

Introduction

Computer animation has been defined (Cox, 1987) as the representation of a simulation by user-chosen shapes moving at user control with at least two degrees of freedom. Moving bar charts, digital readouts and other dynamics screen indicators are not considered true animation. Additionally, time-synchronised changes of colour enhancements can be used within an animation and in the other modes of visual displays. Real world systems can be viewed, predicted, and controlled by the animated simulation environment whether it be focused on a mill yard or on other forest operations. Animation can be further supported by active screen windows or by sequenced printer outputs or pen plottings.

Hierarchy

The art and science of simulation modelling has been described as a hierarchal progression (Johnson and Poorte, 1988). Namely the five stages of progression in modelling, particularly suited for assistance by computer animation are:

1. debugging;
2. verification;
3. validation;
4. analysis;
5. communication and presentation.

In the development of a simulation model, animation is the trustworthy friend of the modeller. Animation provides the capabilities to follow multiples of entities through their travels in the modelled system. Johnson and Poorte (1988) noted that it allows for a better understanding of the interactions between these entities and their contributions to events important within the system than would be possible simply though a computerised trace of model's events. The obvious advantages to debugging or error correction stage should be apparent as should the value to whether a model behaves as conceptualised which is the verification stage.

Validation of a model and it animation also has important linkages. Since validation is meant to ensure that the model is representative of the real system in concept, data and operation. There may be a variance between that which is conceived by the modeller and what way was intended by the system's expert if the modeller and expert are not in a common personage (Sargent, 1986). For the modeller, and more particularly for the expert, direct inspection of flow logic via computer code or the digesting of periodic static results are not the most efficient, if even effective, of chores. Therefore, animation plays an important role - what you see is what you get.

The seeing is a graphic representation of events and the contributing entities that appear to be as dynamic and can be as satisfyingly realistic as would be a viewing of the real world system. The computerised imagery perhaps by design need not be confusingly complex but could solicit windows of numerically discrete but continually updated results overlaid in support of the graphic depictions. The latter would thereby give more meaning to the animated flow that would usually be visible in the real world flow.

Observations via animation by an analyst can provide information not available to other performance measures suited to an analysis. Performance evaluations in analysis can, for example, discover problems but perhaps not their source. It was further stated that interactive on-line animation of manufacturing systems has been used to deploy manpower as adjustments to avoid or alleviate bottlenecks in production thereby decreasing work-in process and increasing output.

Smith and Platt (1987) in part stated that animation makes lively and accessible what would be a dry and needlessly obscure presentation of results in the form of reams of computer-generated output and inherent therein or derived tables and figures. It is without question that animation's most significant contribution to the tool of simulation comes through in the presentation phase. Animation, according to Johnson and Poorte (1988) provides the dynamic movement and colour to portray the intricacies of a system never fully described by static graphics or written communication. Obviously, simulation via animation offers a higher possibility of acceptance and usage throughout multi-levels of management.

Direction and status

Popular in North America, some modes to micro-processed animation include:

1. GPSS by a variety of vendors (Minuteman Software of Massachusetts, Simulation Software Ltd. of Ontario, nearing completion Wolverine Software of Virginia);
2. SIMFACTORY underwritten in SIMSCRIPT by CACI of California;
3. SIMAN by Systems Modelling Corp of Pennsylvania;
4. TESS (and SLAM) by Pritsker and Associates of Indiana.

Simulations with animation developments at the University of Maine include the use of GPSS and of SIMFACTORY and both as they relate to differing views of the operation and management of wood yard facilities. While these animated models are reasonably functional, the detail level can be described as at best into level II. The projected descriptive levels are three in number:

1. FIRST LEVEL - low recognition: recognisable only to modeller;
2. SECOND LEVEL - moderate recognition: recognisable to those familiar with the system and explainable to others;
3. THIRD LEVEL - high recognition: recognisable to most without explanation beyond the setting of the scenario.

A continuation in development is on-going even as this preliminary discussion is being delivered.

Conclusions

The computer (including peripheral devices) and accompanying graphics software have become the tools for users to save time, increase efficiency, and facilitate the decision making process. Computer graphics is the process of using computers to generate, refine, and display graphic images. The designer or decision maker can use the software to generate and edit a variety of images. Typical editing features include copy, move, zoom (enlarge or reduce), pan, rotate, mirror, trim, divide, stretch, and delete. A geometric feature can be surrounded by a window frame (rectangle) for manipulative purposes such as pan, zoom, copy or erase. The direction of viewing a picture or the 'position' of the observer can readily be changed to enhance visualisation. Since the computer is used graphically to simulate a system, the designer can readily explore changing behaviour and response to a variety of conditions.

Normally, the computer graphics are displayed on a screen or plotter, where the images are two-dimensional. However, spatial relationships can be displayed and are enhanced by the use of various colours and/or shading. Images presented in three-dimensional form are the easiest to visualise and are often presented as wire-frame, surface, or solid models.

Dynamic computer graphics or animation is a sequence of motions by a series of images. Once the highly complex software and instructions are loaded, creating motion of animated images is relatively quick and easy. Three-dimensional displays of robots in various positions is an example of the use of computer graphics to analyse not only the robot movement, but also to check clearances or interferences.

REFERENCES

CACI (1987). *SIMFACTORY with animation (Version 1.4 User's Manual).* 12011 San Vicente Blvd., Los Angeles, California. (70pp.)

COX, S. (1987). Interactive graphics in GPSS/PC. *Simulation* **49**(3), 117-122.

JOHNSON, M.E. and POORTE, J.P. (1988). A hierarchal approach to computer animation in simulation modelling. *Simulation* **50**(1), 30-36.

MINUTEMAN SOFTWARE (1986). *GPSS/PC Reference Manual.* P.O. Box 171, Stow, Massachusetts. (371 pp.)

PEGDEN, C.D. (1986). *Introduction to SIMAN.* Systems Modelling Corporation, State College, Pennsylvania.

SARGENT, R.C. (1986). The use of graphical models in model validation. In *Proceedings of the Winter Simulation Conference* (Washington, D.C., Dec. 8-10, 1986), Society for Computer Simulation (SCS), San Diego, California, 237-241.

SMITH, R.L. and PLATT, L. (1987). Benefits of animation in the simulation of a machining and assembly line. *Simulation* **48**(1), 28-30.

STANDRIDGE, C.R. (1986). Animating simulations using TESS. *Computers and Industrial Engineering* **10**(2), 121-134.

Paper 7

Forest Graphics: A Useful Tool for Forest Operations Planning and Control

L.H.C. Carbonnier, Interforest, 63 Lincoln's Inn Fields, London, WC2A 3JX, U.K.

Introduction

In Scandinavia, computers have been used for at least 20 years in the development of systems for forest planning and control. The first systems were based on centralised mainframe computers, far away from the operations and often developed by specialists in computer processing rather than in forest planning.

The long distance, both geographically and philosophically between the computer and the users, i.e. the forest managers, often made them suspicious of the results from the planning system when they were eventually received.

The rapid development of microcomputers has changed this scene drastically. They have brought computer power at affordable prices much closer to forest operations. This closeness has also helped to demystify the use of computers for forest operations planning. The forest manager can physically see the plans are taking shape and has the opportunity to influence the process directly. At the same time there has been a definite tendency to decentralise decision making and operational responsibilities to a district level.

Development of Forest Graphics

It is against this background that we have developed Forest Graphics as an efficient tool for processing cartographic data and drawing forest maps. For 15 years we have worked as international forest consultants assisting forest owners of different magnitudes, from individuals to governments, in establishing and managing their forests. We therefore wanted to develop a computerised mapping system, which together with other packages could be used when building integrated planning systems for forest enterprises. Consequently we shopped around for a basic mapping system which was flexible enough to be easily modified according to the specific requirements of a forest map. Other prerequisites were that it should be microcomputer-based and that the file structure was such that it could be integrated with other databases containing stand data, such as volumes, heights, diameter distributions, etc.

The system we eventually chose had been in operation since 1983 for one of the largest Finnish forest companies, where it had been developed to meet their specific requirements. The advantage of this system was that from the start it had been developed as a dedicated forest mapping system, while most other systems were general Geographic Information System (GIS) systems where considerable adaptions were necessary.

Although the system had been operational for some time when we acquired it we dedicated a full year to improvements and adaptions. The first thing was to have it running on a computer known to a broad audience, so we rewrote it for an IBM compatible computer, which at that time was the AT model. Then we let our inventory and mapping specialists work with it and suggest improvements, especially in the digitising routine, in order to make it efficient and to be as close as possible to the traditional way of drawing a map. We are now satisfied that Forest Graphics is a very useful tool for registering and handling geographic forest data, not only for Scandinavian conditions, but for most forestry conditions in the world.

Map digitising process

The system is vector based, which means that all figures are represented by a stream of co-ordinates. The user defines what coordinate system is to be used, but it is practical to use a national grid as a base.

The internal scale is 1:10 000 with a precision of 0.1 mm, corresponding to 1 m on the ground, but it is possible to digitise the map to any preferred scale. The system computes the scale of the digitising base after receiving the coordinates of three corners of the map. This procedure enables the user to merge information from different maps in different scales. For practical reasons the maximum size in the same database is 19 × 19 km (approximately 36 000 ha), but there is no difficulty in drawing larger maps if needed. This is done by plotting several map bases consecutively on the same paper.

The digitising of a map starts with the roads which are defined by their right edge and a reported width, which should correspond to the area considered to be non-productive land. After that, all required information is digitised and given a preliminary identification. All the borders of a compartment are established before the next object is started. This enables the system to determine the area of any compartment immediately after it has been digitised. When a compartment shares a segment of a border with an already registered object there is an easy procedure to utilise that information and avoid unnecessary digitisation.

Once a map has been completed it is possible to create a final numbering of the forest compartments according to directions given by the user. Final areas can also be computed by adjusting the individual compartment areas to a known total area. The system then produces a list of all identified objects with their areas and circumferences.

Finally, the map can be plotted at any preferred scale. Texts are defined in a separate file and can also be plotted at different scales, as well as shadings and user defined symbols identifying bare rock, peat land, etc.

Figures 7.1–7.4 illustrate a range of examples of maps produced by the system.

Figures 7.1 and 7.2 represents two parts, digitised separately, of the same property and Figure 7.3 shows the map where they have been merged. The reason for separating them was that the company for which they were made wanted the map division to coincide with the economic maps.

Figure 7.4 demonstrates an overview of the company's forests where the property has been shaded on to a topographic map at a scale of 1 : 50 000.

Advantages of the system

Some of the advantages with a computerised mapping system are:

1. the area measurements are accurate and are automatically generated by the system. They can also be transferred directly to a compartment database;
2. it is very easy to update a map with, for example, new compartments, roads, etc.;
3. the user has great flexibility in producing different maps for different purposes at a low cost;
4. by establishing a geographic database, interesting possibilities for integrated planning systems have been created;
5. in the long term, with increased costs for human resources and decreased costs for hardware, computerised map production will be economic. A skilled operator can digitise approximately 100 hectares an hour, which is about the same time it takes to do traditional area measurements.

Relationship to forest operations planning

We now consider a map database as one of the corner stones for forest planning. To illustrate this, an example of an integrated forest planning system is shown in Figure 7.5. This shows three levels of planning: strategic, operational and follow-up.

Strategic planning analyses the long term consequences and establishes medium term production targets for the main operations, such as forestation, logging and transport. At the operational planning level, operations are scheduled, the resource requirements are estimated, and a base for an annual budget is produced. The follow-up routines compare achieved production and costs with planned, and compile productivity statistics. All this is fed back to the planning routines to improve future estimates.

Each of the indicated planning routines are or could be intimately related to forest mapping. The consequences of the simulation process in the strategic planning would be more visual and easier to conceive by producing a map where areas selected for felling are shaded according to year and type of cut. The follow-up routines provide the base for updating the maps with new plantations and revised compartment borders.

The examples referred to, illustrating the use of map information in forest planning, in our view justify the position of Forest Graphics as one of the cornerstones for forest planning.

Figure 7.1

Figure 7.3

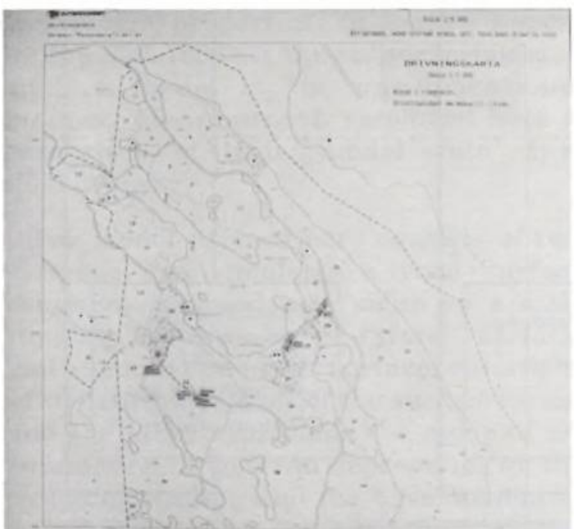


Figure 7.2

Figure 7.4

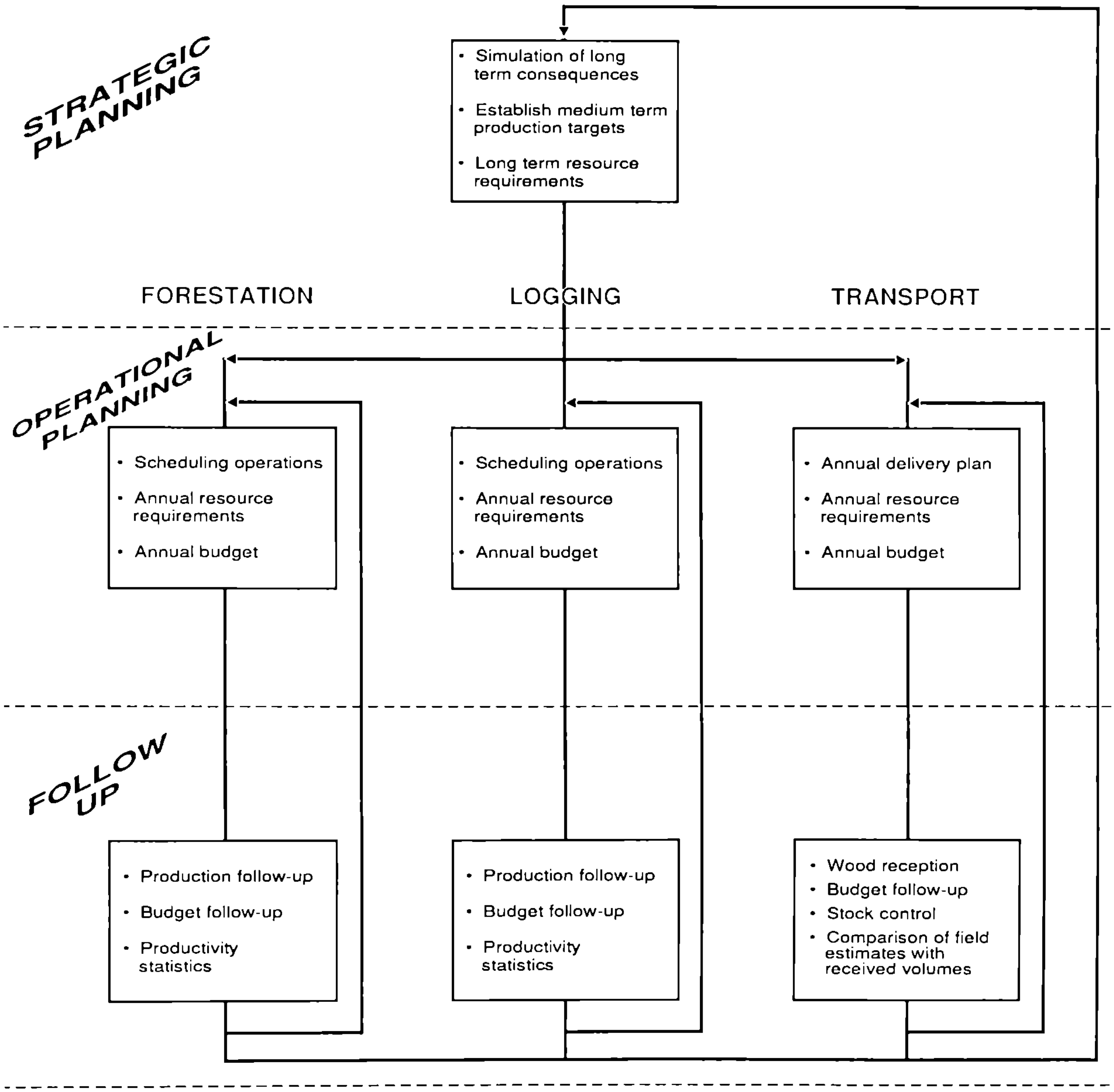


Figure 7.5 *Major components of a forestry planning and follow-up system.*

Paper 8

A New System for Quantitative Descriptions of Drainage Processes on Irregular Surfaces of Road Segments Based on Advanced Computer Simulation Techniques

M. ***Shiba,*** *Research Fellow of the Alexander von Humboldt Foundation: AvH, Institute of Work Science and Operational Methods in Forestry, Faculty of Forestry, University of Munich, 8000 Munich 80, Federal Republic of Germany*

Summary

This paper presents a simple system of quantitative descriptions of drainage processes on irregular surfaces of road segments based on advanced computer simulation techniques, and it proposes an alternative flow model which more closely takes into account linked geomorphic and hydrologic properties. In earlier papers (Shiba *et al.* 1986/87), the author formulated such a model in the one-dimensional manner. The approach employed here is extension of this model into two-dimensions.

The model derived here consists of two systems: one simulates a road surface roughness defined as a value on a scale ranging between equal ('trend' surface) and random ('residual' surface) variations of structural features of the surface forms, and the other represents the mode of accumulation of water in depressions on the irregular surface and the development of oversurface flow. The simulation system used to generate two-dimensional surface roughness is formulated by using a first-order Markov process model (Auto-regressive (AR) Model). The surface flow system is also simulated by a simple storage model. The assumptions behind a model postulated as describing the model of accumulation of water on irregular surfaces are that the infiltration capacity of the soil is exceeded and the rainfall continues. Accordingly, the residual water ratio (the depression-storage of irregular surfaces) can be derived in a simple way.

In order to verify the applicability of these models for practical purposes, several types of road surface consolidated by different combinations of operations and machinery were analysed. It has not yet been possible to test the proposed processing systems in their entirety, but no major obstacles to their adoption are suggested by these preliminary results.

Introduction

During recent decades, there has been considerable evolution in the methods and techniques used in forest operations and control. In general it can be said that all forest operations have been affected by this development. There are many reasons, social, economic and technological, for these changes; reasons which are complex but sufficiently known for it to be unnecessary to mention them here.

There are, however, certain forest types which are not suitable for the systematic application and use of such techniques. Forests in mountainous regions are an example of sites which by their very nature constitute an obstacle to progress, which it is often difficult to approach. A significant portion of the world's forest is located in these mountainous regions where in addition to their traditional role as a source of raw materials, they also have an important protective function of natural environment. It is therefore not surprising that many experts in this field have become more and more concerned by the limitation of access facilities and relative stagnation of mountain forests compared with general development. In order to realise better the multiple economic and social benefits which can be derived from the appropriate utilisation of these mountain forests, it is necessary to apply basic principles to forest operations carried out under increasing difficult terrain conditions, especially through the opening-up of the inaccessible forests by means of well-planned and well-designed forest roads.

Japan may be one of the typical examples of these situations; over 120 million people on about 38 million hectares of land area of which two-thirds is forested in mountainous regions and difficult terrain. The area, including non-productive forest lands, per capita is as low as 0.23 ha, which is almost equivalent to that for France, less than one fifth of that for the United States, and which is only one about one quarter of the world average. With the rapid increase in the degree of mechanisation of timber harvesting and other forest operations, forest road construction in Japan has increased year by year. Because of the small size and scattered locations of cutting areas, increases in the thinning and rationalisation of management in natural forests require the further construction of high density forest road networks. However, abundant and heavy rainfall in addition to large amounts of rock, rough terrain, and unstable surface deposits demands very high cost in maintenance of road segments both during construction and after completion.

Road sites occupy a small percentage of the forest areas, but they have a high potential for supplying sediment to stream. Movement of soil and rock for road construction and routine maintenace changes the distribution of material on the terrain, increasing the potential for various erosion processes. Roads can also interfere with the natural drainage network, increasing sediment production by channel erosion where water has been concentrated. Road segments on the steep slope terrain commonly include sites with persistently bare soil. Frequent passage of heavy machinery and transport vehicles on unpaved roads generates fine particles from the road bed. Besides the effects of various harvesting activities, a large quantity of sediment production from road segments might be caused by the surface flow of running water during periods of intense storms.

Despite the high potential for roads as a source of sediment, the accessibilty of the road segment provides a greater opportunity to mitigate erosion risks than that in other parts of the steep terrain. Therefore, much attention must be paid to drainage, consolidation, and alternative surfacing techniques, in order to maintain the long-term effectiveness of forest roads.

Procedures for measuring the spatial properties of surface roughness

Approach to modelling surface flow

Perhaps the most ubiquitous process operating on a soil-road surface is erosion and the transport of running water on the road. In an optimal design of surface drainage systems, it becomes a matter of importance how to provide a framework for understanding the behaviour of rainfall and runoff and their relation to surface conditions. Rain falling on an irregular surface disposes itself in a number of different ways. If the soil is not saturated, moisture will infiltrate into the ground at a rate controlled by the soil texture, material cover, and degree of saturation. Initially the rate of infiltration is rapid, but after a period of time the rate approaches an asymptotic limit, defined as the 'infiltration capacity' of a particular soil. The infiltration capacity is the maximum sustained rate at which a particular soil will absorb water. If the infiltration capacity of the soil is exceeded and the rain continues, water will collect in depressions on the surface of the ground. These depressions may be minute or large in size, but in general newly constructed or coarsely consolidated soil-road surfaces are highly irregular.

The runoff from a small catchment of road segments is considerably affected by the characteristics of surface configurations. An alternative approach to modelling surface flow must take into account the non-linearity associated with spatial variations of flows which may arise from differences of surface irregularities. Any flow model used to predict runoff from rainfall in these processes of water transport should include the roughness parameters related explicitly to significant characteristics of surfaces forms, especially when the model is used to analyse any changes in the surface flow due to variations in geometric properties within a drainage area.

Roughness parameters describing irregularities of road surface

Characterisation of road surface roughness is thus the first aim of the work. This procedure will be helpful in providing broad coverage by a standardised method, permitting comparisons of roughness parameters for different areas. A concise definition of surface roughness is probably impossible. The only usable definitions are incomplete because they describe only a few of the physical or mathematical properties of a surface. There may be as many of these definitions as there are roughness studies themselves. It quickly becomes apparent that different types of investigations require particular sets of roughness parameters. In the description of surface within this realm of road segments, roughness parameters should be established that can be used to describe surface irregularities ranging from a few millimetres to many centimetres.

In determining the effect of roughness parameters on a particular activity, the activity for which performance predictions are desired must be clearly defined, the analytical or mathematical performance predication model to be must used be identified, and the performance predictions desired must be specified. These considerations indicate the roughness parameters that have to be available for practical problem solution. From the viewpoint of the drainability associated with spatial variations of surface flows which may arise from difference of surface irregularities, the geometric properties of surface which might represent such structure as large-scale or regional trend configurations (linear, convex, and concave components) and small-scale or local irregularities (bump or elevation frequency concerning the roughness continuity) can be considered the most significant terrain information for drainage and alternative surfacing techniques in relation to the optimal design of surface drainage systems.

The above-mentioned concepts of surface roughness show that all of its parameters may be defined in terms of height (ups and downs of surface elevation) and are describable in terms of the statistical parameters of the surface microrelief. Each derivative provides a map of point values, producing a statistical distribution which may be characterised descriptively, by their first, second, and third moments, expessed as mean, standard deviation, and skewness. Hence, the system of derivatives of height at a point, and moments of their distributions over an area, directly cover all morphometric concepts expect for the horizontal dimension. The latter is implicit in horizontal convexity and in the parameters taken in combination; there is probably less of a degree of freedom in the variation of parameters. More information about horizontal distributions may be obtained by the autocorrelation properties of height and its derivative, leading to a stochastic time-series analysis.

According to the reasons given above, the three statistical parameters such as mean, standard deviation and autocorrelation function of stationary height variations (trendless) are adopted as the derivative indicators of surface roughness. This type of analysis and application to digital terrain data is described extensively by the authors (Shiba *et al.*, 1981/82/83/84/86). Statistics such as mean and standard deviation are widely used, and then it is sufficient to point out here that the two-dimensional autocorrelation function $R(\tau, \eta)$ of surface height distributions has the general form of:

$$R(\tau, \eta) = \frac{1}{4XYS^2}\int_{-Y}^{Y}\int_{-X}^{X} Z(x,y)\,Z(x+\tau, y+\eta)\,dxdy \qquad \ldots\ldots(1)$$

where $Z(x, y)$ = deviations from the mean level at (x, y) point;
$Z(x + \tau, y + \eta)$ = deviations from the mean level at $(x + \tau, y + \eta)$ – lag point;
S^2 = variance;
$X \sim -X$ or $Y \sim -Y$ = border points in direction $x-$ or $y-$ coordinate axes.

Design of a measuring method

It is necessary to choose and verify a method of measurement. It is hoped that this method would be both accurate and simple. The surface measurement for the present study was made by conventional ground surveying techniques using autolevels and staffs, after the consolidation work had been performed. This is a perfectly satisfactory method technically but is very slow and tedious because it involves measuring heights at a large number of discrete intervals along the ground. More advanced methods therefore, for example using a comination of acceleration and displacement instrumentation, are expected to be necessary in this application but here this problem is not essential for following analytical procedure and is beyond the scope of this paper.

Measurements must be made on the unit area of the linear segment which is small fractional parts of the areal dimension of individual road surface. To quantify this statement is difficult because no rigourous rules have been set up for field measurements. The approach proposed here is a statistical treatment in which the relative frequencies of occurence of the linear segment of given lengths, or classes of lengths, are determined for an entire tract of surface, or estimated by means of a small rapidly measured sample. Figure 8.1 is the schematic illustration of the unit length of linear segment of a road surface (lower) and the histogram of frequency distribution of linear segment lengths measured by the field survey at the test site (upper). Six main routes of the road network in this area are set for analysis and total lengths of surveyed distance are roughly 20 km on the ground.

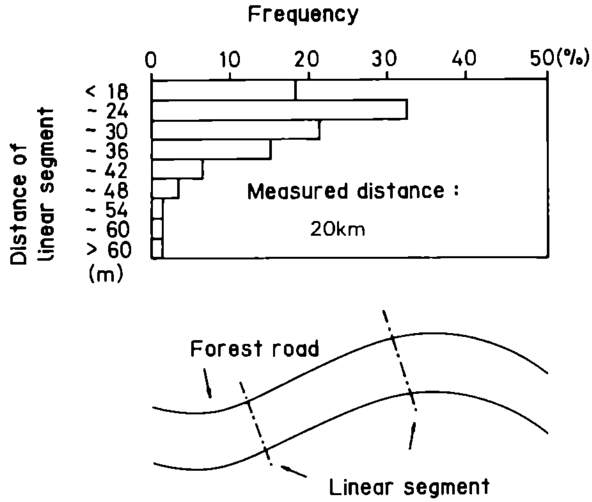


Figure 8.1 *Schematic illustration of the unit length of linear segment of a road surface (lower) and the histogram of frequency distribution of linear segment lengths measured by field survey at the test site (upper).*

The histogram shows that the greater part of the linear segment occurs at the unit length of less than 42 m and therefore, it may be considered that the linear segment lengths of 30 to 40 m reflect general properties of surface roughness in the test site. According to this result, the surface stretch of test plots was arranged with 30 to 40 m lengths.

Test plots were covered by a rectangular grid with a spacing of the intersection points of the grid-lines at 20 cm intervals on the ground, and the heights of surface were measured off at each intersection of mesh. In this procedure, the surface configuration is defined mathematically by inputting X–(longitudinal), Y–(cross-sectional) and Z–(vertical) coordinates for each measured point on the test plot.

General description of test sites

Figure 8.2 shows the topographic map of all-over part of the test site (contour interval is 10 m). Total area shown is 502 ha in extent. The map also indicates the existing forest road network (bold lines) and test sites for road surface inventories (dotted symbols). Topographic characteristics of this area are uplifted plateaux which are irregularly rugged and dissected by many small valleys, and the surrounding plateaux sides consist generally of plains and gently rolling hills. The forest roads are divided into main and secondary, the former type has a width of 3 to 4 m available for trucks of the 6 ton class, and the latter a width of 2.5 m available for small trucks, with a capability for future road widening. Further, these two types are laid out along the ridge sites in general and the interval between corresponding roads is designed to be roughly 100 to 200 m in slope distance.

Figure 8.3 shows plots of the annual change of cumulative length of forest road (solid lines with open circles) and the road density (solid lines with dots) from 1965 to 1983. The diagram indicates that road construction in this area has increased year by year and has now reached a road density of about 63 m ha^{-1}. The characteristics of forest roads in this area are that the cost of construction is very cheap because the route is located to realise easy construction, fewer structures and safety on earth work. The customary logging practice here is the stem-length ground skidding operation by bulldozers weighing 3 tons and the articulated wheel type logging tractor weighing 5 tons, which are used to skid trees out to landing point of either roadside. An average skidding distance is commonly less than 100 m.

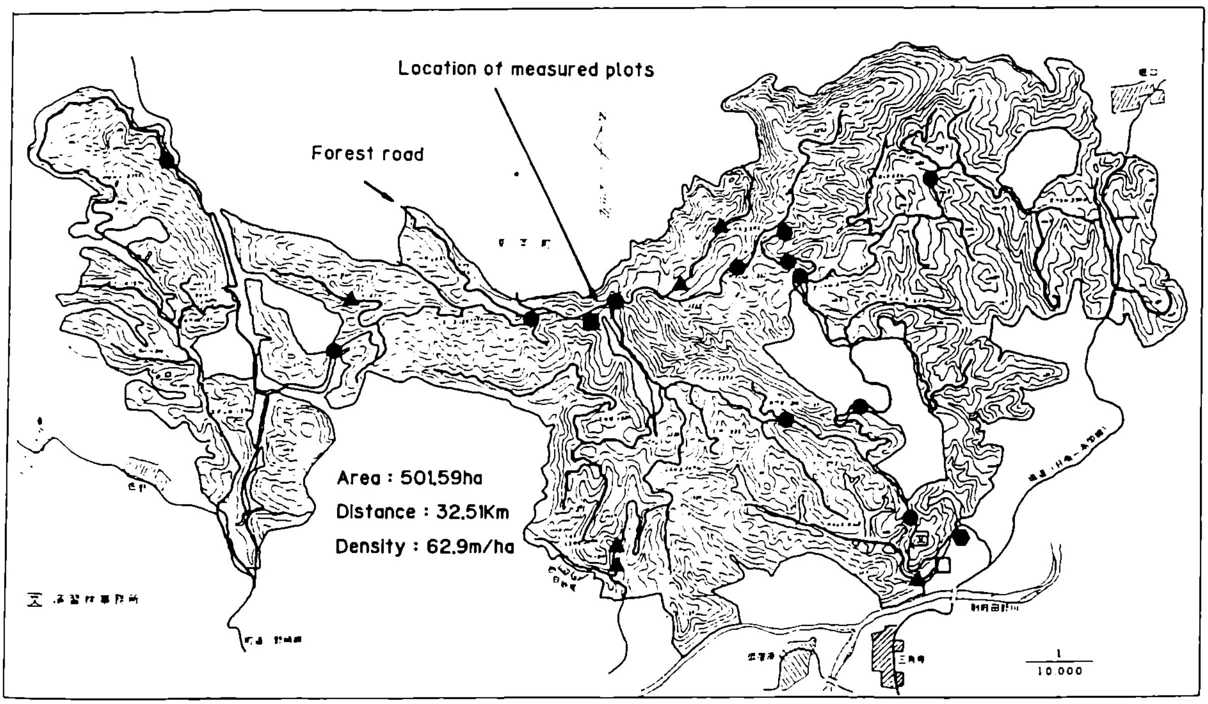


Figure 8.2 Topographic map of the test site. Contour interval is 10 m; total area shown is 502 ha; the locations of the existing forest roads are indicated by bold lines.

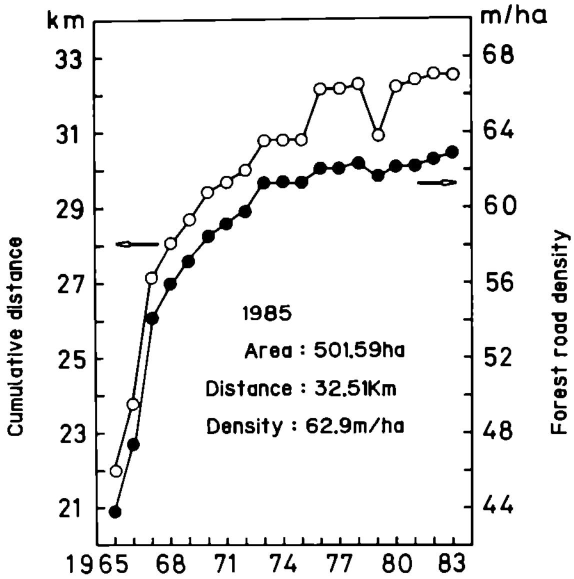


Figure 8.3 *Plots of the annual change of cumulative length of forest road (solid lines with open circles) and the road density (solid lines with dots from 1965 to 1983. Diagram indicates that road construction in this area has increased year by year and now reaches a road density of about 63 m ha^{-1}.*

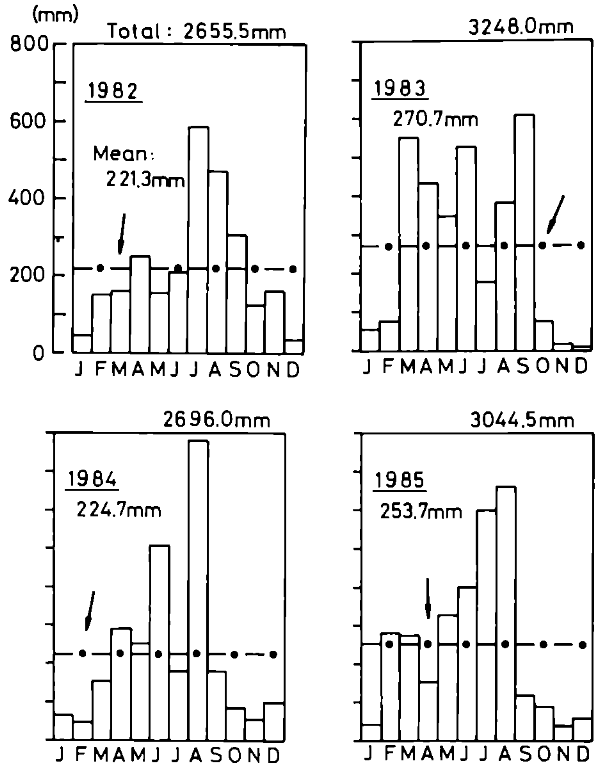


Figure 8.5 *Statistical diagram of the precipitation in this area for the years 1982–1985. The arrow head shows the annual mean precipitation.*

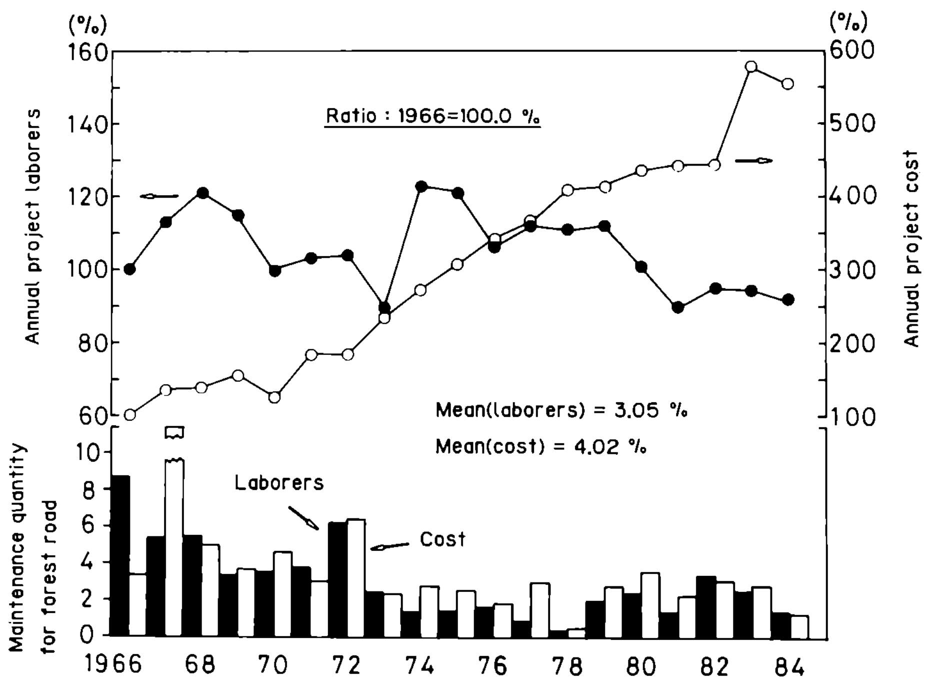


Figure 8.4 *The change of percentage of road maintenance inputs covered in the annual expenditure.*

Figure 8.4 shows the change of percentage of road maintenance inputs covered in the annual expenditure. The plots show that the annual maintenance cost of forest road is commonly about 2 to 4 per cent of the total direct cost, although a rapid increase in the amount of newly-constructed forest roads in the period from 1966 to 1972 is accompanied by a temporal increase in the annual maintenance cost. Figure 8.5 is the statistical diagram of the precipitation in this area for the years 1982-1985. The graph shows that it rains here much more than compared with the annual average rainfall of 1800 mm in Japan.

Statistical properties of the surface roughness

The aim of this preliminary estimate is focused on quantitative comparisons of several types of road surface consolidated by different combinations of operations and machinery, and furthermore these general considerations lead to the formation process for the modelling of the surface roughness. To compare the effectiveness for consolidation work here, two types of machines, the crawler-type KOMATSU bulldozer (4 tons) and the wheel-type TCM loader (4.8 tons) are tested under the operational preconditions such as the 'normal surfacing' and the 'extra smoothing with surface compaction'. Figure 8.6 shows a schematic illustration of the two types of machine. Each machine worked with the same operator, and performance conditions were roughly similar and well within machine capabilities. Table 8.1 is an outline of the operational conditions for consolidation practice.

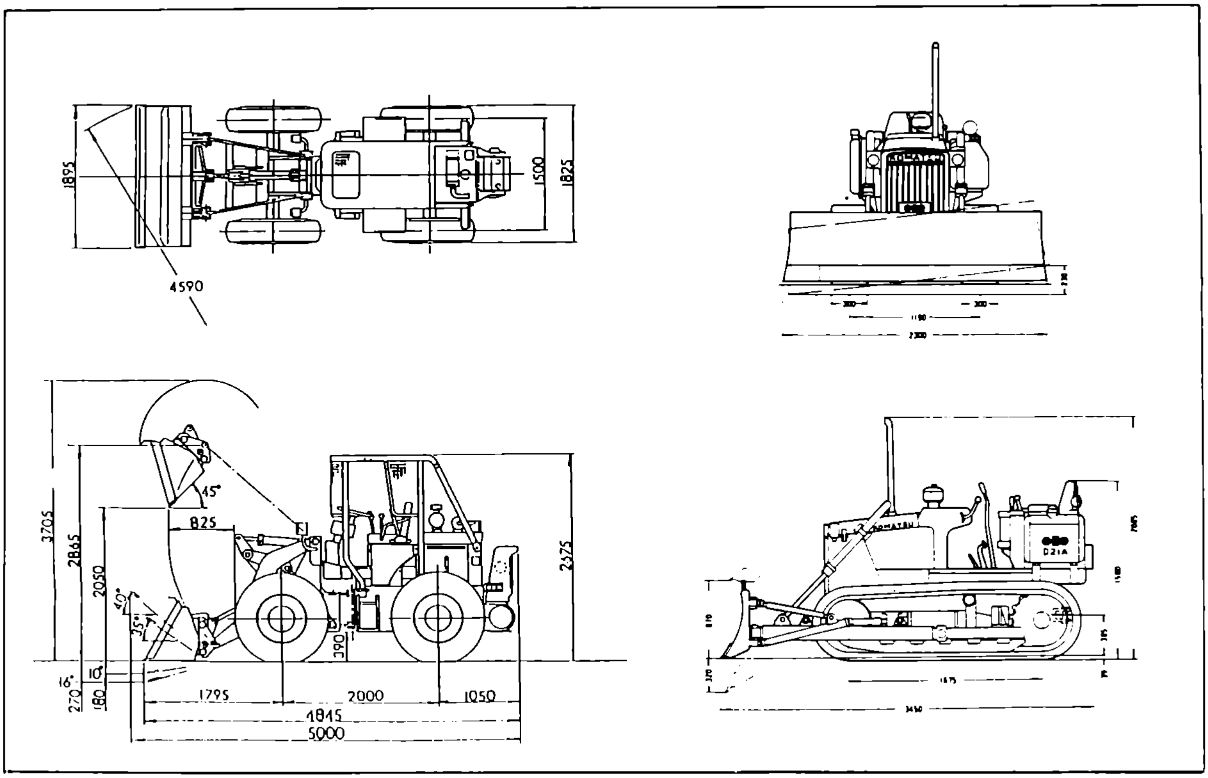


Figure 8.6 Schematic outlines of two types of machine: the crawler-type KOMATSU 4 ton bulldozer (right) and the wheel-type TCM 4.8 ton loader (left).

The mechanical properties of consolidated road surfaces should also be mentioned. To compare the surface strength, a simple load-sinkage (penetration) test was performed using an iron rod with a sharpened conical head (length 204.5 cm; weight 7.7 kg; diameter 2.4 cm; conelength 7 cm; tip angle 21°). Penetration depths obtained by a rod falling at a height of 50 cm, 100 cm and 150 cm from the surface were measured at 20 random sampling points on each test plot. The results are summarised in Table 8.2.

Table 8.1 Outlines of the operational conditions for consolidation practices. X-Coor. = longitudinal direction; Y-Coor. = cross-sectional direction.

Plot	*Operational condition*	*Linear segment* X-Coor.	Y-Coor. (m)*	*Machine*
P_1	Extra smoothing with surface compaction	40	2.8	Crawler-type KOMATSU bulldozer (4 ton)
P_2	Normal surfacing	30	3.2	
P_3	Extra smoothing with surface compaction	34	3.6	Wheel-type TCM loader (4.8 ton)
P_4	Normal surfacing	34	3.2	
P_5	Control plot	30	3.6	Without consolidation practices

Table 8.2 Summary of load-sinkage (penetration) test. Penetration depth obtained by a rod falling at a height of 50 cm, 100 cm and 150 cm from the surface are measured to 20 random sampling points on each test plot.

Falling height:	*50 cm* M±SD(cm)	CV(%)	*100 cm* M±SD(cm)	CV(%)	*150 cm* M±SD(cm)	CV(%)
Plot						
P_1	5.95±0.83	13.95	7.55±1.13	14.97	8.71±1.54	17.68
P_2	8.40±1.80	21.43	11.80±3.33	28.22	12.53±2.91	23.22
P_3	6.65±1.74	26.17	8.20±2.10	25.61	9.53±2.27	23.82
P_4	6.25±1.42	22.72	7.58±1.73	22.82	8.85±2.39	27.01
P_5	6.25±1.24	19.84	7.98±2.08	26.07	9.18±2.10	22.88

Notes: M = mean
SD = standard deviation
CV = coefficient of variation
Rod dimensions = length 204.5 cm
weight 7.7 kg
diameter 2.4 cm
cone length 7 cm
tip angle 21°

It can be seen that each machine has the merits or demerits of the effectiveness in compacting the surface. The KOMATSU bulldozer performs better than the TCM loader in the extra smoothing but is less effective in the normal surfacing. On the other hand, the TCM loader shows relatively little difference of measurements between both operational conditions, compared with that of the KOMATSU bulldozer. The coefficient of variation of penetration values, which reveals the standard deviation as a proportion of the mean, also indicates that in their capability of ensuring the full range of surface conditionings in compaction practice, the KOMATSU bulldozer has certain advantage over the TCM loader.

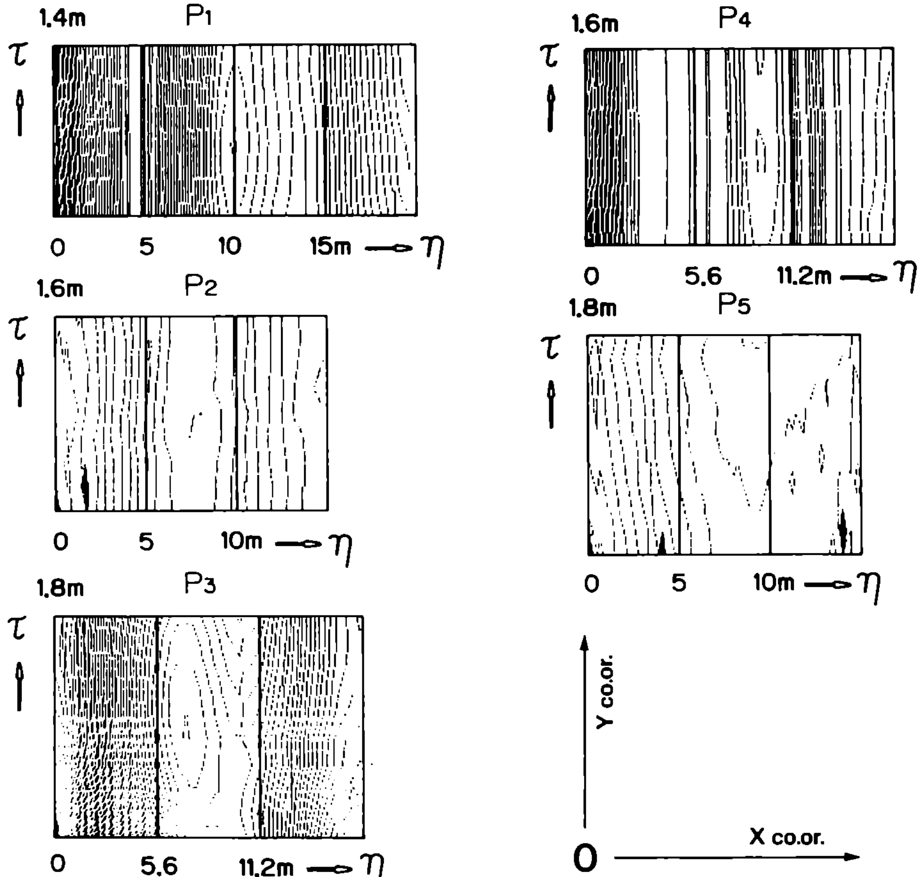


Figure 8.7 Computer-drawn contour map of road surfaces corresponding to each test plot. Contour interval is 5 cm. The longitudinal direction is set to X-coordinate axis and the cross-sectional direction to Y-coordinate axis.

Figure 8.7 shows the computer-drawn contour map of road surfaces corresponding to each test plot. The contour interval is 5 cm. It may be recognised that these surface configurations are considerably related to the regional disparity on the degree of consolidation practices. P_1 and P_3 plots represent the pattern of uniform surface containing the dominant linear trend component. On the contrary, more complex surface with undulating patterns and ripples appears in P_2, P_4 and P_5 plots. Figure 8.8 shows the cumulative frequency diagram of deviation heights from the mean level (trendless height distribution). The straight line fitted to each plot does not exactly fit the points, but it is close enough to them to indicate that they are distributed nearly normally. Figure 8.9 is the comparison of contour maps of normalised surface roughness with zero mean and

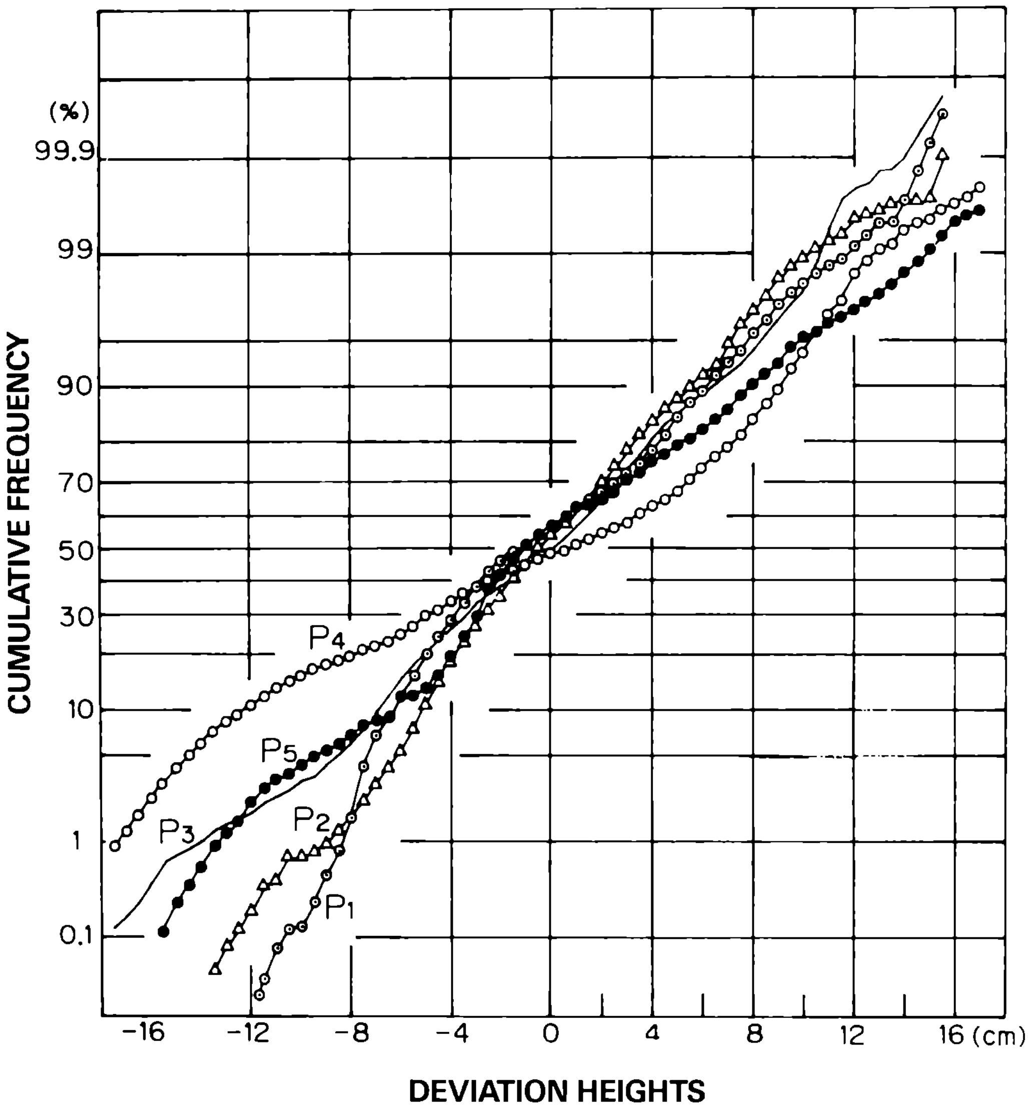


Figure 8.8 Cumulative frequency diagram of deviation heights from the mean level.

variance 1.0. Normalised deviation values from the mean level are a measure of the amount of surface distortion along the base-plane positions.

Table 8.3 is the summary of statistical properties of surface surface roughness. The estimates of P_2 and P_5 types represent a flat configuration with a rough surface since the surface contains relatively large variations with short wavelengths. On the other hand, the estimates of P_1, P_3 and P_4 types characterise a slightly rolling configuration with a smooth surface since the surface contains small variations without short wavelengths. Direct comparison of each

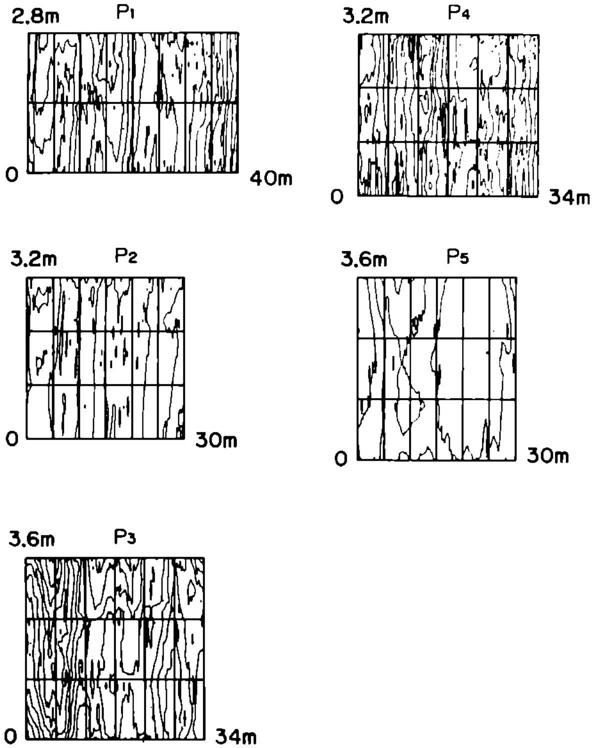


Figure 8.9 Comparison of contour maps of normalised surface roughness with zero mean and variance 1.0. Contour interval is 0.5 cm.

surface roughness on comparable standard deviation and autocorrelation basis, is that P_1 type provides better estimate in smoothing aspect than any other types.

Figure 8.10 shows the comparison of the behaviour of the two-dimensional autocorrelation function of surface roughness. Graphs are represented as the correlogram which is a diagram of the standardised autocorrelation function corresponding to X- and Y-coordinates axes. Contour interval is 0.02. Autocorrelations decline steadily with a distance lag and the correlograms show a simple geometric curve without the apparent periodicity of the peaks and troughs. The high, long-range autocorrelation such as P_1, P_3 and P_4 type is due to the superimposed low frequency fluctuations of surface roughness, where the correlogram shows rather steadily decreasing correlation. In lineated surface roughness such as P_2 and P_5 type, auto-correlation declines more rapidly across the trend of lineation than parallel to it. Figure 8.11 also shows the comparison of the longitudinal section of correlograms along the X-coordinate axis. These characteristics of the correlogram

Table 8.3 Summary of statistical properties of surface roughness to each plot.

Plot	*Trend surface component* — *Mean gradient* *X-Coor.* *tan* θ_x	*Mean gradient* *Y-Coor.* *tan* θ_y	*Goodness of fit* *(%)*	*Standard deviation* *(cm)*	*Autocorrelation* *X-Coor.* ρ_x	*Autocorrelation* *Y-Coor.* ρ_y
P_1	-0.028	-0.028	97.8	4.95	0.917	0.956
P_2	0.032	0.066	86.8	11.18	0.136	0.129
P_3	0.055	-0.059	98.9	5.56	0.863	0.780
P_4	-0.003	-0.064	39.1	7.98	0.942	0.960
P_5	0.024	-0.043	66.9	15.14	0.149	0.144

Notes: Mean gradient = tangent values of the linear trend component fitted by the least-square criterion to observed data.
Goodness of fit = estimated values expressed as the percentage of total sum of squares of linear trend component fitted to the data.
Standard deviation = deviations of the amounts of surface distortion along the base-plane positions.
Autocorrelation = estimated values of autocorrelation coefficient (correlogram values) at the distance lag of 20 cm corresponding to X and Y-coordinate axes.

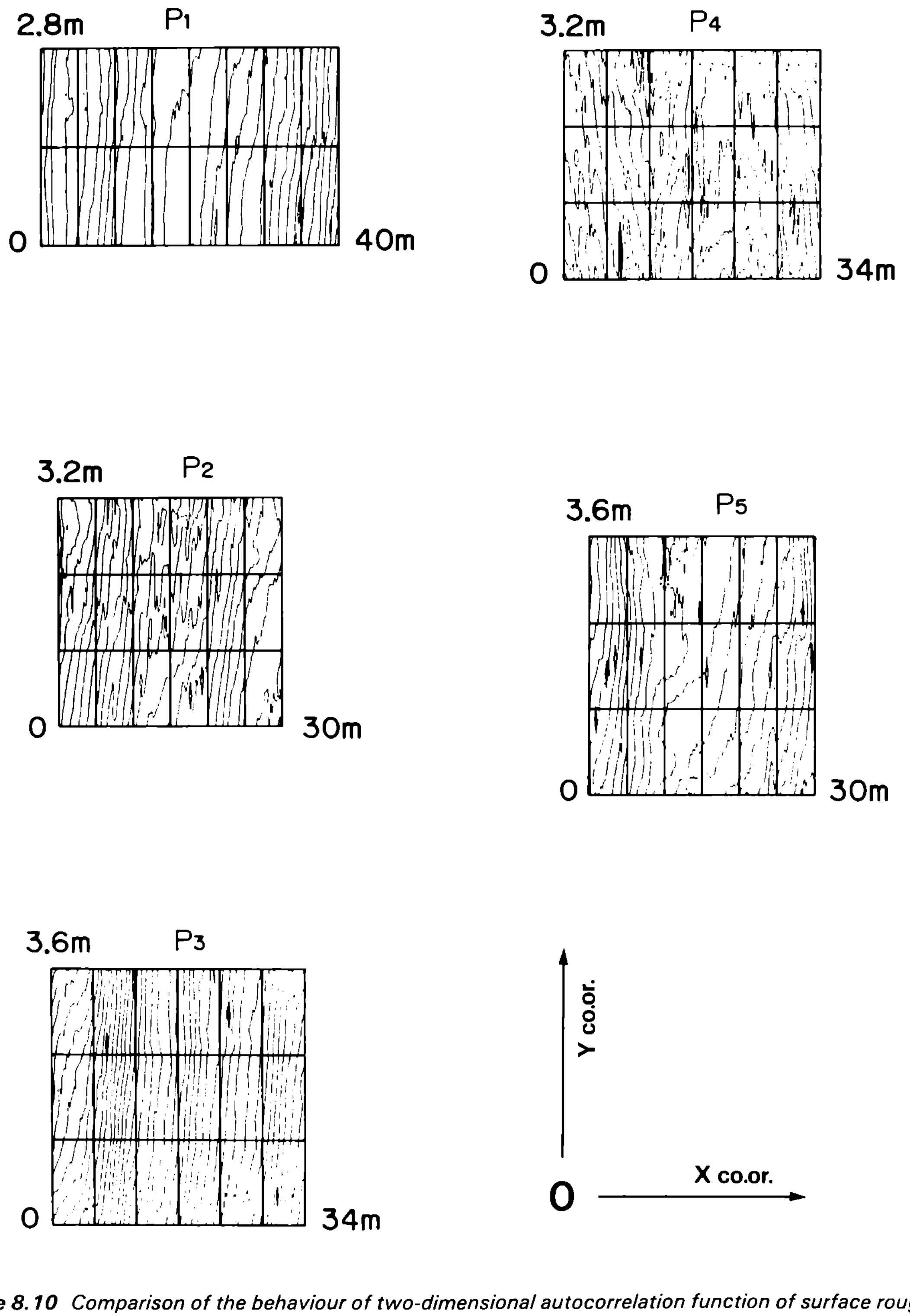


Figure 8.10 *Comparison of the behaviour of two-dimensional autocorrelation function of surface roughness (correlogram). Contour interval is 0.02.*

are typical for auto-regressive process which indicates a first-order autoregressive regular component. Like the discrete Markov-chain model, the lower-order autoregressive process can be fitted as the first approximation to a wide variety of such series.

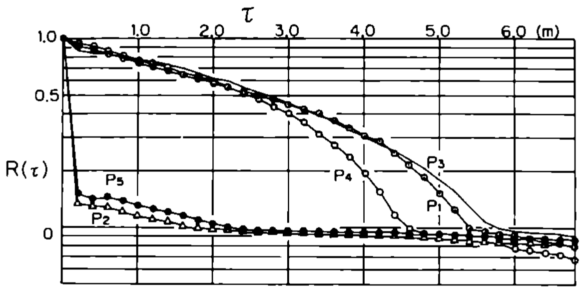


Figure 8.11 Comparison of the longitudinal section of correlograms along the X-coordinate axis.

Framework for computer simulation of road surface roughness

Simulation model of surface roughness

The simulation system to generate two-dimensional surface roughness is formulated by using the first-order Markov model (Auto-regressive (AR) model) which can be represented as:

$$Z_{x,\,y} = \rho_x Z_{x-1,y} + \rho_y Z_{x,\,y-1} + \varepsilon' \qquad \ldots\ldots(2)$$

where $Z_{x,\,y}$ = height distributions of a surface in the $X-Y$ coordinate plane (regularly spaced grid points);

ρ_x and ρ_y = autocorrelation coefficients of standardised height distributions estimated at first-lag position with respect to the longitudinal ($X-$) and lateral ($Y-$) directions;

ε' = white-noise random disturbance with a zero mean and variance 1.0.

Within this autoregressive process, the height distribution at every grid point is characterised by a condition in which the value $Z_{x,y}$ is dependent upon the previous values $Z_{x-1,y}$ and $Z_{x,y-1}$ respectively. In this equation, since the least-squares estimates of the coefficients are obtained by minimising the sum of squares of errors, the term involving ε' is transferred to the right-hand side of equation (3):

$$\varepsilon' = \varepsilon\sqrt{1.0 - \rho_x^2 - \rho_y^2} \qquad \ldots\ldots(3)$$

where ε represents a normal random number. This the AR model of equation (2) can be rewritten in the form of equation (4) as follows:

$$Z_{x,\,y} = \rho_x Z_{x-1,\,y} + \rho_y Z_{x,\,y-1} + \varepsilon\sqrt{1.0-\rho_x^2-\rho_y^2} \qquad \ldots\ldots(4)$$

The procedure for deriving the simulated suface by using equation (4) is briefly described as follows.

First one random number is generated at the original point ($x=0$, $y=0$) in the $X-Y$ planes, as the initial value of the $Z_{x,\,y}$. The values of $Z_{x,0}$ on the $y=0$ line are obtained by setting to zero the coefficient ρ_y of equation (4). The other values of the $Z_{x,\,y}$ under the condition of $y \neq 0$, then are calculated by carrying out the successive substitutions of equation (4).

Here, to generate a normal random number $\{\varepsilon\}$ from a uniform random number $\{z\}$, a simple equation of the following integral form containing exponential of ε is also given as follows:

$$z = \frac{1}{\sqrt{2\pi}}\int_{\varepsilon}^{\infty} e^{-\frac{\varepsilon^2}{2}}\,d\varepsilon \qquad \ldots\ldots(5)$$

As pointed out previously, the values of the $Z_{x,y}$ calculated by using the above procedure indicate the normalised deviation heights. To obtain the real-scaled deviation heights of surface, therefore the normalised values are transformed into the real-scaled values using the following two steps.

A uniform random number $\{\rho_{ea}\}$ is generated by applying equation (6) which has the integral form containing exponential of the $Z_{x,\,y}$.

$$\rho_{ea}=\int_{Z_{x,y}^2}^{\infty} e^{-\frac{Z_{x,y}^2}{2}} dZ_{x,y} \qquad \ldots\ldots(6)$$

Finally the real-scaled deviation height $\{h\}$ is derived from the integral version of equation (7).

$$\rho_{ea}=\frac{1}{\sqrt{2\pi}}\int_{h}^{\infty} f(h)dh \qquad \ldots\ldots(7)$$

where $f(h)$ is the probability-density function according to the frequency distribution of the measured values, and then the approximation of the estimates of equation (7) depends upon the linear interpolation.

AR model fitting to two types of road surface

Here to simulate the surface roughness, two types of road surface P_2 (ρ_x=0.136: ρ_y=0.129: σ=11.18) and P_5 (ρ_x=0.149: ρ_y=0.144: σ=15.14) are tested. Figure 8.12 shows the histogram of deviation heights of two types of road surface.

The diagram indicates a large difference of standard deviation between two types, which could be reflected in the difference of the amount of surface distortion in vertical variations along the base-plane positions. The histogram also represents a similiar characteristic of both surface roughnesses which is a lineated flat configuration with a rougher surface, because the surface contains relatively large variation with various short wavelengths. The two distributions are reasonably symmetric and resemble normal distributions, although their tails are somewhat longer than those for theoretical normal distributions. Figure 8.13 illustrates the estimates of the auto-correlation obtained by applying AR model. The contour interval is 0.05. The auto-correlation function of the simulated surface indicates an arithmetic

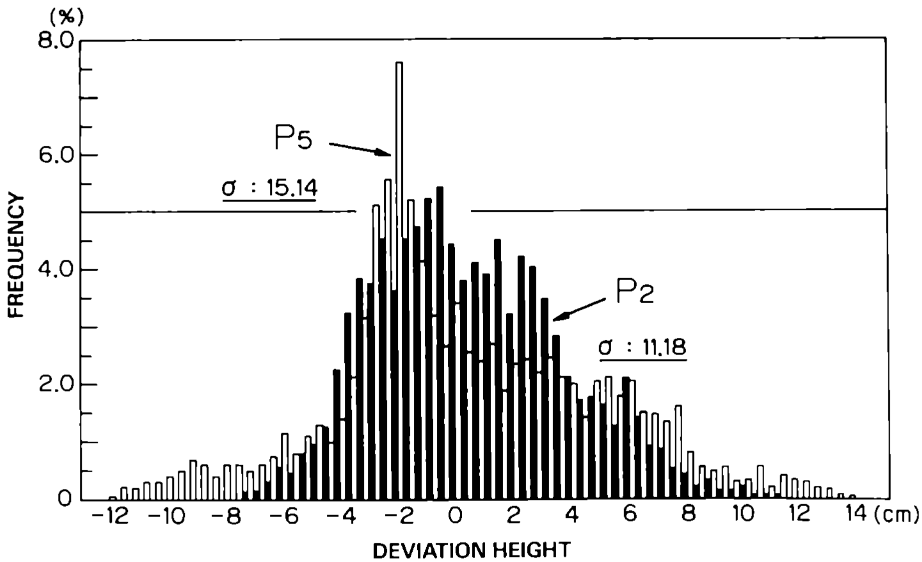


Figure 8.12 Histogram of deviation heights of the two types of road surface.

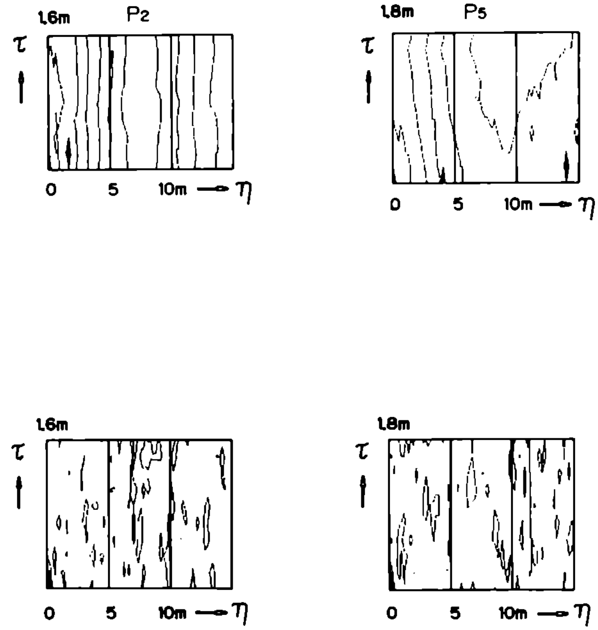


Figure 8.13 Estimates of the autocorrelation obtained by applying the AR model: measured surface (upper), simulated surface (lower) and contour interval is 0.05. The autocorrelation of simulated surface indicates an arithmetic mean of ten-times estimates of model fitting to the same set of data.

mean of ten-times the estimate of model fitting to the same set of data.

The correlogram of the simulated surface roughness is fairly similar to that of the measured surface roughness. There is, of course, some loss in detail in model estimates compared with that of observed data but there is no great difference in its autoregressive conformation among them. In other words, although the statistical properties such as mean, standard deviation and autocorrelation are considerably preserved in the simulated surface roughness, observed data seem to require autoregressive models of high orders for a full description. It should be also mentioned that these preliminary results overcome many of the difficulties of the modelling of the surface roughness and provide a basis for the development of identification of the high-order AR models.

Flow model to estimate the maximum storage capacity in depressions on a rougher road surface

General properties of the surface flow

As was shown above, the microrelief on road surface is highly irregular, and then flow over the surface is usually not steady and uniform but consists instead of intermittent slugs of flow or surges. the oversurface flow moves in trains of waves across the surface. These may be effective in increasing the erosive ability of the flow. Irregularities on the surface also concentrate the flow in rills or in paths which, on a microscale, join together the portions of the slope in depression storage.

General flow models are usually evaluated on the basis of their predictive success to the greater lengths of flow, but it is desirable that they should be applicable not only to large basins but also to small catchments and even to segments of the road surface if they are to have any explanatory power. Although a large number of models to predict runoff from rainfall have been proposed, many of those of practical use are essentially black-box systems in which the operations to convert rainfall to runoff have no counterpart in the physical processes involved. To fit observations on all scales, a flow model must take account of all the processes involved, so that field measurement of road surface and channel characteristics may be related to model parameters.

The approach proposed here attempts to link geomorphic and hydrologic processes more closely, and demonstrates some alternative models which take account of surface flow measurements and can be applied to small catchments. A study is made of the possibility of representing the mode of accumulation of water on a rougher surface and development of oversurface flow by a simple flow model using computer simulation techniques. From the practical viewpoint, knowledge of drainage and alternative surfacing techniques for road maintenace would be enhanced by extending this type of study.

Structure of the proposed flow model

Figure 8.14 is a schematic diagram of the proposed flow model to estimate the maximum storage capacity of rainfall on the road surface. The model shows how the flow moves into irregular depressions. Here, it is assumed that two open channels are arranged at places along the cross-section at both ends of the linear segment and the surface water exceeding the maximum depression storage capacity is thus led into either of these open channels. The computerised procedure to simulate the development of water accumulation in depressions is described as follows.

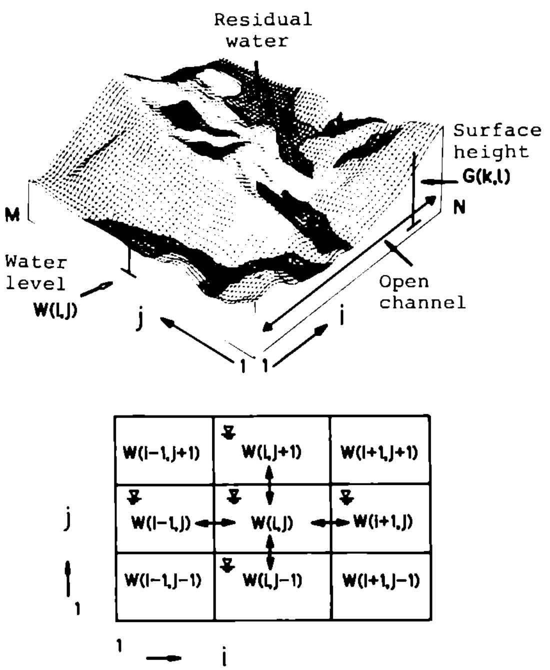


Figure 8.14 A schematic diagram of the proposed flow model to estimate the maximum storage capacity of rainfall on the road surface. Here it is assumed that two open channels are arranged at places along both cross-sectional ends of the linear segment and the surface water exceeded the maximum depression storage capacity and is thus led through either of these open channels.

The road surface is expressed as the unit square in the $X-Y$ plane and it is discretised as an $M \times N$ grid of points. It is assumed that the infiltration capacity of the soil is exceeded and the continuous rainfall is considered to be of uniform intensity.

Let us now image the amount of rainfall R(mm) to be uniformly given on the surface and consider the residual water to be accumlated in depressions. Denote the height distributions of surface by $G_{i,\,j}$ and its water level by $W_{i,\,j}$ which is given by $G_{i,\,j}$ plus R. Then the water level at every grid point is decided by scanning the difference between the height at the neighbours of point (i, j). Here it seems reasonable that the water level at every point connected with open channels, is equal to the height of the channels, therefore the surface water exceeding the channel height is certainly led into the channel. Hence at the initial condition of the loop on scanning the surface, the starting point $(i=i_0, j=j_0)$ is set to the first point (i_0, j_0) of the channel line.

All the necessary computation to estimate the water level, $W_{i,\,j}$ at every point (i, j) in the array and its three neighbours $(W_{i-1,\,j}, W_{i,\,j+1}, W_{i,\,j-1})$ in deciding singularity is performed by the following algorithm.

$$W_{i+1,\,j} = W_{i,\,j}$$

$$\text{if} \quad W_{i+1,\,j} < G_{i+1,\,j} \text{ then } W_{i+1,\,j} = G_{i+1,\,j}$$

In this double loop, the new displacement array can be successively computed from the old displacement array.

Now assuming that water at any point on the surface may be connected to the water level of the channel from various directions, some random point on the surface is reset to the first point, as the starting point in the double loop. Then the water level at every point in the array and its three neighbours in deciding singularity is also scanned by the following algorithm.

if

$$W_{i+1,\,j} > W_{i,\,j} \quad \text{then} \quad W_{i+1,\,j} = W_{i,\,j}$$

$$W_{i+1,\,j} < G_{i+1,\,j} \text{ then } W_{i+1,\,j} = G_{i+1,\,j}$$

Accordingly, by repeating these successive calculations the residual water ratio $Q(R)$ at each amount of rainfall R(mm) can be derived in a simple way written as:

$$Q(R) = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M}(W_{i,j} - G_{i,j})}{R \cdot N \cdot M} \times 100 \qquad (\%) \qquad \ldots\ldots(8)$$

where $Q(R)$ = residual water ratio;
R = amount of the continuous rainfalls;
$W_{i,j}$ = water level;
$G_{i,j}$ = surface heights;
N and M = the size of input matrix;
i and j = the index of grid points.

Estimate of *Q(R)* to different types of road surface

Figure 8.15 is the test run for the function check of the proposed flow model. Output maps show the simulated situation of residual water after rainfall of 100 mm: surface roughness with 1.0 cm contour interval (upper), water level with 1.0 cm (middle) and water depth with 2.0 cm (lower). Estimates of water level and depth obtained by applying the flow model reflect the spatial correspondence of distributions between roughness and accumulated water in surface depressions. As a simulation model of surface flow, the proposed model would clearly pass the test.

Figure 8.16 shows the estimates of the residual water ratio $Q(R)$ corresponding to each type of road surface after removal of the linear trend component. The graph indicates that an increase in rainfall is accompanied by a decrease in the residual water ratio. It appears that initially the ratio is greater, although, for points of increasing rainfall, it approaches an asymptotic limit which may be defined as the 'maximum storage capacity' of the particular road surface conditions. With even these slight differences in surface roughness, each surface tends to produce the saturated accumulation of residual water in depressions preferentially. This result indicates that in potential drainability of surface, P_1 type has a certain advantage over other surface types.

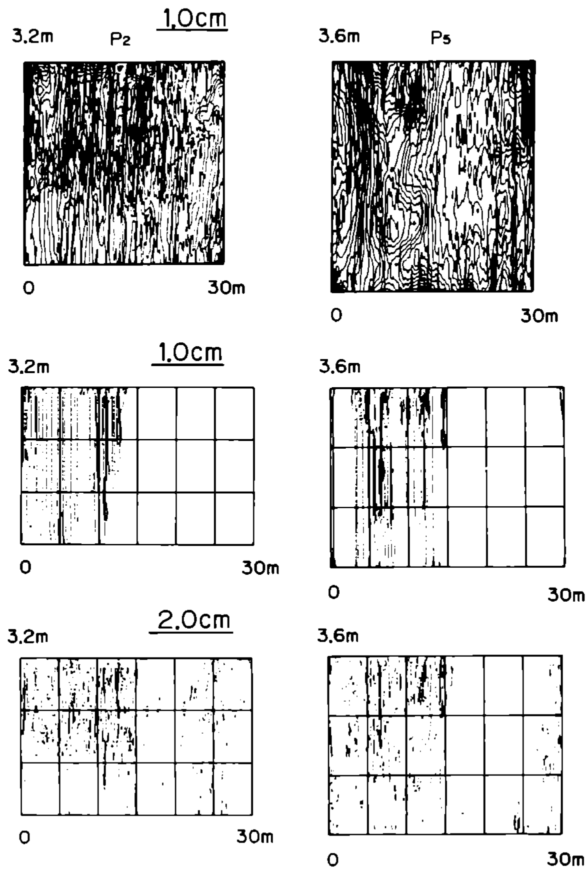


Figure 8.15 Test run for the function check of the proposed flow model. Output maps show the simulated situation of residual water at rainfall of 100 mm: surface roughness with 1.0 cm contour interval (upper), water level with 1.0 cm (middle) and water depth with 2.0 cm (lower).

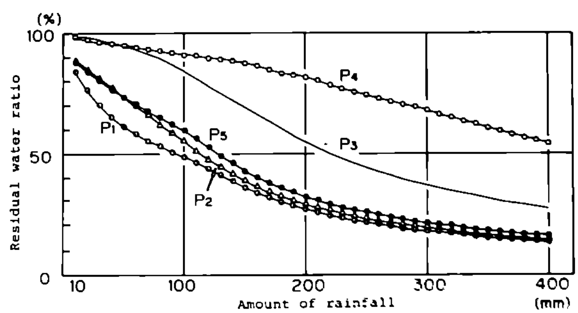


Figure 8.16 Estimates of the residual water ratio Q/R corresponding to each type of road surface, with linear trend component removed.

Figure 8.17 shows the estimates of the residual water ratio *Q(R)* corresponding to each type of road surface with the linear trend component included. The effect of gradient in reducing the residual water in depressions on the road surface appears more clearly in this diagram. With even slight tilting of a surface, the residual water can be considerably reduced. The extent of this tendency in P_1 and P_3 types roughly spread up to 5 to 10 per cent. The effect of differences in surface roughness (including the trend component) on the residual water ratio should be noted. The effect of gradient is here only modified for surfaces with a uniform gradient or with relatively small variations of short wave-length. It may be seen that the influence of a rougher surface with long wavelengths would be to localise the high storage capacity and susceptibility to saturation by oversurface flow into the basal portion of the slope. This means that if the variation of surface roughness is relatively larger than that of the existing trend component, a sufficient reduction of the residual water in depressions by tilting the road surface may not occur because the influence of gradient is blocked by the macrorelief of surface configurations.

Figure 8.18 shows the estimates of the residual water ratio *Q(R)* obtained by applying the simulated road surface corresponding to P_2 and P_5 types. Estimates from the AR model reveal a remarkable difference in the residual water ratio compared with that of the measured surface, But there is no great difference between them in its decrement pattern. This is due to the fact that the first-order AR model is less capable of approximating the complicated surfaces, on a term base, than are AR models of higher orders. These results therefore seem to require AR models of higher orders for a full description of the surface configurations.

Conclusions

This paper presents a simple system of quantitative descriptions of drainage processes on the irregular surfaces of road segments based upon advanced computer simulation techniques, and it proposes an alternative flow model which more closely takes into account linked geomorphic and hydrologic properties. The essential particulars clarified here are listed as follows.

1. The theoretical correlogram of the first-order autoregressive process is a simple geometric curve which declines rapidly when he autocorrelation is weak and less rapidly when its strong. Like the discrete Markov-chain model, the first-order autoregressive process can be fitted as a first approximation to a wide variety of height-field series. Although the statistical properties such as the mean (the best-fit planar surface for heights found using the least-squares method), the standard deviation (the square root of the squared sum of deviations from the mean) and the autocorrelation are considerably preserved in the simulated surface roughness, observed height-field records seem to require autoregressive processes of higher orders for a full description.

2. The simulation by flow models with various gradients and patterns of irregular depressions on a road surface, provides a basis for evaluation of the effects of tilting and smoothing on the surface consolidation. The maximum storage capacity of a surface rapidly decreases with an increase in surface gradient, therefore, the residual water in depressions on a surface can be reduced to small amounts with even slight tilting of the trend surface.

3. The effect of differences in surface irregularities on the residual water ratio must also be noted. The effect of gradient is only modified for surfaces with a uniform gradient or with relatively small variations of short wavelength, but the effect of irregular surfaces with long wavelengths, for example, would be to localise the high storage values and susceptibility to saturation of surface flow in the slope-base portion. This means that if the variation of roughness is relatively larger than that of a given trend surface component, a sufficient reduction of residual water in depressions by tilting a road surface may not occur. The influence of gradient is blocked by the macrorelief irregularities of the surface configuration.

Acknowledgements

The author would like to thank Prof. I. Sasaki and Dr T. Yamamoto of Kyoto University for much encouragement, particularly for

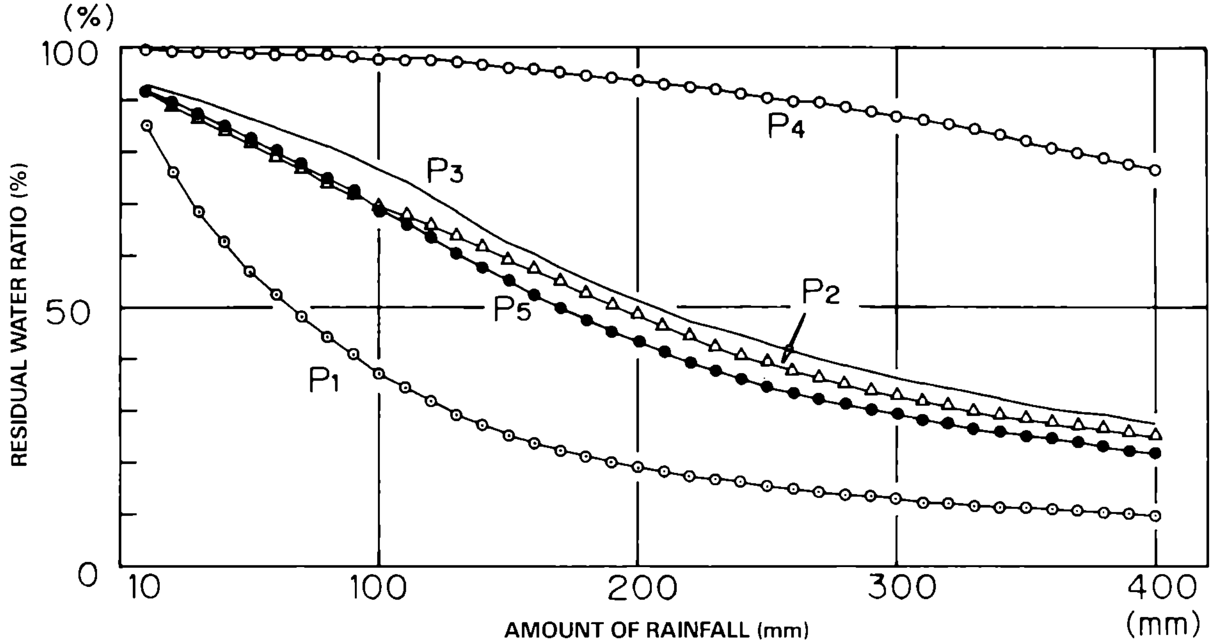


Figure 8.17 Estimates of the residual water ratio Q/R corresponding to each type of road surface, with the linear trend component included.

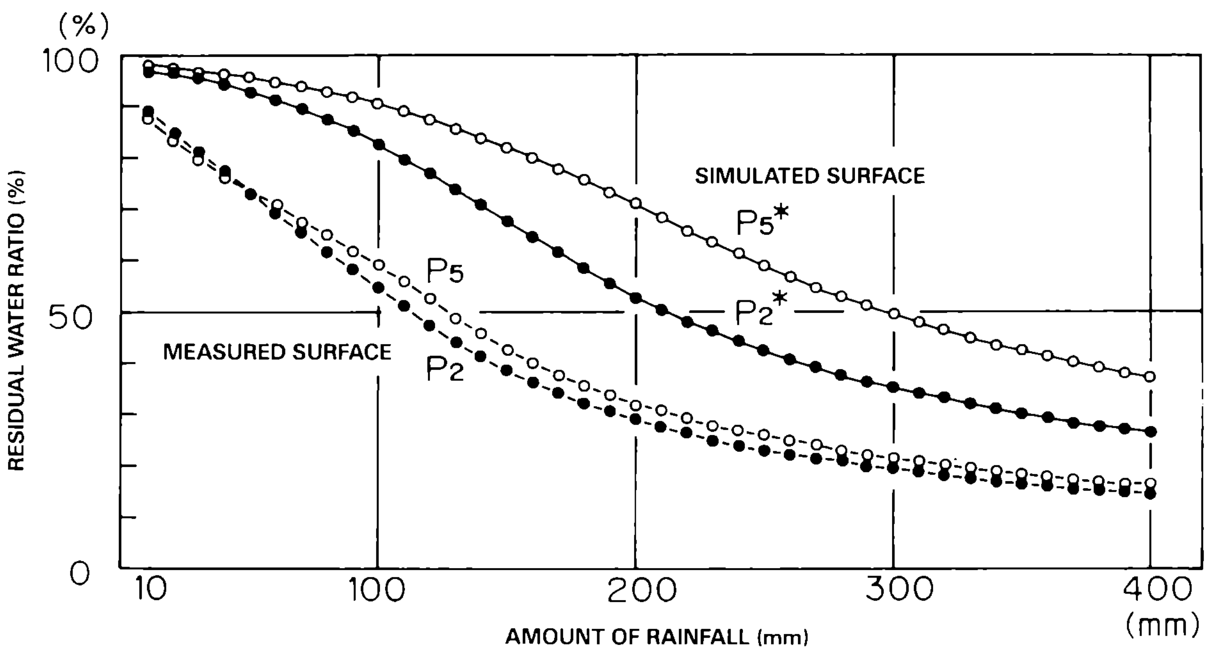


Figure 8.18 Estimates of the residual water ratio Q/R obtained by applying the simulated road surface corresponding to P_2 and P_5 types.

discussions in the early stages of this work. Thanks are also due to Prof. H. Löffler and fellow members of University of Munich for their stimulating advice and many important suggestions on this topic. Finally, the author wishes to express his indebtness to the Alexander von Humboldt Foundation (AvH) for financial assistance to attend this symposium.

REFERENCES

SHIBA, M. (1986). Computer simulation of road surface roughness using the point-by-point information and its applicability to the behaviour of surface drainage. Submitted poster paper (*Proceedings s:3:04*) presented to the *XVIIIth IUFRO World Congress*, Ljubljana, Yugoslavia.

SHIBA, M., SASAKI, I. and YAMAMOTO, T. (1986). Computer simulation of road surface roughness and its applicability to the behaviour of surface drainage. (I). Statistical properties of surface roughness and a computer simulation model. *Transactions of the 97th Annual Meeting of the Japanese Forestry Society*, 637-640*.

SHIBA, M., SASAKI, I. and YAMAMOTO, T. (1986). Computer simulation of road surface roughness and its applicability to the behaviour of surface drainage. (II). Estimation of residual water on road surfaces using a linear flow model. *Transactions of the 97th Annual Meeting of the Japanese Forestry Society*, 641-644*.

SHIBA, M., SASAKI, I. and YAMAMOTO, T. (1987). Studies on drainability and consolidation of forest road surface. *Bulletin of the Faculty of Agriculture, Miyazaki University* **34**, 157-174**.

SHIBA, M. and SASAKI, I. (1981). Application of spatial harmonic and spectral analysis to the quantification of terrain variation in mountainous regions using FACOM M-200 computer. Submitted poster paper (*Proceedings s:3:04*) presented to the *XVIIth IUFRO World Congress*, Kyoto, Japan.

SHIBA, M., YAMAMOTO, T. and SASAKI, I. (1982). Quantification of terrain variation in mountainous regions based upon numerical map analysis by means of electronic computer (II). *Bulletin of the Kyoto University Forests* **54**, 140-163.

SHIBA, M., FURUTANI, S., YAMAMOTO, T. and SASAKI, I. (1983). Quantification of terrain variation in mountainous regions based upon numerical map analysis by means of electronic computer (III). *Bulletin of the Kyoto University Forests* **55**, 194-221**.

SHIBA, M. and SASAKI, I. (1984). Satistical model estimation and identification by Information Criterion. (I). Structure of meteorological time series and accuracy of prediction through autoregressive model fitting. *Bulletin of the Kyoto University Forests* **56,** 98-120**.

SHIBA, M. (1986). *A fundamental study of the quantification of the geomorphological properties of landforms in mountainous regions.* Doctor's Thesis of Kyoto University, 1-208**.

* In Japanese with English titles.
** Japanese with English abstract/summary.

Paper 9

Design and Application of a System Data Bank for Computer-based Forest Operations Planning

*W. **Patzak**, Institute of Work Science and Operational Methods in Forestry, University of Munich, Federal Republic of Germany*

Summary

This paper reports research carried out to develop a knowledge-based decision making system (expert system) to be run on a microcomputer (PC). This system could become a helpful tool for field foresters as well as for scientific researchers. As a first step in this direction, for a solution of the task 'selection of an optimal timber harvesting system under existing pre-conditions', it is proposed to develop a harvesting system data bank based on ORACLE, which is a relational database management system plus a set of integrated software tools for application development and decision support. The concept of the work will be demonstrated by using an example.

Introduction

Nowadays it is becoming more and more important for the forest industries to apply computers in their administrative work and in their operations planning. It is also used to increase the efficiency in the decision taking process. The Institute of Work Science and Operational Methods in Forestry has as one of its goals the development of a knowledge-based decision making system (expert system) to be run on a microcomputer (PC). This system should be an up-to-date tool in respect of the database, the knowledge base and the decision making processes for field foresters as well as for scientific researchers.

The Institute is involved in problems of analysing and synthetising harvesting systems and, according to the available computer hardware in the past, efforts were made to build up a data bank for harvesting systems. As a general view the concept of the work was delineated by a poster presented to the XVIIIth IUFRO World Congress in Ljubljana 1986 (Löffler, 1973 and 1978; Warkotsch, 1975; Patzak, 1984; Patzak and Löffler, 1986). Based on this experience the above-mentioned decision-aid for foresters will be developed. For this task all possible means of advanced computers (PC) and extended software available today have to be used, for example, a database management system with integrated software tools for fast developing applications.

The problem

Such a decision aid has to include the most significant decision methods and has to be flexible and adaptable in use. Sensitivity analysis should make the effects of the decision parameters apparent to the final results, and the possibility of studying alternatives should help to prepare an optimal decision. Generally speaking, for decision making in a practical situation it is more difficult to get reliable information for the special case in a short time than to find the correct decision methods. The solution to this problem could be to develop and use a database for the main activities of a forest enterprise or a forest service. Figure 9.1 shows this problem in outline and indicates a method of solving it.

Proposed solution

The ultimate objective of our research is an expert system. To reach this goal more experience and further advanced software are required. As a first step in this direction the task 'selecting an optimal harvesting system' will be solved by use of ORACLE; this is a relational database management system plus a set of integrated software tools for application development and decision support which runs on a wide range of machines including the IBM PC/AT (ORACLE Corporation, 1987). This system together with the tool SQL*Plus (an interactive command-driven interface to ORACLE, useful for *ad hoc* queries and report writing) makes it easy to survey in two-dimensional tables (rows and columns of data values) on one hand and at the same time query (retrieving data from the database) the stored information on the other hand. It allows the user to define relationships between items in a table and between items in different tables. Database access is via SQL (pronounced 'sequel') a Structured Query Language. SQL allows the user to retrieve, insert, update and delete data; add new tables to the database and so on. SQL is easy to learn because it is used to

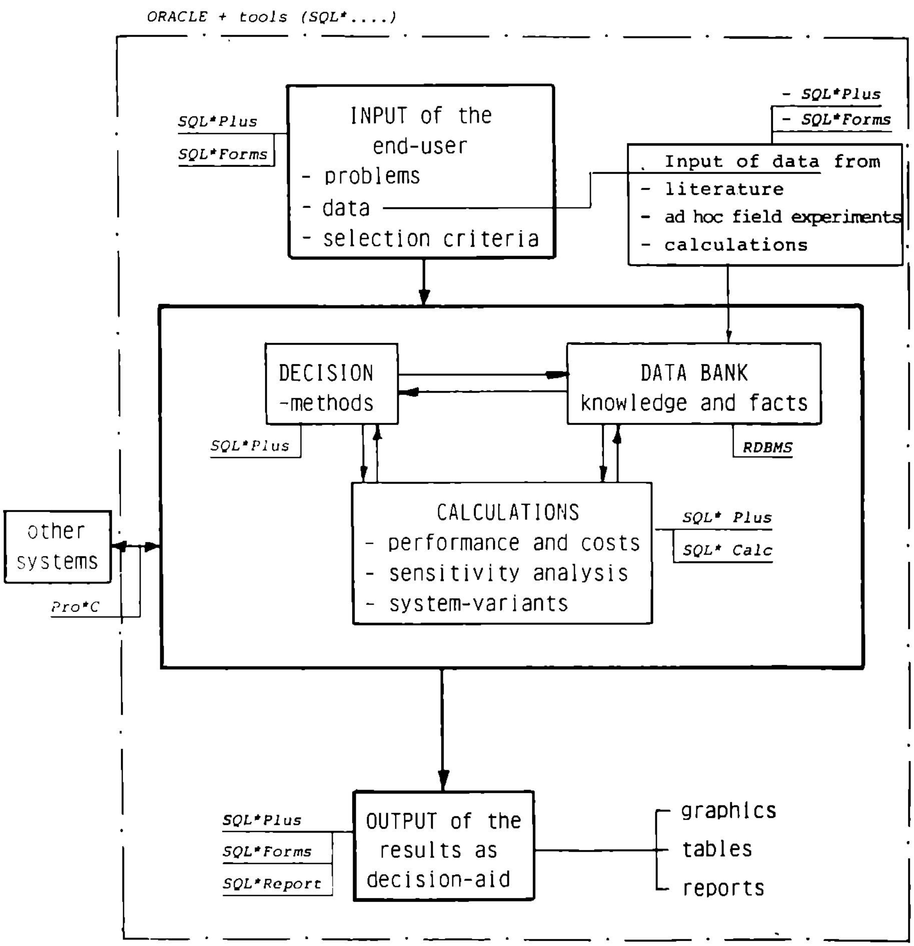


Figure 9.1 *Schematic structure of a computer-supported decision-aid based on the ORACLE database management system.*

specify what is to happen rather than how to make it happen. SQL can be used through an interactive interface or by embedding statements in programs written in a procedural language such as C or FORTRAN. It is an important feature of the ORACLE system that the decision on how to store information need not be made when the database is defined.

A relational database management system stores all database information in a uniform way - as values stored in fields. Any value can be used to associate or join one table to another, and relationships are defined when a query is entered (with SQL*Plus) and not when the table will be created. In short, relationships in a relational database are value-based and dynamic, which means that ORACLE gives the user maximum flexibility in responding to spontaneous queries. This is the case with ORACLE, because SQL works with a set-at-a-time and non-procedurally. The user tells ORACLE WHAT data is required, not HOW to get it. The user can also control the order in which the selected results are displayed and the appearance of the output can be changed. ORACLE supports a complete set of arithmetic and string manipulation functions. These arithmetic and string operations can be performed within the query by the tool SQL*Plus. In case these calculations are not enough, when the tool SQL*Calc (a spreadsheet interface fully integrated with ORACLE data) can be used. In addition, the programmable interface Pro*C (or Pro*FORTRAN) can be used for complex calculations outside of ORACLE. This tool enables the user to write database application programs in a procedural programming language. The results of the programs then flow back to ORACLE for decision making. The decision itself is in most cases based on rules like

IF A . . . , THEN B . . . .

and can be performed by the complex query and selecting feature of SQL*Plus.

The data input into the database and the definition of the query for decision making will be supported by the tool SQL*Forms (it is a full-screen forms interface which allows users to create, modify and use full-screen forms interactively for entering and retrieving database information. Predefined Forms or Masks on the screen will be filled by the end-user, on the one hand as data to store facts and knowledge and on the other hand as query and select criteria to find a suitable solution.

For the output of the results the screen can be used, supported by the tool SQL*Forms or a further tool SQL*Report which is a report generation program that allows users to include database information in reports and to format complex reports. With these tools the results as decision-aids can be presented as reports (text), as tables or graphically. A printer or a plotter can be used as an output device.

According to the conception of the decision-aid generally the following tasks have to be performed:

to enter all decision-relevant criteria into the tables of the database in suitably arranged groups;

to define the required associations in predefined queries or to enable the end-user to perform *ad hoc* queries supported by full-screen forms;

to implement the algorithm for the calculations;

to develop the connection to other programs outside ORACLE for complex calculations and to other data banks.

Example

The flow chart in Figure 9.2 shows how the optimum techniques, working methods and organisation pattern can be chosen under existing preconditions in timber harvesting by the help of computer-supported data banks and analysis methods. Using the example 'production of forest biomass as green chips' the various steps are demonstrated.

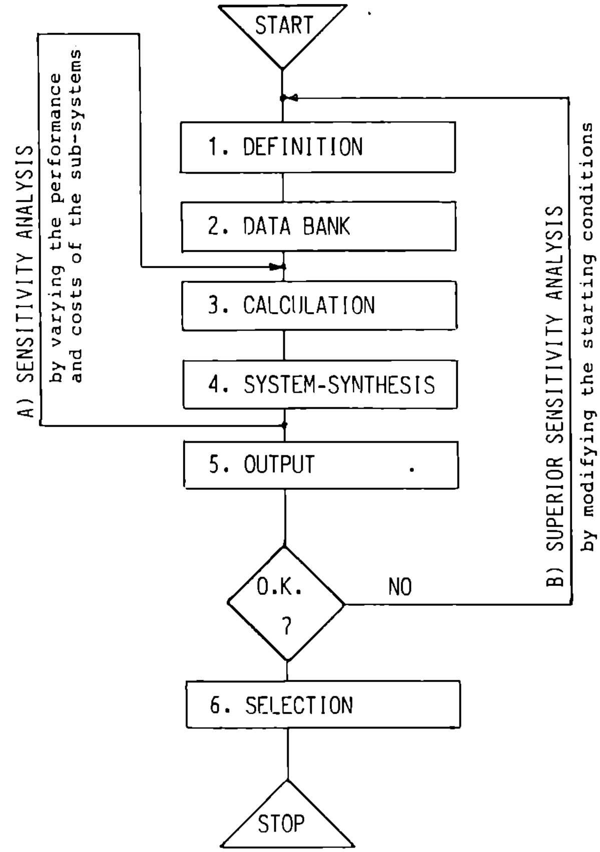


Figure 9.2 Steps to select the optimal timber harvesting system.

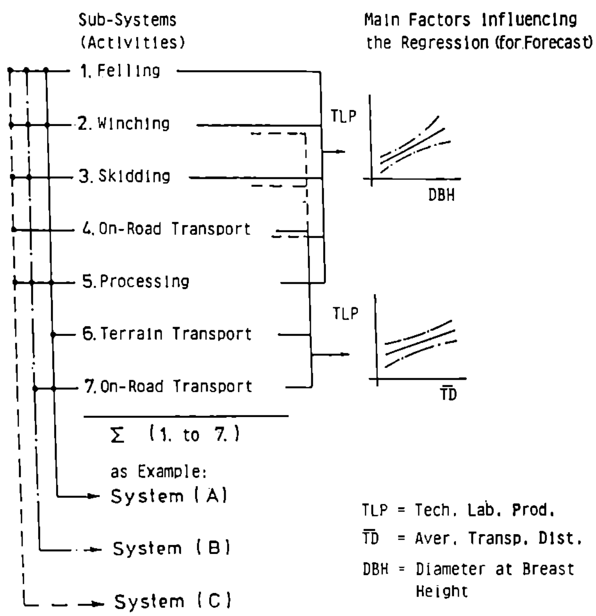


Figure 9.3 Possibilities to combine sub-systems to entire harvesting systems (e.g. system A, B and C).

Step 1: Definition

The definition has to be made:

of the task (e.g. first thinning);
of the preconditions (e.g. species, DBH, etc.);
of the proposed harvesting system (e.g. the work elements) in Figure 9.3; and
of the organisation of the work.

Step 2: Data bank

The subsystems with the characteristics:

of the methods; and
of the working means (e.g. equipment)

must be selected from the data bank (Figure 9.4).

Step 3: Calculation

The calculation of performance and costs (average and variability) must be done:

for the subsystems; and
under the given preconditions

as shown in Figure 9.5.

Step 4: System-synthesis

In this step the following operations must be done according to Figure 9.5.

The calculation of performance and costs with their variabilities—

for the entire harvesting system; and
under the given preconditions

with the result as shown in Figure 9.6.

The sensitivity analysis of the total costs, according to loop A in Figure 9.2 and as shown in Figure 9.7.

The calculation of further parameters of the harvesting system mentioned in Figure 9.8.

X. Equipment

Source mark-number	*Performance m³/MAS*		*Costs DM/MAS*		*Further factors and preconditions*			
	±%		±%		±%			±%
1	2	3	4	5	6	7	8	etc.
001								
002								

2. Winching (pre skidding)

Source mark-number	*Performance m³/hGAZ*				*Costs DM/h*				*Further factors and preconditions*	
	personnel		*equipment*		*personnel*		*equipment*			
		±%		±%		±%		±%		
1	2	3	4	5	6	7	8	9	10	etc.
001										
002										
003										

1. Felling

Source mark-number	*Performance m³/hGAZ*				*Costs DM/h*				*Further factors and preconditions*	
	personnel		*equipment*		*personnel*		*equipment*			
		±%		±%		±%		±%		
1	2	3	4	5	6	7	8	9	10	etc.
001										
002										
003										

MAS = MH = machine hour GAZ = TWT = total working time

Figure 9.4 *Example of the layout of the data bank (relational database).*

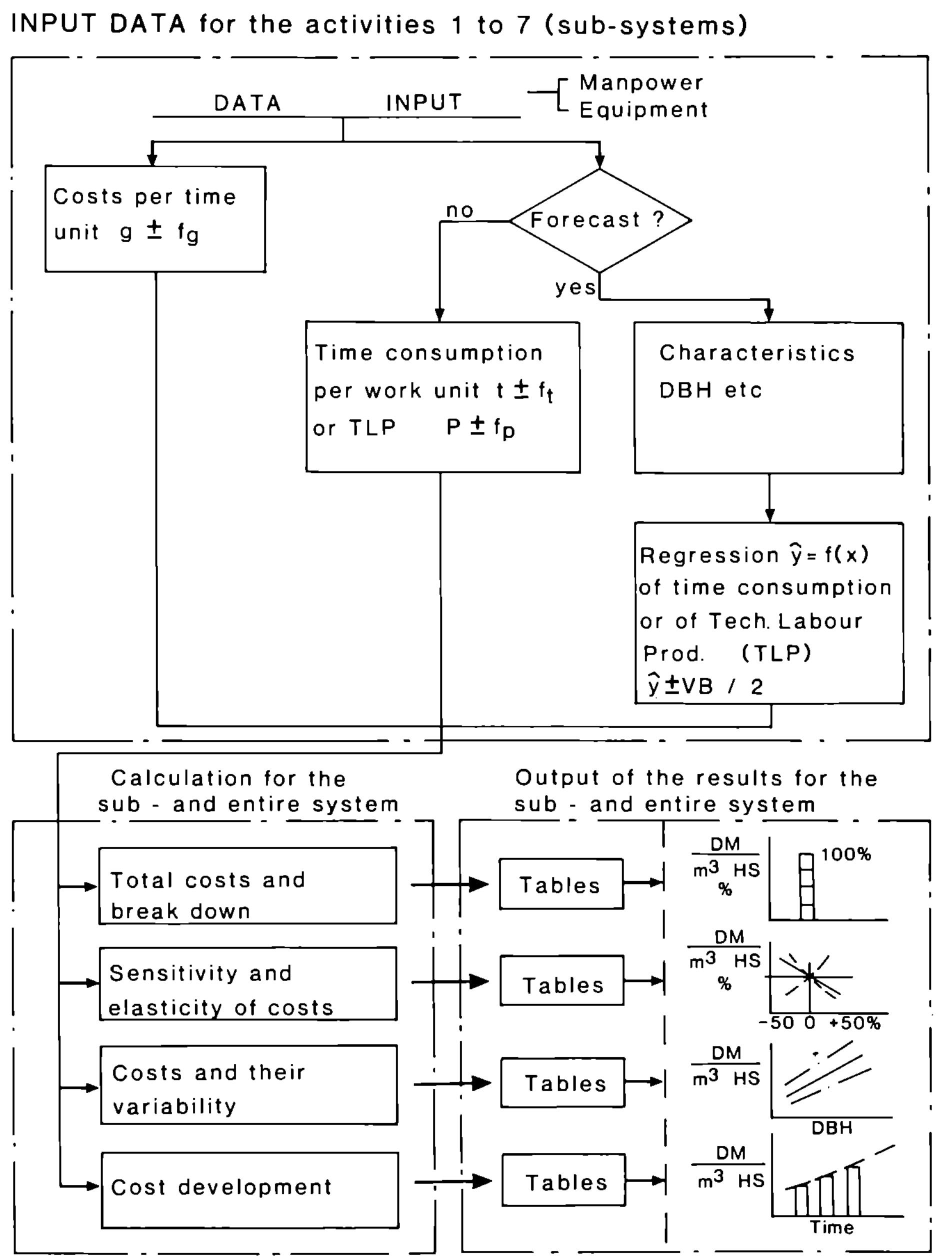


Figure 9.5 *Flow chart for the system-cost-analysis (and synthesis) of timber (chips) harvesting.*

Step 5: Output

The out of data for decision making (overall result) is in the form of tables and graphs (Figures 9.6, 9.7 and 9.8).

Step 6: Selection

The selection of the optimum harvesting system under the existing preconditions will be reached by an iterative process with a superior sensitivity analysis by modifying the starting conditions according loop B in Figure 9.2.

Figure 9.6 *Example of an output of step 5 in Figure 9.2. Biomass chips harvesting cost and estimated uncertainty (probable error ±%)* for system (A), variant 1.

Bulk density 6 × 0.1550 tatro/m³HS **Error** L × 15.00% **Volumes harvested** M × 160.00 m³HS/ha
Error O × 40.00%

	Time consumption		*TLP*		*SP. costs*		*Cost and its errors*						
	min/ m³HS	*error ±%*	*m³HS/ hGAZ*	*error ±%*	*DM/ h*	*error ±%*	*DM/ m³HS*	*error ±%*	*DM/ tatro*	*error ±%*	*DM/ ha*	*error ±%*	*Change of U%*
	N	*O*	*P*	*Q*	*R*	*T*	*U*	*Y*	*V*	*F*	*X*	*V*	*S*
	12.82	50.60	4.68	50.60	25.00	50.00	5.34	71.14	34.46	72.70	854.70	81.61	0.00
Felling	12.82	50.60	4.68	50.60	8.00	50.00	1.71	71.14	11.03	72.70	273.50	81.61	0.00
	0.00	0.00	0.00	0.00	33.00	75.91	7.05	56.58	45.49	57.83	1128.20	64.92	0.00
	17.60	17.80	3.41	17.80	25.00	50.00	7.33	53.07	47.30	55.15	1173.01	66.46	0.00
Winching	17.60	17.80	3.41	17.80	20.00	40.00	5.87	43.78	37.84	46.28	938.42	59.30	0.00
	0.00	0.00	0.00	0.00	45.00	39.56	13.20	35.33	85.14	36.90	2111.42	45.36	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Skidding	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VB-on-road transport	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11.39	98.00	5.27	98.00	25.00	50.00	4.74	110.02	30.61	111.04	759.01	117.06	0.00
Chipping	11.39	98.00	5.27	98.00	100.00	60.00	18.98	114.91	122.42	115.88	3036.04	121.67	0.00
	0.00	0.00	0.00	0.00	125.00	136.16	23.72	94.52	153.03	95.33	3795.05	100.11	0.00
HS-terrain transport	4.45	12.40	13.48	12.40	25.00	50.00	1.85	51.51	11.97	53.65	296.73	65.22	0.00
	4.45	12.40	13.48	12.40	70.00	40.00	5.19	41.88	33.50	44.48	830.86	57.91	0.00
	0.00	0.00	0.00	0.00	95.00	35.91	7.05	33.70	45.47	35.69	1127.59	45.99	0.00
HS-on-road transport	1.50	50.00	40.00	50.00	25.00	50.00	0.63	70.71	4.03	72.28	100.00	81.24	0.00
	1.50	50.00	40.00	50.00	90.00	50.00	2.25	70.71	14.52	72.28	360.00	81.24	0.00
	0.00	0.00	0.00	0.00	115.00	76.15	2.88	57.43	18.55	58.71	460.00	65.99	0.00
Total system	47.75	27.88	1.26	27.88	125.00	22.36	19.90	38.25	128.37	39.05	3183.45	43.61	0.00
	47.75	27.88	1.26	27.88	288.00	27.97	33.99	65.17	219.31	65.81	5438.81	69.58	0.00
	0.00	0.00	0.00	0.00	67.71	51.64	53.89	43.47	347.67	43.94	8622.26	46.75	0.00

changes of variant x against variant 1

average cost of one system hour (DM/h/man)

average technical labour productivity of the total system

ha = hectare VB = whole tree HS = chips TLP = technical labour productivity GAZ = TWT = total working time tatro = ton oven dry

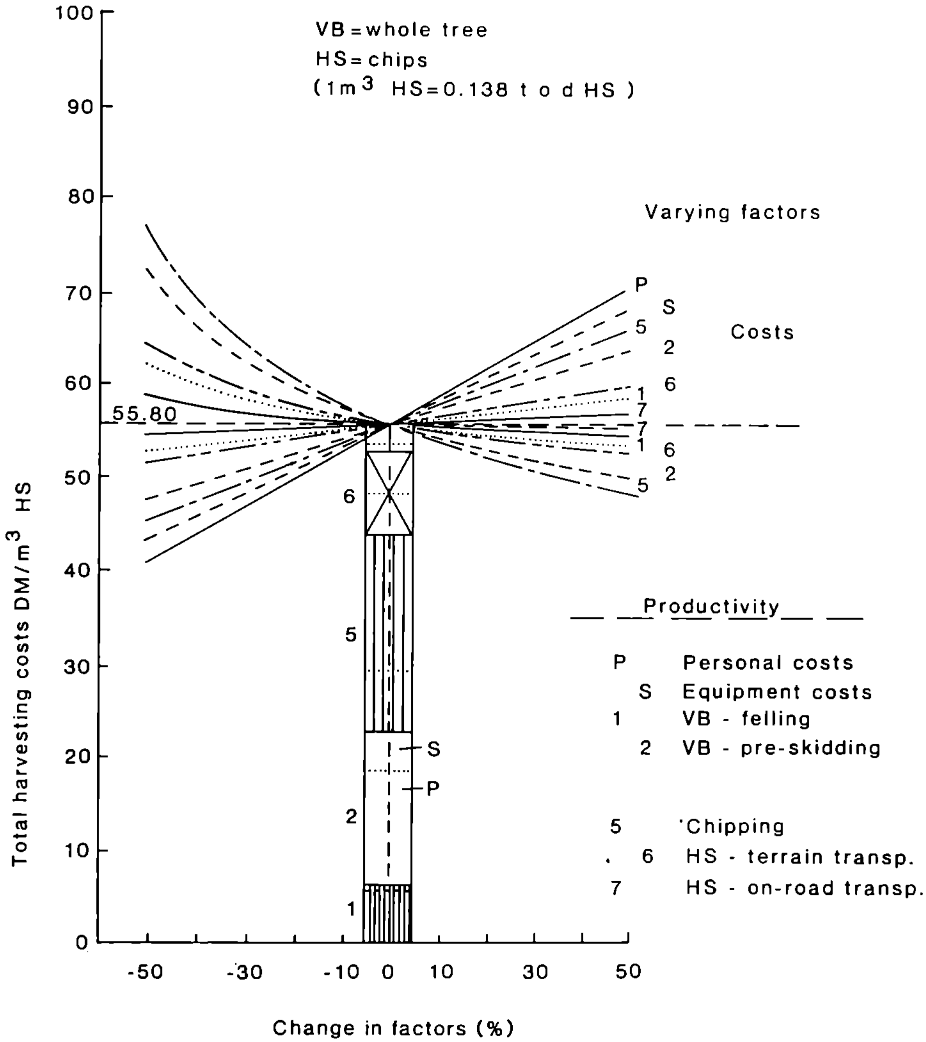


Figure 9.7 *Example of an output of step 5 in Figure 9.2. Breakdown and sensitivity of costs for harvesting whole-tree chips, by system (A) with bag-system, selective first thinning of spruce stands.*

The procedure of selection itself can briefly be described as follows. First the user has to enter the data. They comprise the figures of those parameters which describe the task, the preconditions and the subsystems. They are simultaneously the criteria to be used for the selection of the working methods and the technical means from the data bank (step 2).

The calculations for step 3 and step 4 are performed either within the select and output routines of the ORACLE-tools or in separate computer programs which are connected with ORACLE by a language interface. To support the end-user to choose a suitable harvesting system in step 6 the output of step 5 comprises the following decision-aids:

the total cost of a system and its structure (e.g. the column in Figure 9.7);

the sensitivity (elasticity) of total cost (e.g. as an effect of a change in any of the productivity or cost factors in each work phase (1 to 7) in Figure 9.7);

the effect of uncertain data entry on the total cost (e.g. in Figure 9.6); and

the possible cost development in the future.

In addition to these the following are presented for the entire harvesting system (Figure 8):

the average technical labour productivity (TLP);

the working area required by the system;

the personal requirements;

the energy input; and

the financial requirements for investments.

```
FURTHER CRITERIA

AS DECISION-AIDS:


SYSTEM

- AVERAGE PERFORMANCE IN M3/HOUR

- WORKING AREA REQUIRED IN HECTARES/DAY

- PERSONAL REQUIREMENTS

- ENERGY INPUT IN KWH/M3

- FINANCIAL REQUIREMENTS IN DM
```

Figure 9.8 *Example of an output of step 5 in Figure 9.2. Further criteria of the entire harvesting system as decision-aids in step 6.*

Conclusions

With the proposed conception of a computer-supported and data bank based decision-aid the end-user should be able to find a suitable system for the task:

- if this system really exists and it is stored in the database;
- or else the user should be able to configurate a system according to his needs, with stored subsystems and components.

The present development of the proposed decision-aid is still at a prototype stage. The next steps which are needed for further development of this tool are:

to add more data to the tables of the database;

to implement further algorithm for calculation;

to design user-friendly data-input forms and forms for query and selection;

to develop suitable outputs (tables, graphs and reports) for practical use to make decisions flexible and extensive.

The aim, to develop an aid for decision-making for field work based on the database management system ORACLE, seems to be feasible with the suggested conception. The decision itself at this stage has to be made by the end-user. To reach the goal in making the decision automatically by use of a computer, according to stored decision-rules in a knowledge-base (e.g. with an expert system), there is still a long way to go. For this task, other more advanced methods and software tools (e.g. expert system shells) have to be used. But the proposed harvesting system database which is still in the initial stages could be an element of an expert system in the future.

REFERENCES

LÖFFLER, H. (1973). Die Planung von Holzerntesystemen in Rahmen des Zielkonzepts eines Forstbetriebs (ein methodischer Beitrag zur Anwendung system-analytischer Methoden in der Forstwirtschaft). In *Tagungsmappe des VII. Internationalen Forsttechnischen Symposium 1973,* Münchehof/Reinbek, hrsg. vom Institut für Forstliche Arbeitswissenschaft der Bundesforschungsanstalt für Forst- und Holzwirtschaft Reinbek.

LÖFFLER, H. (1978). Arbeitswirtschaftliche und technische Analyse der Holzernte im Bauernwald. *Allgemeine Forstzeitschrift,* Nr. 20/21.

ORACLE CORPORATION (1987). *Documentation - ORACLE for IBM PC/MS-DOS.* Belmont, California, USA.

PATZAK, W. (1984a). Bereitstellung forstlicher Biomasse aus Erstdurchforstungen in Fichten- und Kiefernbeständen. Teil I des Abschlußberichtes zum Projekt: 'Bereitstellung forstlicher Biomasse'. *Bericht des Lehrstuhls für Forstliche Arbeitswissenschaft und Verfahrenstechnik der Universität München, Forschungsbericht C 076/I* des Bundesministeriums für Forschung und Technologie, Bonn.

PATZAK, W. (1984b). Untersuchung von Systemen zur Bereitstellung forstlicher Biomasse auf der Grundlage einer Analyse des Schrifttums. Teil II des Abschlußberichtes zum Projekt: 'Bereitstellung forstlicher Biomasse'. *Bericht des Lehrstuhls für Forstliche Arbeitswissenschaft und Verfahrenstechnik der Universität München, Forschungsbericht C 076/II* des Bundesministeriums für Forschung und Technologie, Bonn.

PATZAK, W. and LÖFFLER, H. (1986). Computer-supported analysis of timber harvesting. *Beitrag zur Poster Session der Div. 3 beim XVIII. IUFRO-Weltkongreß 7.-21.9.1986,* Ljubljana, Yugoslavia.

WARKOTSCH, W. (1975). Darstellung und Analyse von Systemen und Verfahren der Holzernte. *Allgemeine Forstzeitung* **30,** 859-861.

Paper 10

Access to the Subcompartment Database at Local Level

*A.J.A. **Betts**, Forestry Commission, Forest Research Station, Alice Holt Lodge, Wrecclesham, Farnham, Surrey, GU10 4LH, U.K.*

Abstract

The availability of reliable information on productive forest crops is of crucial importance for planning and forecasting. In the British Forestry Commission a crop and site database has been in existence since 1976 but only since 1986 have the data become available to staff on their local microcomputers. Formerly, computer facilities were centrally based and local managers could only interrogate their data through an intermediary. The software now available at local level allows for general interrogation of data (e.g. sorting, listing, ranking). It does not enable more sophisticated use such as is required for production forecasting. Nevertheless local access to data has given managers the ability to analyse information more effectively and to use it as a routine tool for forest management.

Introduction

The ready availability of reliable information on the forest estate is of crucial importance to the forest manager. Short-term planning and long term forecasting both rely heavily on data collected in the forest - indeed the success of management programmes is often directly related to the quality of data available. Foresters have long recognised that their efforts are best supported by up-to-date maps and associated crop details. Nowadays the forest manager will control many thousands of hectares and as a result the style of management will tend to be extensive rather than intensive. The need to maintain proper records is thus of great importance where management may need to rely more on written records than personal knowledge.

The average Forest District in Great Britain for example will have about 15 000 hectares of forest divided into perhaps 750 compartments. Each compartment is likely to have a number of separate subcompartments (i.e. distinct stands according to species and age) and it would not be unusual to have over 5000 distinct stands - each with specific information available on species, age, area, growth rate, etc. Not only does the manager have this large quantity of existing information, but there is also a need to predict future production of the forest by combining such information with silvicultural and economic prescriptions. The use of computers is well suited to the storage and manipulation of crop and site data.

Historical background

Within the British Forestry Commission a computer-held database describing crop and site features has been in existence since 1976. Formerly, records at the subcompartment level were maintained on individual paper cards by local forest staff. Although some manual sorting of data was possible (by means of holes punched in the cards) the detailed work required to produce crop summaries and forecasts of timber was extremely onerous. It was in an effort to reduce this workload that a computer-held subcompartment database (SCDB) was originally developed. Thus it should be appreciated that the SCDB was developed to carry out specific tasks rather than to make record keeping easier. This emphasis on production forecasting determined what data was originally incorporated into the database - indeed it could be said that the SCDB is geared to present and future requirements rather than for the storage of historical information.

Content and maintenance of the subcompartment database

The subcompartment database is centrally held and maintained at the Forest Research Station, Alice Holt Lodge, near Farnham, Surrey. It contains information on:

1. location and area (e.g. compartment, map grid reference);
2. legal status (e.g. purchased, leased);
3. land use classification (e.g. forest, agricultural);
4. forest crop (e.g. species, age, growth rate);
5. site (e.g. altitude, soils, windthrow hazard);
6. designations (e.g. conservation constraints);
7. management regimes (e.g. a code to link the SCDB with management prescriptions).

In addition there is scope for several fields to be used for information only important at local level (e.g. thinning cycle, local site types).

Subcompartment database records are amended in two ways. Firstly, as a result of new surveys. Data for a whole forest is normally completely revised every 15 years by a specialist survey team. Input of data from surveyors is by a manual form, the contents of which are then punched for computer entry by trained operators. A new printout of the data is then passed to local forest staff with the master copy remaining on computer file at Alice Holt.

Secondly, as the result of annual revision by local forest staff. Using the same input form as the surveyors, information on major changes to the growing stock is submitted each year by the staff actually responsible for the changes. Most of this information relates to the felling and subsequent replanting of specific areas but staff may change any part of the database if they have good cause. The base date for this revision is 31 March of each year. A new printout of the complete SCDB is returned to the forest manager after the data have been checked by the database manager and subjected to verification programs held in the computer. It is very easy for mistakes to occur and it is only really possible to check those which conflict with data structure. For example, if a forest crop is given a land use code indicating a reservoir the computer will alert staff. However, if the wrong species is given at time of replanting the mistake may remain undiscovered for many years until time of a new survey. It is interesting to note that the quality of local updating varies enormously from one Forest District to another.

The revised printouts of the SCDB are returned to forest managers about a month after submission of amended data although this can be much delayed if there are errors to be corrected. Although individual record cards still exist in many forests (they were continued for some time after the introduction of the SCDB) use of the computer printout as an aid to management planning is now routine. In combination with stock maps, the printout can be used in a systematic way to prepare and plan for both harvesting and forest management work. Using centrally held programs forest managers are able to request listings and analysis of their data.

Uses of the data

The main use of the subcompartment database at national level is for the production of twenty-year production forecasts. For each subcompartment (of which there are 200 000 in Britain) crop data combined with yield model data derived from permanent sample plots (Edwards and Christie, 1981) and management information (e.g. time of felling, type of thinning). Forecasts for each Forest District are produced and summated to give regional and national figures. It is extremely important that forest managers are involved in this exercise, as they are in the best position to describe the particular management regimes existing in their own areas. As well as providing major forecasts (which are now nationally revised every 3 years) a valuation of the Forestry Commission estate is also required. Increasing use is also being made of the SCDB at national and regional level to determine land use statistics - a requirement for which the SCDB was not originally designed. There is also some research use of the SCDB at regonal levels to identify likely experimental areas and to investigate relationships between species growth and site factors.

Microcomputer support of the subcompartment database

It is only within the last 2 years that Forest District staff have been able directly to access their crop and site data in computer-held format. This has come about as a result of a general move towards the use of computers at Forest District offices for a range of tasks (including the payment of staff wages and invoices). The existing structure of the SCDB has been adapted to make use of a 'packaged' suite of software written by BOS/Finder to work on Merlin microcomputers. Thus, the data available at local level is structured in a different way from the main SCDB held centrally, and as such is distinct. However, the actual data is the same and can be used by local staff with the same confidence that they enjoyed with the main SCDB.

Essentially, local access to the SCDB copy has meant that simple analysis (i.e. listing, sorting and ranking) can now be carried out informally at the Forestry District office. More complex analyses of the growing stock and the production forecasting exercises are still carried out centrally. Each year, the master computer file, after updating, is copied on to individual disks for use in each Forest District. Once loaded on to the local microcomputer (to replace the previous data) the disk is safely stored in case the loaded copy is corrupted in any way.

The present software is designed primarily to store information by a key field and to provide a descriptive link to this in a text field. As the package was not specifically designed for use with the SCDB there are a number of limitations in the capabilities.

The software package has 12 key fields and 30 text lines available, whereas the existing database has 27 fields in use (of which five may be regarded as key in nature). Thus the package has enough capacity to accommodate the SCDB. However, only key fields on the software package can be sorted with any speed or analysed according to range (e.g. between two planting years). The central computing facility allows rapid sorting of all fields.

The software package is owned by the manufacturing company and any additional programs may need to be authorised by them - and possibly also written by them. Thus there is little flexibility in adjusting the software to our own needs. A good example of this is the updating (revision) of individual records, which can be carried out using the software but which does not suit our particular needs. This at present cannot easily be changed, although extra programming could be carried out to provide the validation so necessary for updating.

As the local copy of the database is not updated at source, it is the centrally-held SCDB which must be revised annually. Thus any records which are only held locally (in one of the spare software text lines) will be lost each year when a new disk is loaded.

The ability to interrogate crop and site data locally has been wholeheartedly welcomed by forest managers. A training manual (originally supported by training courses) has provided sound guidance for all those interested in the analysis of data. One of the results of local data access has been an increased awareness of the importance of data and a better realisation of the consequences of poor maintenance.

Examples of use at local level include:

sorting of areas by land use classes;
sorting of forest crops by species, by age and by yield class;
sorting of crops within geographical areas;
ranking of species by yield class;
summation of areas;
addition of information to text fields;
amendment of existing data.

REFERENCES

EDWARDS, P.N. and CHRISTIE, J.M. (1981). *Yield models for forest management.* Forestry Commission Booklet 48. Forestry Commission, Edinburgh.

HORNE, A.I.D. and WHITLOCK, M.D. (1984). *The Forestry Commission subcompartment database.* Research Information Note 94/84/FS. Forestry Commission, Edinburgh.

Paper 11

System Dynamics Modelling of Roundwood Supply

H.O. Canham, Professor of Forestry Economics, State University of New York, College of Environment Science and Forestry, Syracuse, New York 13210, U.S.A.

Abstract

The flow of wood from the forests of a region, termed the roundwood supply, is the result of the interaction of many biological, engineering, and economic variables affecting forest owners, timber harvesters, and primary manufacturers. Modelling the microeconomic behaviour of these three sectors was accomplished using DYNAMO, a systems dynamics programming language.

The Dynamo programming system is briefly described. The roundwood supply model, termed ROSUM, is also described showing its structure, information flows, and major assumptions. A test of the model against some real world data is shown. Three illustrative computer simulation cases are shown to illustrate how the model in concert with the DYNAMO system can be applied to study timber supply and logger behaviour.

Objective

During the past two decades supply-demand models for the wood-based sector in the United States have evolved from simple procedures that projected the 'gap' between aggregate timber consumption and production at assumed price levels to complex systems capable of projecting consumption, production, and price behaviour for an array of products in spatially disaggregated markets. Much of the progress has been with long-range, market projection econometric models to identify broad trends in macro market activity. At the local, regional, and state level, planners, utilisation and marketing foresters, and others, need tools for projecting future trends in local timber supply, timber harvesting activities, and roundwood conversion activities. Such models should also be suited to the evaluation of the impact of public policy on the forest industry.

The Roundwood Supply Model (ROSUM) is designed as a tool for meeting some of the local and regional analyses needs. It is a short-term, preferably no more than 20 years, dynamic, deterministic, microcomputer-based simulation model of timber harvester (logger) and mill level supply of roundwood products. (Roundwood is the initial form in which wood products are harvested from the forest; sawlogs for lumber, pulpwood, fuelwood, veneer logs.) The model simulates the activities of timber growing, harvesting, and primary manufacturing of lumber in a regional setting, usually a group of counties or an entire state. Economic relationships within the timber harvesting and sawmill sections are the principal focus, however ROSUM also considers the biological timber growth, in a simple fashion, and the technical efficiencies of timber harvesting and sawmills. It is a behavioural model: it predicts the manner in which variables, such as lumber production, will behave in response to change in other variables such as lumber price or prices of competing products.

In constructing the model emphasis was placed on setting parameters to coincide with conditions in the north-eastern United States, and particularly for hardwoods. This reflects the principal funding sources for the research and the region in which the model was first envisioned. However, the programming language, DYNAMO, and the structure of the computer program allows for relatively easy adjustment of parameters to reflect conditions in other regions

Model structure and flow of information

The general flow chart (Figure 11.1) shows the major movement of information through the ROSUM simulator. The time interval in the model is one week. That is, ROSUM simulates behaviour on a weekly interval based on prior and current conditions stipulated or calculated in the previous time period. (This is not to be confused with computer time to run the simulator. An entire 10 or 20 year simulation run takes less than 10 minutes on an IBM PC or compatible.)

There are four major sections, or activities considered, in ROSUM: exogenous prices and quantities demanded, sawmill production, timber harvesting, growing stock inventory. Each is modelled to certain levels of specificity.

Exogenous price changes supplied by the user are required for the four products currently recognised by the model: lumber, pulpwood, fuelwood, export logs. The model computes sawlog roundwood prices endogenously after lumber price and expected orders are run through the sawmill production section. For lumber both price and quantity changes are required. This is based on the theory that sawmills react both to price changes and changes in orders received. Although this a slight variation of the neoclassical model of perfect competition, this phenomenon has been observed at the regional level when sawmills operate in national markets. At present in the model, pulpwood, fuelwood, and export logs are considered to leave the system at the roundwood level. There are open ended orders for each. That is, it is assumed that the market will purchase all that loggers in the region will supply. The model starts from equilibrium thus only initial quantity harvested of these products and expected future price changes are required from the user.

Three subsections comprises the sawmill production section (Figure 11.2): desired lumber production, sawmill costs, the production function.

Sawmills are assumed to determine their desired lumber production by following the rule of profit maximisation: they will continually adjust their desired lumber production until sawmill marginal cost is brought into equality with marginal revenue. (Lumber price is marginal revenue in the perfectly competitive market assumed in ROSUM.) The adjustment in desired lumber production is not smooth. Instead, firms will, if profit margins permit, set desired lumber production at the rate at which infilled orders for lumber are recieved. Desired lumber production fluctuates around unfilled orders received because the rate at which orders are received for lumber is unlikely to also be the profit maximising output level and because of adjustments in production due to sawmill inventory conditions.

Desired lumber production is composed of two level variables: desired sawmill output and total inventory correction. Any change in desired lumber production must come as a result of a change in either desired sawmill output or total inventory correction, or both. During each weekly simulation interval, firms consider their current profit margin, output level, inventory levels, and other variables to determine the desired direction and magnitude of change in desired sawmill output and total inventory correction.

The model assumes sawmills base their production decisions on short-run conditions. Costs that are fixed in the short-run do not directly enter into the equations for determining the profit maximising level of output but they do have an indirect influence on production and capacity adjustment decisions. For example, changes in sawmill capital costs resulting from exogenous movements in the price or productivity of capital tranforms the least cost combinations of labour and capital. This in turn alters sawmill labour productivity and marginal costs. And, since mill delivered price paid for roundwood sawlogs is computed as a residual after meeting other costs, it too is affected.

The two most significant components of sawmill marginal cost are considered to be mill delivered price for sawlogs and sawmill labour cost; together comprising 77 per cent of the total cost of production in hardwood lumber in New York state (Schnick, 1970). Hence, both variables are computed endogenously in the model. Mill delivered price paid for sawlogs is computed as a residual of lumber price. adjusted up or down depending on mill log inventory coverage. Sawmill labour marginal cost comes from the production function in the model. The other components of sawmill marginal cost (inventory cost, other variable costs including power, normal rate or return) are set exogenously by the model user as a percentage of average total costs. Cost multipliers can also be given to show how these costs are forecast to vary over the length of the simulation. Default values are set in the simulator to keep costs at a set level. Potential output of the combined sawmill labour and capital is modelled using the Cobb-Douglas production function (Chiang, 1985).

The timber harvesting section consists of three subsections: desired logger output, logger costs, production function.

Loggers (timber harvesters) are modelled as profit maximisers who continually adjust their disired output as long as marginal costs and marginal revenues are unequal. Unlike sawmills, who base desired output in part on orders received for lumber, loggers are not modelled to receive orders for log deliveries from sawmills. Instead they deliver as many logs to the sawmills as profitable, given the current mill delivered price and their marginal costs. The change in desired logger output is smoother than that of sawmill output. Furthermore, loggers shift production to other products (pulpwood, fuelwood, export logs) as relative prices for these change. The initial equilibrium starting conditions set prices of these, in equivalent quantities, equal to the initial endogenously computed mill delivered price for sawlogs. In addition, the user provides initial harvest quantities of pulpwood, fuelwood, and export logs. These initial production levels will remain unless relative prices shift either as user supplied inputs or in response to other endogenously computed shifts in costs and profits from other specified exogenous changes (as seen in the example in the next section).

As in the sawmill costs section, the model assumes loggers base their production decisions on short run cost conditions. Marginal revenue is the weighted price of roundwood products. Fixed costs have an indirect effect on capacity and output.

Logger marginal cost is composed of logger other variable cost, normal rate of return, stumpage price, and labour cost. The latter two are estimated collectively to account for 80 per cent of logger costs of production (based on information supplied by local loggers) hence both are computed endogenously in ROSUM. Stumpage price is computed as a residual of mill delivered price minus logging costs. Labour marginal cost is determined through the Cobb-Douglas production function. Similarly to the sawmill section, other variable costs and normal rate of return can be supplied by the user or the default values used.

The growing stock section is divided into sawtimber and poletimber. The user supplies the initial inventory level of each and a growth rate percentage. An exogenously supplied availability factor, representing the percentage of stock available for harvest, is used to compute the amount of stock available for harvest. The model does not include a stumpage supply function; instead the model assumes all the available stock can be harvested above an exogenous stumpage price floor. These assumptions are based on findings of a number of forest landowner studies in the United States that suggest landowners are largely passive in placing timber on the market; responding to signals received from loggers, consulting foresters, and others. (See for example Binckly, 1981; Canham, 1971; Ferretti, 1984.)

Testing the model

Testing, that is verifying, a large multi-equation simulation model is difficult and sometimes almost impossible. Comparing model results with existing historical data is appealing but such data may not be available free of 'noise' or other non-modelled variation. Biological system simulation models can sometimes be tested by waiting to see if predicted results compare with actual plant or animal growth and development. Engineering system simulation models can sometimes be tested by building a prototype and subjecting it to the same stresses as in the computer model. However, to build and topple large buildings or bridges can be very expensive. Testing economic or other policy-oriented models has the added consequence that it may be economically unattractive or socially undesirable to allow the real system to develop in a particular fashion. Alternatively, one may test a model by either verifying the realism of its assumptions, or examining its internal consistency and agreement with accepted theory.

One external test of ROSUM has been achieved by running it for national United States hardwood lumber production from 1976 to 1984. This period and product were chosen because of the availability of much data not only on lumber production and price but also on other variables employed in the model (unfilled orders backlog, shipments from stock, sawmill inventory levels). Data for this test came from the National Forest Products Association. In revision and calibration of parameter values the model shows remarkable similarity with the actual lumber production (Figure 11.3). There is also reasonable agreement with actual unfilled order backlog (Figure 11.4). However, there is some discrepancy between model gross lumber stocks on hand at sawmills and the reported actual inventories (Figure 11.5).

Examples of model use

The case examples discussed in this section are from actual simulation runs of ROSUM with the model calibrated for New York state conditions. That is, since the model starts from equilibrium conditions, these initial conditions and the cost and revenue functions were specified for the state. Running the model at these initial conditions produces no interesting output, the initial conditions are merely repeated. Instead the model reacts to specified changes in one or more of the input variables. The three cases shown run the simulations for eight years. This is not special, it is merely the length for which the model happened to be set up at the time.

In Case I the price of fuelwood is forecast to increase 5 per cent every half year over the initial price. That is, a simple rate of growth is assumed, not a compound rate of growth. The effect on production (Figure 11.6) is an increase in fuelwood harvest (RWS(FUEL)), a decrease in pulpwood (RWS(PULP)) and export log harvest (RWS(XPRT)). Sawlog harvests (RWS(SAW)) initially decrease followed by a decrease in sawmill log inventory and lumber production with a subsequent slight increase in mill-delivered sawlog prices. This coupled with the exogenous price increase in fuelwood increases logger profit margin (LPM) and motivates loggers to harvest slightly more sawlogs (Figure 11.7), much more fuelwood and less of the relatively less profitable products; pulpwood and export logs. Mill delivered price (MDP) and mill log inventory (MLI) of sawmills oscillates somewhat about an average as the mills attempt to find the right price for sawlogs to attract the right volume (Figure 11.8).

The final effect on sawtimber inventor (STI) and poletimber inventory (PTI) are dramatic

(Figure 11.9). Inventories of both increase during the first years since cut is below growth. However, the increasing fuelwood price stimulates more and more logger production due to increasing profit margins. In the fifth year cut equals growth and then surpasses it, leading to a decrease in inventory.

Poletimber inventory does not decrease in the model run time because of two settings made for New York. First, only 25 per cent of the poletimber inventory was available for harvest; and second, 80 per cent of the fuelwood cut from live timber came initially from sawtimber.

In Case II fuelwood prices are still assumed to rise by 5 per cent every 6 months, but in addition it is assumed that loggers costs will also rise 5 per cent every 6 months. Thus it might by hypothesised that fuelwood prices are increasing due to a rise in oil and associated petrochemical prices. This price increase would also affect loggers using oil and gasoline engine driven harvesting equipment. The results in harvest are still an increase in fuelwood harvest and adjustments by sawmills to obtain sawlogs but the increase in fuelwood harvest is less than in Case I due to the damping effect of cost increase which wipes out much of the increase in logger profit margin (Figures 11.10 and 11.11). And the peaking of sawtimber inventory is put off until the seventh year (Figure 11.12).

The third case is drawn from examining the possible impacts of an increase in highway use taxes coupled with lower load limits. Such laws, rules, and regulations are being promulgated in many areas in the north-eastern United States. It is postulated that there will be a 50 per cent increase in logger other variable costs (LOVC) (Figure 11.13). These are the costs other than labour, capital, and stumpage, that enter into the logger profit margin calculations. This postulated cost increase is assumed to take place during the second half of the first year of the simulation. After that it will remain at the higher level.

This action produces a shock to the system which then attempts to return to equilibrium. Logger profit margins decline (Figure 11.14) and all roundwood starts also decline. As mill log inventories (MLI) decline, prices offered by sawmills for sawlogs (MDP) increase (Figure 11.15). This in turn increases the harvest of sawlogs but other products remain at the low level. Note that the sawmills' adjustment in log prices is not complete and near the end of the eight year simulation mill log inventories begin to decline somewhat and log prices again go up. Note, however, the vertical scale in all the figures, not just the graph lines. There is no noticeable effect on either sawtimber or poletimber; both continue to increase at a constant rate (Figure 11.16).

The DYNAMO programming system

The DYNAMO programming system (Pugh-Roberts Assoc., 1986) is a special purpose program designed for building and running continuous feedback simulation models. There are several different modules in the system (Figure 11.17). In the Editor a model is written using the DYNAMO language. The Compiler module prepares the model for a simulation run. Included in this and the Editor module is an extensive error detector and editor that greatly facilitates correcting programming errors. The Simulator module runs the compiled model and permits changes in parameters, number of simulation periods, and variables to save for review after the run. The Viewer module permits both tabular and graphic display of saved variables, either singly or in combination with other variables. The results are also printed from this module. The final module is Tools, which contains many different routines for working with the model.

Three types of active equations are used in writing DYNAMO programs. Levels are integrative or accumulative equations. Lagged variables are used in their construction and they are similar to the typical difference or differential equation. Rate equations are computing equations giving amounts for which levels or auxiliaries change over time and are distinguished by an interval time subscript rather than a discrete time. Auxiliary equations are used to bridge the gap between levels and rates and for computing many intermediate conditions needed to compute changes from period to period. They are similar to usual BASIC or FORTRAN equations. In addition, in the version used in ROSUM, namely PROFESSIONAL DYNAMO PLUS, both arrays and scalar variables can be used.

Constants, initial values, parameters, and table values are each specified in other equations. The Table function is especially useful. Through it a graphic response function can be specified. The function need not follow a mathematically tractable formula. Dependent variable results are specified for computed values of a specified independent variable. In ROSUM, table functions are used to specify the rate at which loggers respond to changes in profit margin, supply elasticities, and to provide a way for the user to specify changes in prices and orders over time. The Changes routine in the Simulator module allows the user to alter a table in a graphical mode on the screen.

For all its positive virtues, the DYNAMO program is not without problems. The model builder can become enchanted with the elegance permitted in a model and develop a detailed model which might approach reality but becomes very confusing to trace or to alter. Along with an extreme level of detail often comes the need to specify more parameters. Many of these cannot be verified and in calibrating the model to agree with outside evidence it becomes difficult to know which parameter must be changed, and by how much. Second, since this is a continuous feedback simulator, small roundoff errors can promulgate into large differences over time leading to widely oscillating conditions not representative of actual conditions. This can be corrected by inserting rounding routines and zeroing specifications but care must be taken not to overdampen the model. Finally, as with any programming language, even the best Edit routine cannot correct for inherent logical errors. These can only be detected after intelligent study of, and common sense interpretation of simulation results. However, I recommend DYNAMO to anyone considering building a simulation model. Its built-in functions, excellent editor, supported graphics, and ease of writing equations, make it a good choice for modelling systems in forestry.

REFERENCES

BINCKLEY, C.S. (1981). *Timber supply from non-industrial private forests.* Yale University, School of Forestry and Environmental Studies, Bulletin 92. New Haven, Connecticut.

CANHAM, H.O. (1971). *Timber ownership and supply in New York.* State University of New York, College of Environmental Sciences and Forestry, Syracuse, New York.

CHIANG, A.C. (1984). *Fundamenal methods of mathematical economics.* McGraw-Hill, New York.

FERRETTI, W.M. (1984). *A pilot study of non-industrial private forest landowner behaviour.* Ph.D. dissertation. State University of New York. College of Environmental Sciences and Forestry, Syracuse, New York.

PUGH-ROBERTS ASSOCIATES, Inc. (1986). *Professional DYNAMO plus reference manual.* Cambridge, Massachusetts.

SCHICK, B.A. (1970). *An analysis of lumber manufacturing cost in New York state.* M.S. thesis, State University of New York, College of Environmental Sciences and Forestry, Syracuse, New York.

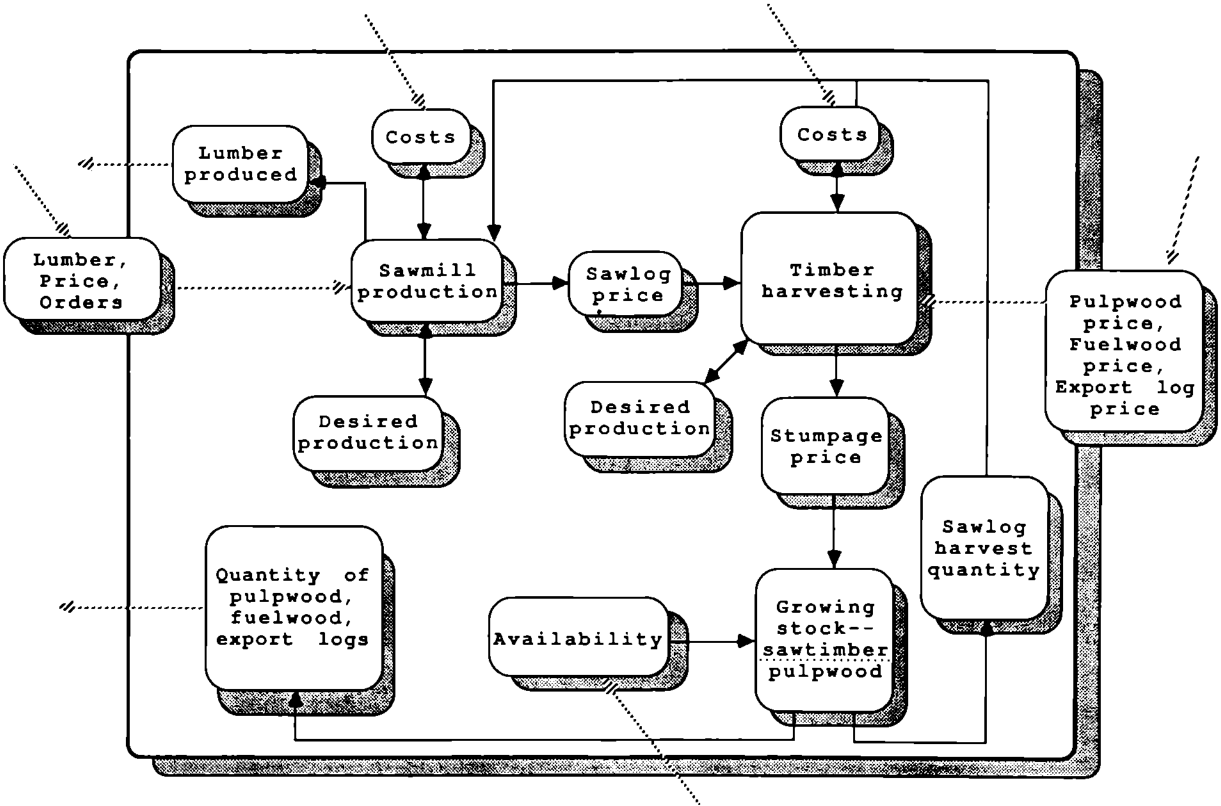


Figure 11.1 General flow chart of ROSUM.

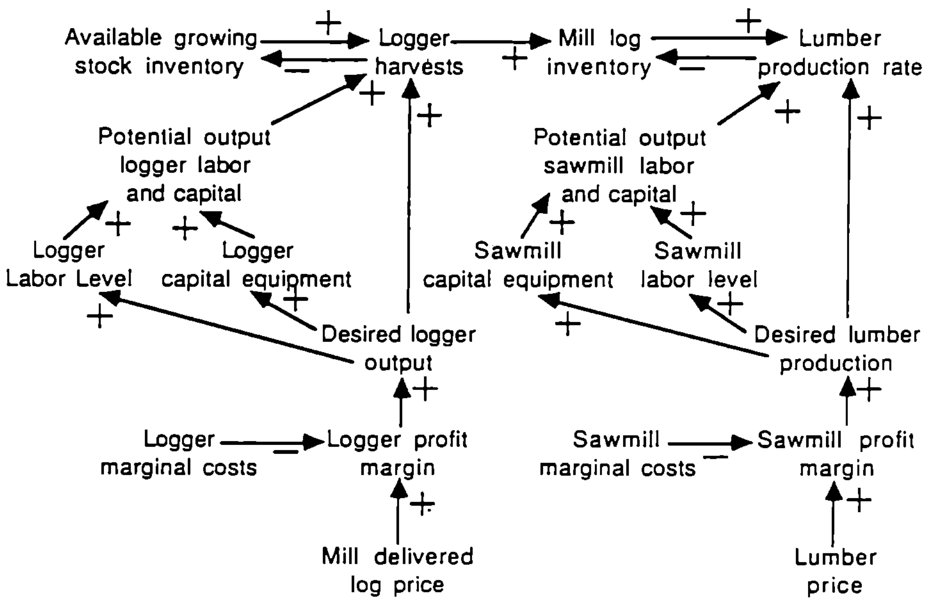


Figure 11.2 Lumber production section of ROSUM.

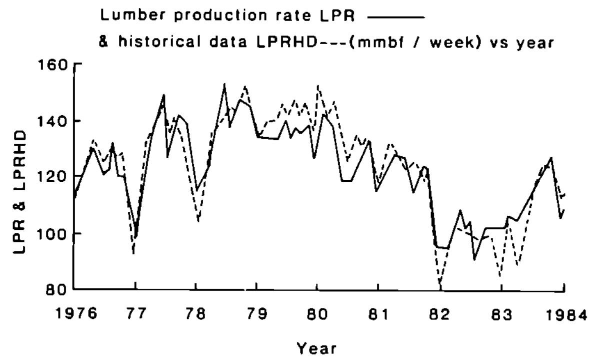


Figure 11.3 *U.S. hardwood lumber production rate from ROSUM and historical data, 1976–1984.*

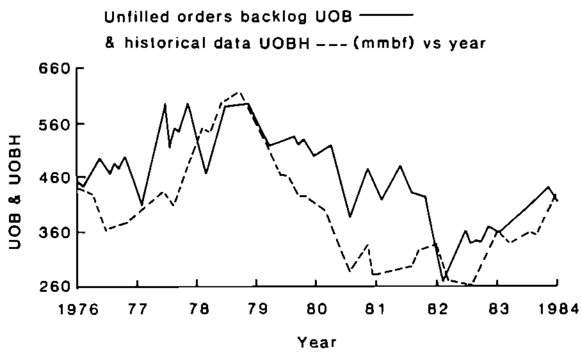


Figure 11.4 *U.S. hardwood lumber unfilled orders from ROSUM and historical data, 1976–1984.*

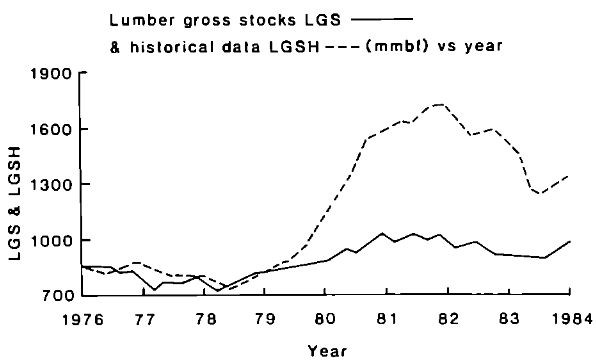


Figure 11.5 *U.S. hardwood lumber gross stocks on hand from ROSUM and historical data, 1976–1984.*

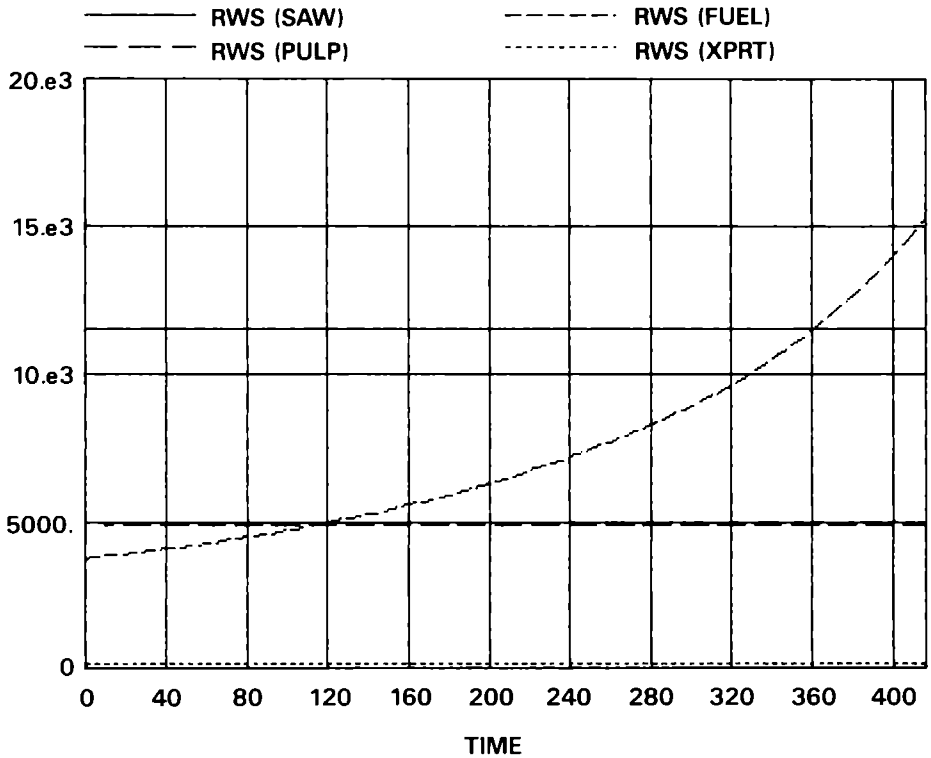


Figure 11.6 *Case I, roundwood production by product.*

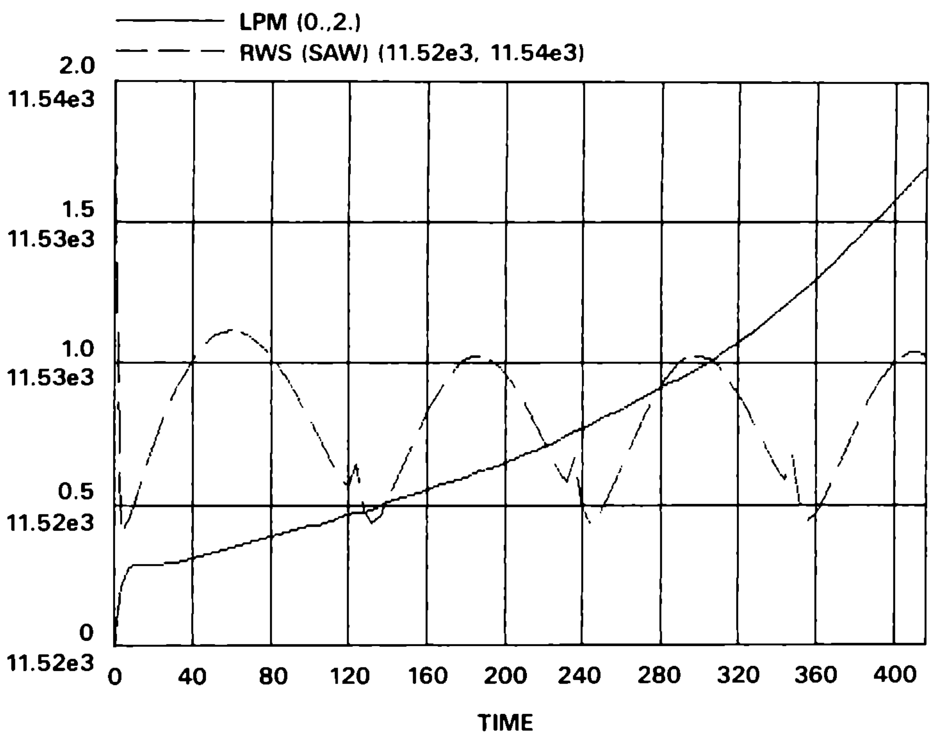


Figure 11.7 *Case I, sawlog harvests and logger profit margin.*

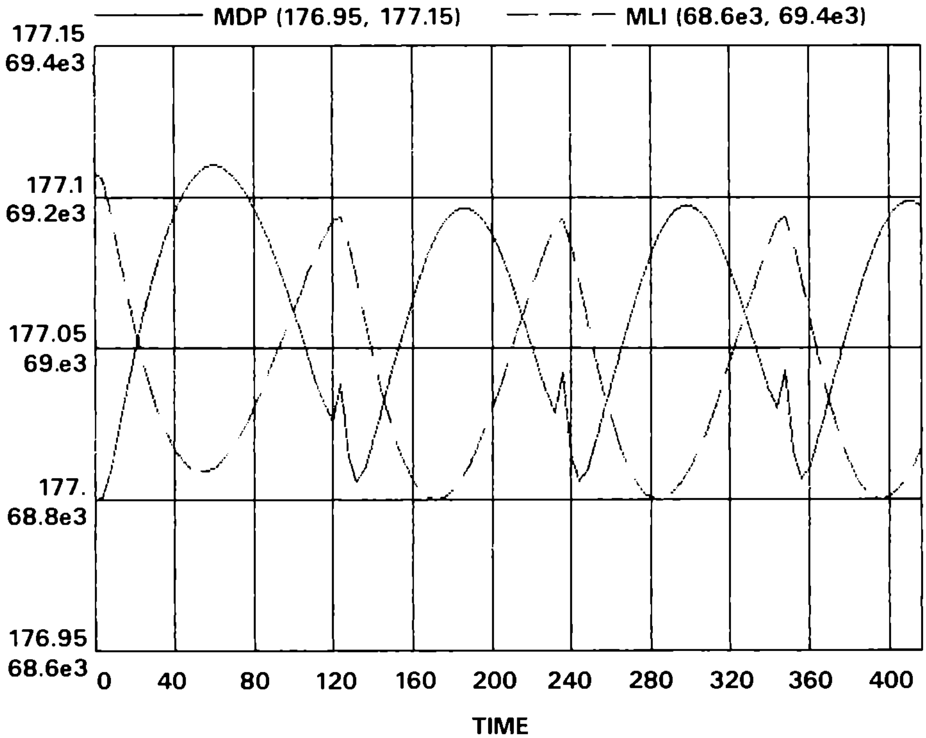


Figure 11.8 *Case I, mill delivered sawlog price and mill log inventory.*

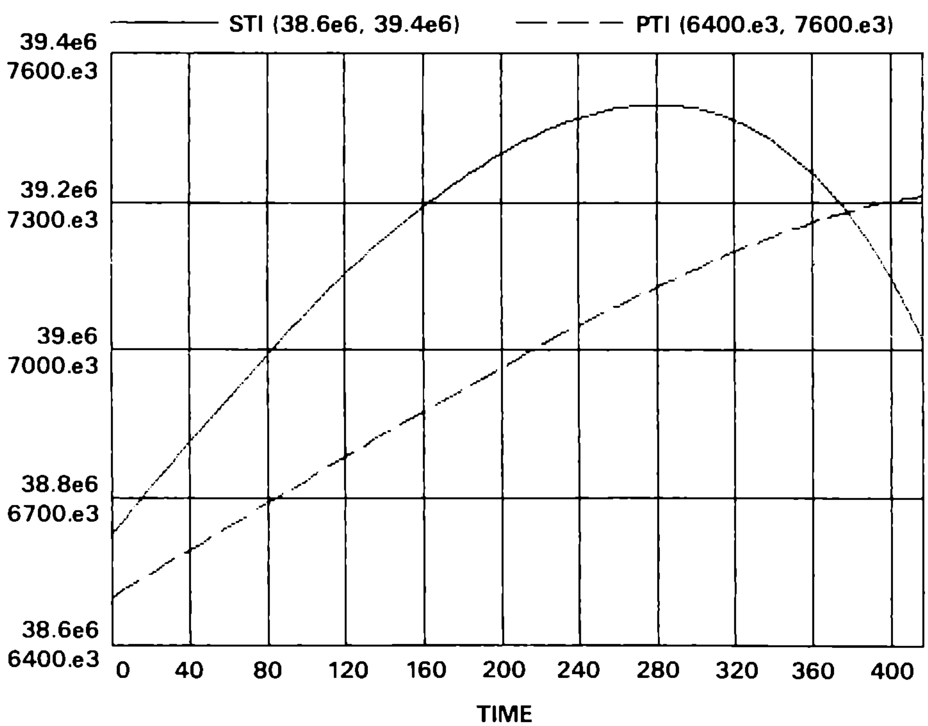


Figure 11.9 *Case I, sawtimber and poletimber inventory.*

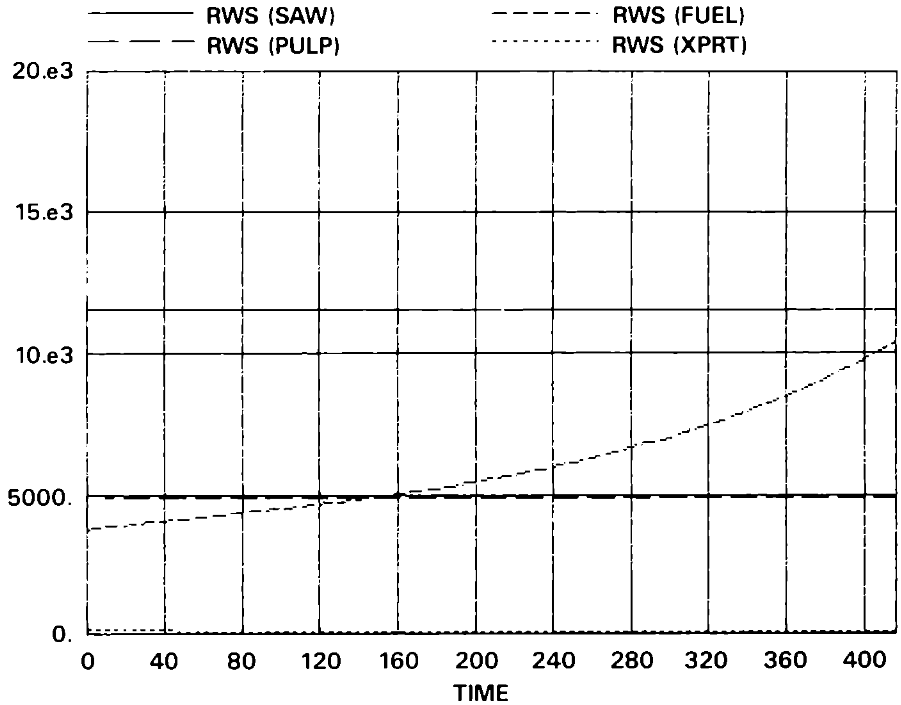


Figure 11.10 *Case II, roundwood production by product.*

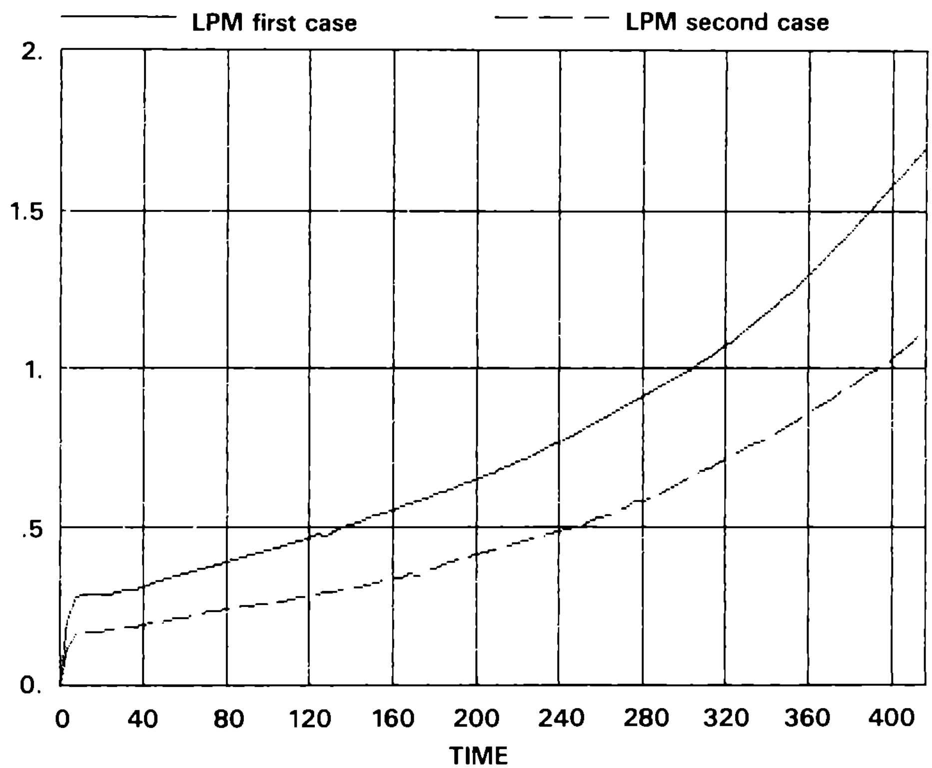


Figure 11.11 *Logger profit margins, Case I and Case II.*

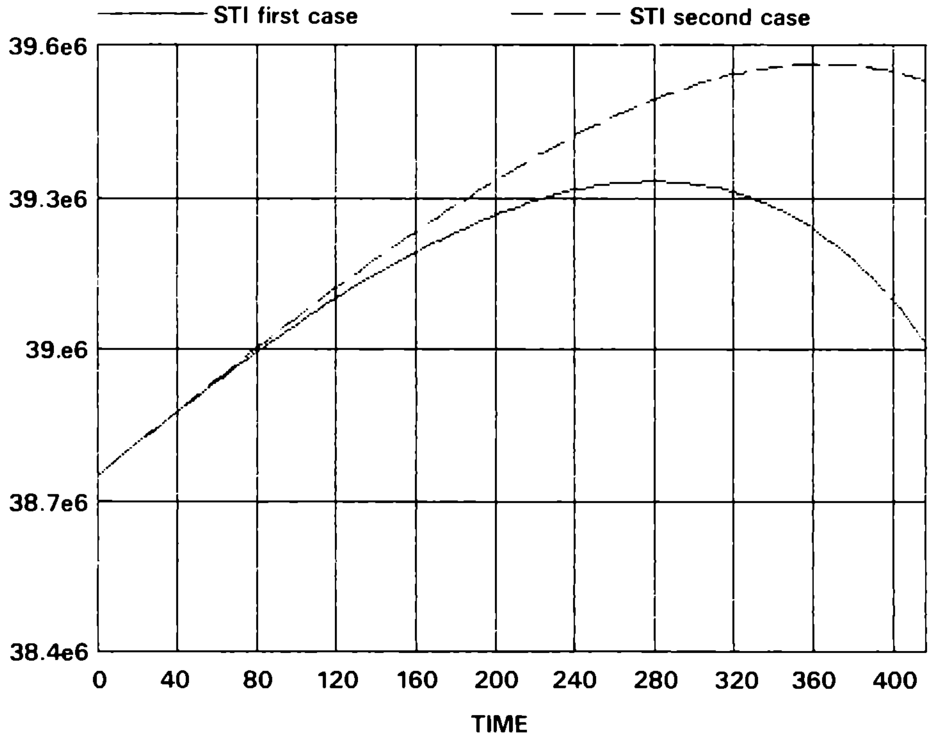


Figure 11.12 Sawtimber and poletimber inventory, Case I and Case II.

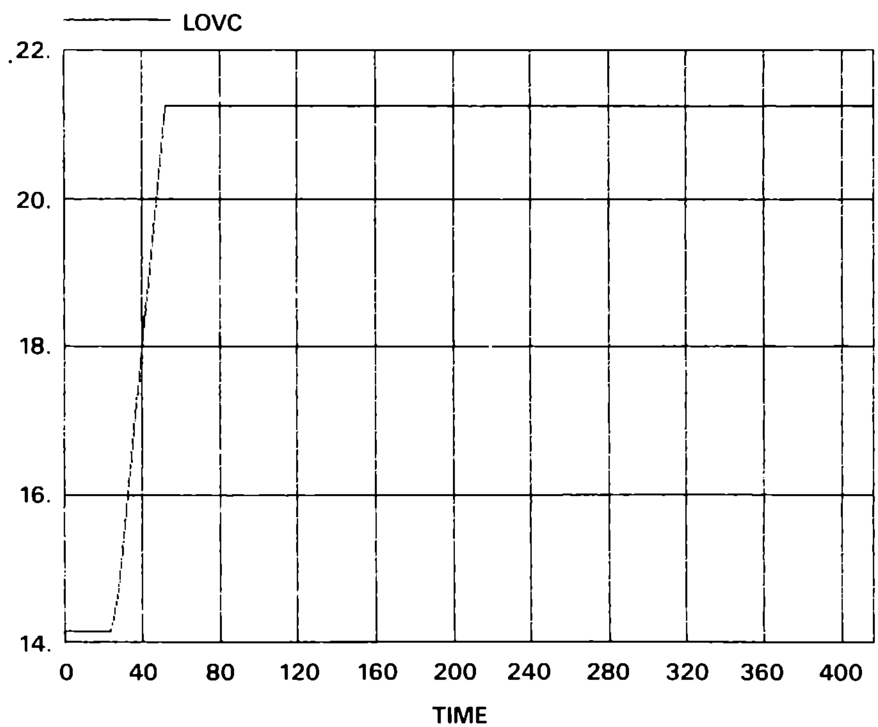


Figure 11.13 Case III, logger other variable costs.

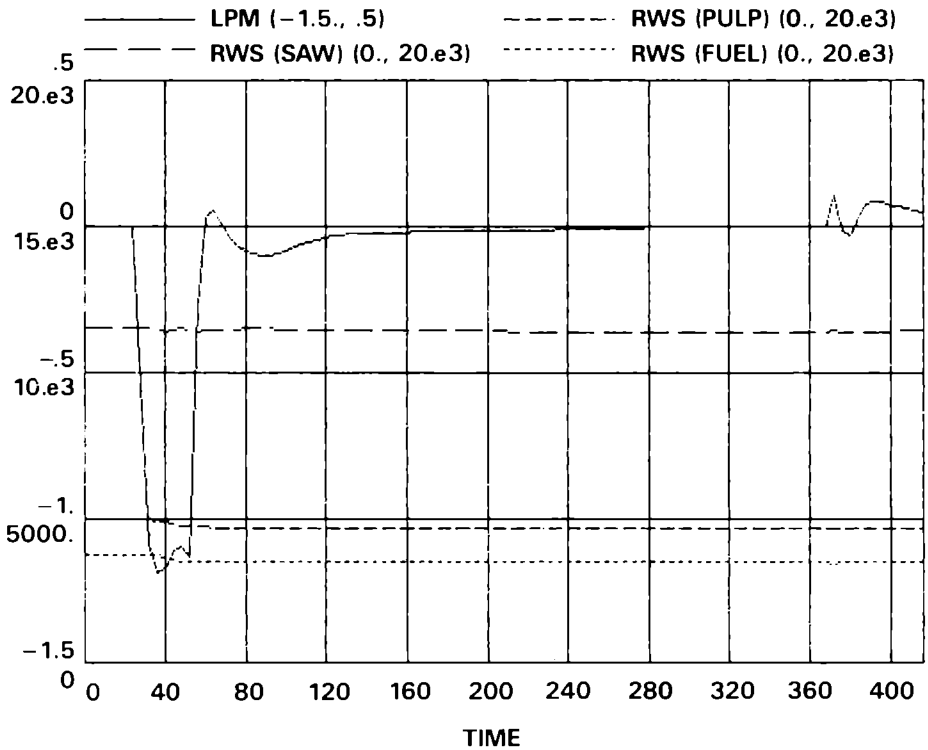


Figure 11.14 *Case III, logger profit margin and roundwood production by product.*

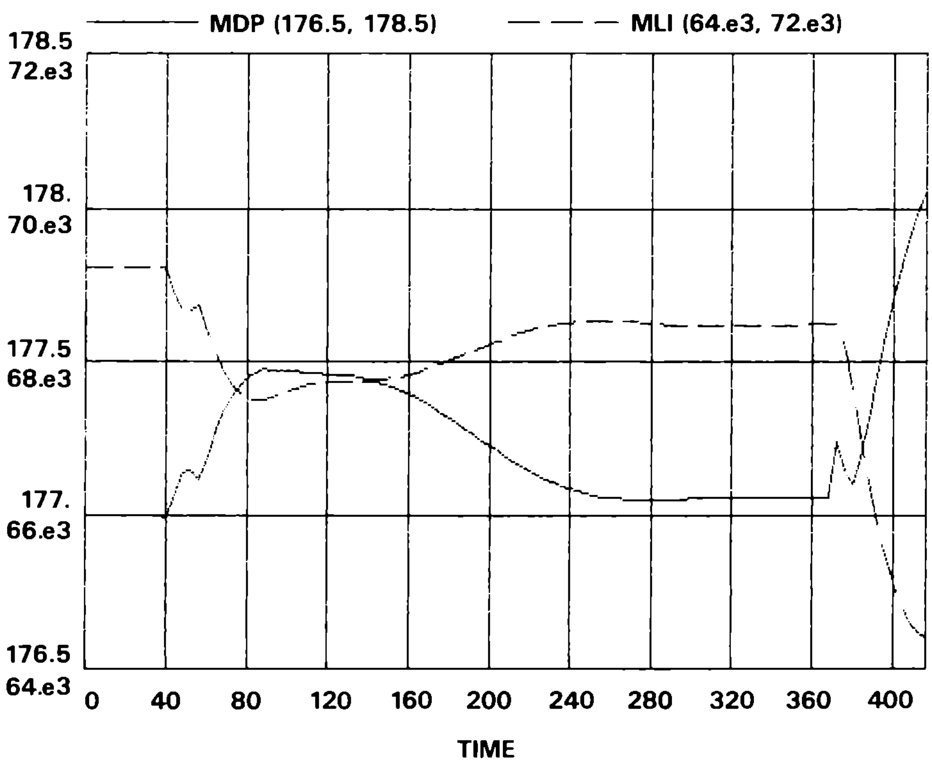


Figure 11.15 *Case III, mill delivered sawlog price and mill log inventory.*

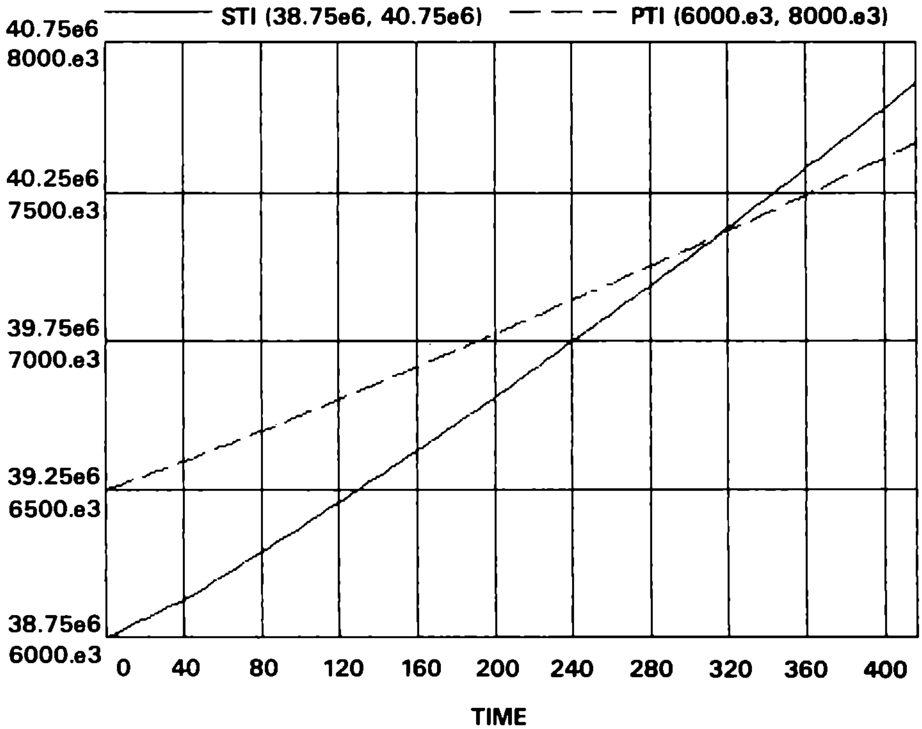


Figure 11.16 *Case III, sawtimber and poletimber inventory.*

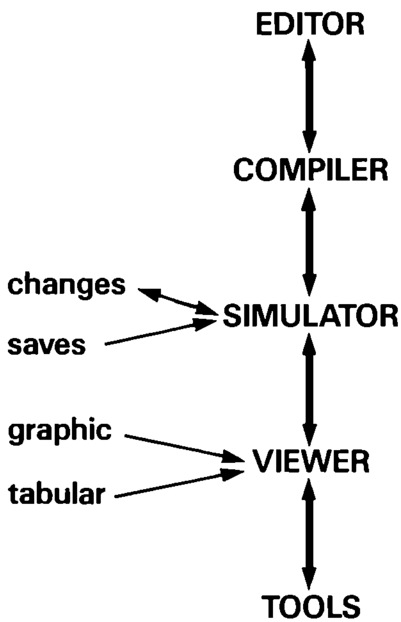


Figure 11.17 *Modules in Professional Dynamo Plus.*

Paper 12

General Systems Theory for the Improvement of Harvesting Operations

*S.C. **Iverson**, Director Industrial Engineering Program, University of Washington, Seattle, Washington, U.S.A. and **E.S. Miyata**, Industrial Engineer, USDA Forest Service, Pacific Northwest Research Station, Seattle, Washington, U.S.A.*

Abstract

Due to the multi-faceted nature of harvesting operations, a systematic and logical procedure is required to improve overall systems characteristics. A general systems approach is able conceptually to formulate and optimise a complex set of variables inherent to harvesting operations within a context to allow decision makers the ability to ascertain evidence to allow for a clear and concise decision analysis. In most cases, the total harvesting costs can be reduced by a significant amount and overall analysis procedures can be reduced by an order of magnitude. General systems theory is described as it relates to harvesting operations.

Introduction

Predicted wood consumption in the United States is expected to increase from 13 billion cubic feet (368 million cubic metres) in 1977 to 29 billion cubic feet (821 million cubic metres) in the year 2030. Most of the projected increase is for pulpwood which is expected to acount for over 50 per cent of the total wood products demand in 2030 (USDA Forest Service, 1980).

There are about 40 million acres (16 million hectares) of commercial forest land in the Pacific Northwest area. About 70 per cent of this forest land in western Oregon and western Washington contains second growth timber stands. Thinning is required on 25 per cent of these lands (MacLean, 1980); furthermore, the future area to be thinned annually is projected to equal that felled in old growth timber (Binkley, 1980). Typical average old and second growth stands in the Pacific Northwest Coast are summarised in Table 12.1 (Jorgensen, 1979).

In addition to these small, low-valued trees to be thinned, some 14 million tons of forest residues, such as dead, or dying trees, tops or limbs accumulate each year (Grantham, 1974). If we can recover and utilise these vast quantities of small, low-valued trees through thinning operations and forest residues, the following benefits could be expected (Erickson, 1976; Leicht, 1979; Oliver, 1986; Tillman, 1985):

Table 12.1 Average old and second growth stand characteristics (U.S. Pacific Northwest Coast)

Stand	*Trees/Area (trees/ha)*	*Volume/Area (m^3/ha)*	*Volume/Tree (m^3)*	*DBH (cm)*
Old growth	318	850	2.66	48
Second growth	743	610	0.82	30

1. additional fibre supplies to meet the increasing demands for wood fibre;
2. reduction of fire, insects, and other environmental problems;
3. improvement of timber stands through thinning operations, which will provide better quality timber;
4. help to reduce our reliance on petroleum imports. Smith and Tillman (1986) reported the residential wood fuel market, now valued at about four billion US dollars per year, which is about equal to all of the plywood produced by the forest industries in the United States. Grantham and Howard (1980) also reported the energy potential of $3\frac{1}{3}$ billion cubic feet (94 million cubic metres) logging residues in pieces 10 cm and larger in diameter annually remaining in the forests of the United States is roughly equivalent to 100 billion (100 thousand million) barrels of oil;
5. improvement of aesthetics, and future management capability for regeneration, soil and water quality, fish and wildlife, air quality, and others.

However, operations in the low value young stands and harvesting the large amount of forest residues are presently limited due to problems associated with the lack of technically sound, economically efficient and environmentally acceptable systems and equipment required to fell and concentrate the material in the woods, yard it to a landing, then process and transport it to a delivery location. Besides economic and silvicultural constraints, some characteristics such as steep slopes, fragile soils, limited road systems for these low value materials, and rugged terrain in the Pacific Northwest area make forestry operations very difficult. Cost reduction in all phases of harvesting operations is a crucial factor in making forest products competitive in the domestic and international markets. This paper presents a methodology to help reduce total harvesting costs by applying the General Systems Theory.

General systems theory

The general systems approach is a process through which an analyst is able systematically and logically to construct a methodology to resolve a complex set of socio-economic and technological problems. Potential improvements to harvesting operations are complex in that they overlap into economic and technological subject areas. Solution strategies must take into consideration many interactive elements which have multiple facets and need to be evaluated simultaneously for each course of action. These problems frequently require a choice in the distribution of scarce resources among competing needs which will meet some demands and fail to meet others. Important secondary impacts of these decisions are also commonly felt in many areas of harvesting and therefore, must be addressed in a realistic manner in the conceptual phase of analysis.

The manner in which a problem situation is defined at the outset directs all future analysis. If any phase of this initial activity is incomplete, the analysis will not proceed towards a best solution and may not even consider the full set of options available to the decision makers. Quantitative techniques are designed to assist the decision makers in their choices by providing evidence in support of alternative options. They are then able to lend insight towards identifying the correct questions requiring the analyst's attention. The choice, then, of a solution methodology involving quantitative techniques must follow, not precede, the conceptual phase of this study. Harvesting operations dealing with the allocation of scarce resources to competing demands where conflicting objectives exist can readily benefit from the use of a general systems approach.

In the simplest situation, most improvements have a set of conflicting objectives built around their economics. Other projects that deal with the development of optimal strategies or involve choices among a wide range of alternatives also justify the use of general systems approaches. The approach is a strategy for structuring a research effort into a logical and systematic framework. It seeks to isolate the underlying problem requiring solution from a set of perceived disequilibriums. It then directs the investigation in such a way as to translate the problem into an analytical framework which can readily utilise a group of techniques such as decision methods and mathematical programming. The approach involves a series of steps which, when properly interfaced, will isolate the key elements required to analyse the problem, and its environment, as well as potential solutions and their repercussions. It then creates a foundation for the decision making which is required. By its nature, the approach lends itself to a sensitivity analysis whereby dissension can be productively explored and resolved.

The process begins with an awareness or perception of a disequilibrium. The introduction to this paper discusses disequilibriums, troubles, and needs that need to be considered with the aim of translating these issues into a rationale for allocating money and resources to improve the harvesting operations.

These statements lead directly to the establishment of a problem definition. The purpose of this statement is to identify the underlying problem which the analysis will address. It is related to the issues statement in that it combines the stated symptoms of disequilibrium into one precise definition of the problem. In most cases, the statement itself should be one paragraph in length and should conceptually formulate the need to which the analysis will be directed. The problem definition for harvesting operations will revolve around the lack of a systematic and logical methodology by which to analyse the multi-faceted problems inherent to increasing the productivity of yarders.

Further qualitative analysis involves the definition of appropriate goals, objectives and measurement criteria, in that order. The goals provide the necessary direction for the planning effort. These precise goals that the systems are expected to fulfil must be developed to obtain and employ information concerning the relative merits of the alternatives produced. The selection of these goals is the classification and weighing of individual preferences which are translated from the issues. The initial goal to improve harvesting operations consists of providing methods to increase the utilisation of small, low-value trees on steep, rugged terrain in the Pacific Northwest region.

This broad goal is then translated into specific operationally defined objectives that are derived to appraise them. This is a delicate step since an incorrect set of objectives will result in the wrong problem being solved. The objectives must be stated in a fashion which will lead to their eventual quantification. They are often in the form of maximising, minimising, increasing, or decreasing a particular variable. The following five objectives are appropriate for our goal:

1. to reduce harvesting costs;
2. to increase the efficiency and effectiveness of operations;
3. to minimise energy used for total harvesting operations;
4. to minimise residual standing tree damage;
5. to minimise the effect on the environment.

The last term used in this qualitative design phase is measurement criteria. Criteria considerations stem from the objectives and are easily measurable elements. They are developed to measure the effectiveness of a design on the basis of how well it accomplishes the stated objectives. In our case, the measurement criteria will revolve around cost, environmental aspects, productivity, and energy consumption. Costs will include the initial and operating costs of each alternative as well as production costs of each alternative.

The environmental critria will include soil erosion and impacts on the forest floor as well as damage to residual standing trees. Productivity items will be associated with set up and rig down time of alternatives, the number of crew required, and the production rate per person days. Energy consumption will be the size of engine horsepower required for each alternative.

The next step in general systems theory requires that a set of alternatives be generated. Evaluation of these alternatives should be deferred until the analysis phase. To improve harvesting operations, the alternatives were as follows:

1. develop small economically feasible yarding equipment and systems;
2. improve harvesting methodologies;
3. improve wood to market transportation schedules;
4. improve harvesting planning techniques.

The analysis phase begins with the initial evaluation of the alternatives. Data collection will yield the necessary information to perform a benefit cost or cost effectiveness analysis. Additional quantitative design will transform the objectives and constraints into a form which is amenable to the use of operational research models. These techniques should not be considered as individual avenues to the right answer, but as potential aids for creating evidence which together with other tools can lead to optimisation.

When a methodology has been designed, the data requirements should be examined to ascertain if any further information needs to be collected and evaluated. If the data is complete, the appropriate analysis will yield an optimisation of alternative policies or choices. Since many of the objectives will be in conflict with each other, the optimisation will have to sacrifice parts of particular objectives for the purpose of designing an overall and best solution. This is commonly referred to as satisfying instead of maximising, and reflects the often required behaviour of harvesting decision makers. For example, the need to reduce harvesting costs is in direct conflict with designing equipment for maximum effectiveness of operations.

The conflicts in objectives can be arranged to identify the kinds of trade-offs that need to be performed. Once the trade-offs are designed, the analyst will address in which order the decisions can be made concerning the trade-offs and decide the relationship between these trade-offs to see if they are interrelated and therefore require an analysis involving recursive formulation of the variables. As the trade-offs are specified, operations research techniques can be organised to create an optimisation of the alternative policies or choices available.

Sensitivity analyses involve two dimensions. The first is addressing the techniques involved and the sensitivity analyses that are common to each of the individual techniques such as linear programming, dynamic programming, and simulation. The second dimension of the sensitivity analysis involves looking at the overall methodology to assess the most important criteria and objectives. If the final decision weighs heavily on an abstract criteria, it may be necessary at this point to evaluate the criteria choice to see if a deeper evaluation will be required. All assumptions should be questioned and an evaluation leading to an interpretation of the results will identify recommendations and an implementation policy.

Conclusions

The use of general systems theory to improve harvesting operations has great potential in creating better use of existing data. The algorithms developed through the general systems theory can make information to planners in a superior form than conventional methods. This capability can lead to improvements in the quality and efficiency of the planning process.

By using the methodology described in this paper for developing decision-making algorithms, the analysis will be formulated in such a way as to force the decision makers to identify their values and priorities and to articulate them. In this way, the algorithm enables the decision maker to analyse all the alternatives systematically in light of the available information emphasising the considerations enumerated within the conceptual formulation stage. The procedure is inherently attractive by enabling the decision makers to use a rational analysis for their design process.

The utilisation of algorithms constructed through general systems theory has the potential of being cost effective over conventional methods by improving the planner's capability in terms of speed and versatility. The decisions for implementing techniques to improve harvesting operations will be able to be undertaken more effectively, efficiently, and systematically. Often, with the use of operations research techniques the computational effort required in analysis can be reduced by an order of magnitude.

Acknowledgement

This material is based on work supported by the Co-operative State Research Service, US Department of Agriculture, under grant number 87-FSYT-9-0251. Any opinions, findings, conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the view of the US Department of Agriculture.

REFERENCES

BINKLEY, V.W. (1980). Timber harvesting in Region 6; the 1970s and now the 1980s. *The Log* 4(7), 12-13.

ERICKSON, J.R. (1976). Harvesting of forest residues. *AlchE Symposium Series* **71**(146), 27-29. American Institute of Chemical Engineering.

GRANTHAM, J.B. (1974). *Status of timber utilization on the Pacific coast.* USDA Forest Service General Technical Report PNW-29. Pacific Northwest Forestry and Range Experiment Station, Portland, Oregon.

GRANTHAM, J.B. and HOWARD, J.O. (1980). Logging residue as an energy source. *Progress in biomass conversion* **2,** 35, Academic Press, New York.

JORGENSEN, J.E. (1979). Rationale for cable systems development. *Proceedings of the IUFRO Symposium on Mountain Logging,* 9-15. University of Washington, Seattle, Washington.

LEICHT, R.E. (1979). Intermountain Region wood utilization and wood energy application program. *Harvesting and utilization opportunities for forest residues in the Northern Rocky Mountains, Symposium Proceedings,* 217-222. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah.

MACLEAN, C.D. (1980). *Opportunities for silvicultural treatment in Western Oregon.* Resource Bulletin PNW-90, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

OLIVER, C.D. (1986). Silviculture: the next thirty years, the past thirty years. Part 1. *Journal of Forestry,* Bethesda, MD, **84**(4), 32-46.

SMITH, R.W. and TILLMAN, D.A. (1986). Residential fuelwood: opportunity for forest products industry. Keynote presented for the *International Conference on Residential Wood Energy,* Reno, Nevada.

TILLMAN, D.A. (1985). *Forest products: advanced technologies and economic analyses.* Academic Press, Orlando, Florida.

USDA FOREST SERVICE (1980). *A report to Congress on the Nation's renewable resources.* RPA Assessment and Alternative Program Directions, USDA Forest Service, Washington, DC.

Paper 13

Future New Zealand Forest Management Software

R.B. Tennent, Forest Research Institute, Rotorua, New Zealand

Introduction

New Zealand forest management software has been developed over the past 20 years on a variety of computers under a large range of operating systems. New Zealand managers have many software tools available, but most exist in isolation. Transferring information between tools is an important part of software design.

The 1980s have emphasised the concepts of compatibility and integration. The 1990s will see the emergence of integrated forest management packages, with standards for data transfer and usage. This paper considers the effect of these trends on future New Zealand yield control software for forest managers.

Existing software

One of the oldest software tools used in New Zealand forestry is the PSP (permanent sample plot) system (van der Voort, 1968; McEwen and Goulding, 1983). This is a database for sample plot data which was developed in the early 1960s on an IBM computer for paper tape storage. The PSP system has been extensively rewritten for successive machines, and now resides on a VAX system using a relational database manager.

Alongside the PSP system a variety of economic planning tools were developed. These included cashflow packages, which were used in economic studies (e.g. Fenton and Tennent, 1976). A statistical package was developed for use at the Forest Research Institute.

Forest management software began to be developed in a more orderly manner after the findings of the New Zealand Forest Service's Mensuration Project Team were released (Elliott, 1979). Tools developed included IFS, an interactive forest simulator (Garcia, 1981), and MARVL, a preharvest inventory system (Deadman and Goulding, 1978). The next major database package was the Stand Record System (Shirley, 1983; M.W. Deadman, personal communication.

The early 1980s saw the development of economic planning tools under the New Zealand Forest Service's Radiata Pine Task Force (Whiteside and Sutton, 1983). The Conversion Planning Team (Kininmonth, 1987) extended the range of models into the utilisation phase and improved the forest models, resulting in STANDPAK for single hectare silvicultural analysis, AGRO for agroforestry analysis and a specialised suite of programs for evaluating conversion options. By the late 1980s computers were being used in the forest as well as in the office (Tennent, 1986), with the range of computer assisted management tools in New Zealand now extending from immediate forest data gathering to stand assessment, midterm, and long-term planning, including interaction with future markets.

In 1988 New Zealand forest managers are faced with a wide variety of forest management tools available on a range of hardware. A key element is the interchange of data between tools, and the development of standards.

Future forest management software

Forest management decisions are based on mensurational data and economic analysis. Of prime importance is the structured flow of data from collection point to use in a decision support system. The Forest Mensuration and Management Systems research field concentrates on the collection of data and provision of decision tools which consider physical quantities of the forests. Data must be provided in forms suitable for econometric planning tools. The research field has been developing a strategy which will allow this responsibility to be discharged. One means of achieving this result is described below.

A five tier software division

Forest management data and decision support tools can be divided into five levels of increasing data concentration and decreasing data specificity.

Level 1 Ground control

At the actual data collection level software and hardware can be combined to ensure that data collection is accurate and efficient. The Forest Research Institute is using portable dataloggers for data collection. Future data collection software will be written in Pascal, in an attempt to avoid hardware specific restrictions. Software is being used for data collection for permanent sample plots, preharvest inventory, log scaling, and general inventory. All data collected includes specialised error checking.

Level 2 Inventory control

Software has been developed to process field data on microcomputers and mainframes. The software provides summary statistics and error checks. Inventory results are presented, with error checking included. Future software will be written in portable languages, such as Pascal or C. The software will be designed to read data from standard formats, and to output standard summary files. The aim is to allow raw data or summarised data to be used by a variety of managerial tools.

Level 3 Data bases

Storage of data in standard formats is necessary to ensure the integrity of the data and to allow ready access. Two main data bases are in use, the Stand Record System, and the PSP system.

The Stand Record System has been developed in parallel on several machine types. Future database development will use a language which allows software to be ported from machine to machine, to avoid continual rewrite of common code. Database environments under consideration include Oracle and Ingres. Geographic information system software is under review, as a GIS database will be a part of future forest management software.

Level 4 Tactical tools

The actual management of forests on a day to day basis requires a series of tactical tools designed to help the manager make specific tending and harvesting decisions. These tools rely on up-to-date data. The results of such investigation will be a data flow for strategic decisions.

An example is the question of scheduling stands for tending. While theoretical considerations may indicate that a certain operation is best carried out in a determined timeframe, practical considerations can dictate otherwise. Scheduling tools need to answer 'what if?' questions, and must function interactively. Such tools are being developed to take advantage of the standard data formats defined at lower levels. The tools will need access to recent data. These tools will be written in portable languages to ensure that they can be used on differing hardware. Examples include scheduling tools, stand and tree volume table generators, growth model validation packages, and mensurational tools.

Level 5 Strategic tools

Forest management is faced with long term decisions, and must have assistance in making these decisions. Strategic tools include growth models, stand-level economic models, forest level models, and regional simulation models. Long-term wood flows must be examined and specific regimes compared.

Strategic tools require access to summary data, stand level data, and raw data. The standard data formats under development will allow future strategic models to use the most appropriate data for the task at hand. Strategic models will be written in hardware independent languages, in an attempt to ensure that they can be used on a variety of machines. The emphasis will be on ensuring that decisions can be made using accurate and appropriate data.

Future software development

New Zealand forestry is undergoing rapid change. The New Zealand Forest Service was restructured into a number of organisations which include a commercial Forestry Corporation and a Ministry of Forestry. The Ministry of Forestry includes the Forest Research Institute as the research arm of state forestry.

The Ministry of Forestry has an external funding target, referred to as 'user pays'. This acts as an incentive to software development. The Forest Research Institute scientists include the largest concentration of software development skills in the forestry sector. These skills are being used to develop an integrated suite of forest management software.

Previous software was developed by researchers in consultation with managers. Software was not recognised as a scientific product as such, and the researcher received credit for publications related to software rather than the actual software. As a result much of the software was only developed to the point that the developer felt was necessary.

The early software was iconoclastic and reflected the developer's skills and ideals to a large degree. There was little incentive for the developer to make software 'user friendly'. Users had to undergo considerable training to make effective use of the software.

The 'users pays' concept has lead to a change in emphasis. Software development is now more oriented towards what the user is interested in, and what the user is likely to pay for. If the user wants changes to the user interface, they are forthcoming.

An example of the new emphasis is 'The Stand Master' (Tennent, 1988). This is a stand record system for MS-DOS industry standard microcomputers. 'The Stand Master' was developed as a commercial product, complete with commercial standards.

The development of 'The Stand Master' required a new set of skills to be developed. The author had to become informed on trademark registration, marketing planning, manual preparation, user support, and other specialised fields. At the planning stage the time to develop the software was estimated accurately, but the time that would be taken with the additional commercial realities was vastly underestimated. Commercial implementation has taken more time than the software development itself.

As sales have increased user feedback has lead to the development of software tools which support the users. The software development has become market-driven. Users have responded positively, and the only restriction has become resources.

Conclusion

New Zealand forest management software is undergoing a radical transformation from a loose set of developer-driven tools to become an integrated set of market-led tools. Future software is likely to provide users with linkages between packages which had not been anticipated. Future software will bear little relation to existing software as a more structured approach is combined with a greater degree of user feedback. The result is likely to be software tools which will greatly enhance New Zealand forest management.

REFERENCES

ELLIOTT, D.A. (1978). *Mensuration for management planning of exotic forest plantations.* FRI Symposium No. 20.

DEADMAN, M.W. and GOULDING, C.J. (1978). A method for the assessment of recoverable volume by log types. *New Zealand Journal of Forest Science* **8**(2), 225-239.

FENTON, R. and TENNENT, R.B. (1976). Export log afforestation profitability 1973. *New Zealand Journal of Forest Science* **5**(3), 323-346.

GARCIA, O. (1981). IFS, an interactive forest simulator for long range planning. *New Zealand Journal of Forest Science* **11**(1), 8-22.

KININMONTH, J.A. (1987). *Proceedings of the conversion planning conference.* FRI Bulletin No. 128.

McEWEN, A.D. and GOULDING, C.J. (1983). The permanent sample plot system of the New Zealand Forest Service. In *Planning, performance, and evaluation of growth and yield studies,* ed. H. Wright. CFI Occasional Paper No. 20.

SHIRLEY, J.W. (1983). Yield control systems for exotic state forests. *New Zealand Journal of Forestry* **28**(3), 356-371.

TENNENT, R.B. (1988). *The Stand Master: data base for plantations.* FRI Software Series No. 1, Forest Research Institute, Rotorua, New Zealand.

TENNENT, R.B. (1986). Computers in the forest. *What's New,* No. 145. Forest Research Institute, Rotorua, New Zealand.

VAN DER VOORT, C.R. (1968). *TRIP: a tree record interrogation package for the Elliott 503 computer.* New Zealand Forest Service, FRI Research Leaflet, No. 20.

WHITESIDE, I.D. and SUTTON, W.R.J. (1983). A silvicultural stand model: implications for radiata pine management. *New Zealand Journal of Forestry* **28**(3), 300-313.

Paper 14

Logging Operations: Planning and Follow-up

S. Westerling, The Forest Operations Institute, Box 1184, S-164 22 Kista, Sweden

Abstract

This paper describes computerised means and routines for the necessary short-term planning at a local level before a logging operation can begin as well as the current and final follow-up of the planned operation. This also includes a routine for gathering field-data with the help of a hand-held computer and an attached electronic caliper. A background to short-term planning is also provided in the form of a description of the earlier phases in the planning process - the long-term and the multi-year planning. The computerised aids for the short-term planning can also be incorporated with routines for financial management and control at a local level.

The overall objective of the planning and follow-up routines is to make management of the forests more reliable, less time-consuming and able to be performed away from the organisations' nucleus. The latter point is especially important in the decentralised organisations of Swedish forestry today.

Trends and needs

Companies and organisations in the Swedish forestry sector are today moving towards greater decentralisation. Authority as well as financial responsibility are moved away from the peaks of the hierarchies. At the same time there is an increasing need for better and more versatile tools that can be used to manage the activities of district and ranger district level more efficiently. The planning and follow-up routines available today are almost always imperfect, mainly due to the fact that they were implemented for organisations other than today's. As a result of this the routines are seldom if ever used.

During the last few years there has been a rapid development in computer technology. Personal computers or terminals are nearly always available in the forest companies from ranger district level and up. Furthermore there has been a steady increase in the use of hand-held computers to collect field data. With the help of this equipment there is great potential to create the means and tools for different purposes and for different users.

The Forest Operations Institute in Sweden has for a number of years been involved in the development of computer-based planning and follow-up routines in co-operation with various companies. The problems associated with planning were studied first and the SKOGPLAN 84 forestry planning system was the result. With the help of this system, plans for future activities in the forest can be implemented. The SKOGPLAN 84 system is currently being used in a number of organisations and the system is being updated in response to demands from users. However, the Institute is now focusing its interest and resources on other aspects of forestry management - the operational planning and follow-up activities.

In this paper some of the routines and findings from the Institute will be presented. The description will concentrate on the latter phases in the planning of logging operations and on the follow-up activities. Information on the earlier phases will also be included for the sake of completeness.

Firstly, a brief note on how the Swedish forestry sector is organised and the terms used in this paper. A big forest company has a main office, where for instance the chief forester is based. The company's forest holding is divided into a number of districts, each led by a district forest officer. The forest area of a district can range between 100 000-200 000 hectares and the yearly cut can be around 0.5 million m^3. Each such district is sub-divided into 5-10 ranger districts. The manager of each area is normally responsible for all activities in his district. In the case of a smaller company the main and district offices are often the same.

A forestry planning system - an overview

The SKOGPLAN 84 planning system has primarily been designed for use by local forest managers in big companies and managers in small companies with forest holdings. The system is versatile and can be used either as a whole unit or in parts. It is microcomputer-based and is available commercially. SKOGPLAN 84 can be obtained from a Swedish computer software company.

The planning system contains a number of different routines, both tailormade for a single purpose, or general purpose ones. Examples of the former kind are the routines for multi-year and one-year planning. General purpose routines are for instance the report generators, which use the different databases of the system. Logging and silvicultural operations are both covered by the system. The system is also readily adaptable to the needs of individual users. A flow chart of SKOGPLAN 84 is shown in Figure 14.1. References to this figure are made throughout the paper.

It is very important at this stage to mention that no component in the planning system can be used as a 'black box', to prepare ready-made plans for the user. The user is in charge and the computerised system is merely the user's 'obedient servant' helping him to undertake all the tedious tasks involved in manual planning work. A short description of the different steps in the planning process and how SKOGPLAN 84 is used is given below. The most important databases are however first briefly described.

Main databases and their contents

There are three main databases in the system, the stand file, the silvicultural file and the logging file.

The stand file contains data for all the separate stands, which together form the total forest holding of the administrative unit in question. The data in the file often reflect the costs associated with fast and general methods of collection. This means that the quality of individual data items in the file is perhaps not the best. Typical data in the stand file are:

identity;
area;
site information (site index, ground class, etc.);
growing stock (age, volume, diameter, height, etc.);
past and planned treatments.

Once the field data has been collected and stored in the database, the file must be continuously updated otherwise the data will become quickly outdated. This can be achieved either automatically by means of growth formulae in the system or when old stand data are updated for new data. The latter situation arises when stands have been treated or on other occasions when changes in an individual stand cannot be taken into account by growth formulae.

Due to the rapid changes in the life of a young stand and the need to follow such stands closely, a silvicultural database has been created within the SKOGPLAN 84 system. The units in this database are the same as those in the stand file, in other words exactly the same area on the ground is described. The stands, which are included both here and in the stand file, are all under a defined age. Planned and actual treatments carried out dominate the data. For example, the number of seedlings planted and the date, proposed year for first precommercial thinning, etc. The file is updated by means of frequent field visits, which is very important since changes may take place very quickly and must be responded to by the local manager.

The logging file contains data on the future logging sites, normally amalgamated from two or more stands. These sites are formed fairly close (1-2 years) to time of harvest. The data in the logging file are of high quality and precision. This is achieved with more precise methods than was the case with the stand file. The methods used will be described later. When compared with the stand file the data is more closely focused on the operation at hand. The data in the logging file include:

- identity;
- area;
- site information (site index, transport distance, etc.);
- diameter distribution;
- accurate volumes, etc.

Since the logging system will be treated in the near future there is no real need for updating the file apart from manual changes of the database.

Long-term planning

At this stage it is taken for granted that a long term cutting calculation (= strategic planning) has been performed. This calculation has been based on either the stand file or a great number of sample plots from the total forest holding. It has given the manager information on availability of wood material in each 10-year period for the coming 50-100 years given a certain management regime. It is prudent here to remember that the normal rotation period in Sweden is 80-120 years.

By basing decisions on the first 10-year period, the user may extract stands from the stand file with the help of the report generator in SKOGPLAN 84, until the required volumes and areas are obtained. The frames were laid down in the long-term cutting calculation. In the selection process the planner uses certain criteria. The criteria used to form the final selection are often of a very tangible nature, such as stands over a certain age, with a growth less than a certain figure. These are saved and later used in the multi-year planning routine. In should be noted that no decision has been taken at this stage to treat a specific stand. The planner has constantly been working with amalgamated stands (= classes). The main object of the long-term plan is to make sure that stands of cetain types are available for treatment during the coming 10-year period. Long-term forest management plans are normally prepared at district level.

Multi-year planning

The multi-year planning routine in SKOGPLAN 04 is a tool tailor-made for its purposes. It is basically used to solve the problem created by the two opposing goals of forestry, namely the need to treat a stand at the right time in the biological sense and the economic and often technical necessity to concentrate the activities in time and space. The object of the plan is to identify stands for every current treatment for each of the coming 3 years.

The planner is using often contradictory criteria from the long term plan when working with the multi-year planning routine. With these, and within current company policy, individual stands are graded to create a list. From the beginning all stands in the file are organised in treatment areas with fixed borders, which is an hierarchical level between stand and ranger district. This level is now coming into use. The planner is not selecting individual stands for treatment from the list, but instead chooses treatment areas with the highest proportion of high-graded stands. The idea is to treat not only stands with an urgent need for treatment while working in the area, but also to deal with stands where treatment from a biological point of view perhaps is somewhat early or late. Concentration of activities is thus achieved. Multi-year plans are prepared in dialogue between the managers at district and ranger district level. A new plan is normally implemented each year.

A local information system

The local information system is intended to cover the various activities within a district but primarily logging and silvicultural work. The system is meant to be used by all management personnel at those levels. The intention however has been to focus the development work on the rangers and supervisors in order to simplify their situation and make their work more efficient.

As can be seen from Figure 14.2, it is assumed that the local information system is an integrated part of the organisation's total flow of information. The higher level systems of which SKOGPLAN 84 may or may not be a part must be there to formulate demands on the current activities at a local level. The rangers and supervisors implement plans for their own acitivies (logging, silviculture, etc.) with support from these plans and demands. These plans are meant to cover the coming year and the routines of SKOGPLAN 84 (mainly the one-year planning routine) are used for this purpose. Before work can start on a given site an operational plan must be brought forward. This plan, which is the most detailed for a forthcoming operation, is produced by the supervisor in close co-operation and dialogue with the proposed workers. Once work has started on the site, the follow-up activities start on a daily basis. This gives an excellent opportunity to match the planned and actual development. The data used for planning on this level are the same and are collected with specially adapted methods. The basis of the budget is also obtained from these plans and the daily follow-up of the actual work will give information for the necessary economic planning and follow-up.

One-year planning

As was the case with the multi-year planning, the one-year harvesting plan is also produced with the help of a tailor-made routine in SKOGPLAN 84. This routine is connected to the logging file. When implementing the plan a major job is to decide for each individual logging site the optimum method, season and bucking policy. This is done in communication with the computer and the consequences of different choices are immediately calculated by the program (see Figure 14.3). The different sums of all these choices and decisions must also eventually match given frames of resources, costs and gains for a ranger district. The result of this comparison can also be studied at any time during the process (see Figure 14.4).

If the given frames cannot be matched with a certain mix of logging sites a number of alternatives are available. The forest ranger can either change decisions already made for sites to the second best, exchange selected sites for others from the logging file or if possible change the frames. A new one-year plan is produced annually but the current plan is of course updated continuously. Such an update is easy to do since all decisions made are saved in the computer and can be recalled immediately for new use.

Output from the one-year planning routine

The results of the planning work are different summaries describing the activities in the year to come (see Figure 14.5). The most important paper however is the document containing the basis for fixing the work rates for each individual logging site. An example of such a document is shown in Figure 14.6. The document contains information both on the standing forest and on the calculated outcome of the logging operation. The information in this document will be used further on in the management process. Apart from the standard output provided by the routine, there are also many opportunities to create tailor-made reports with the help of the report generator (see Figure 14.1).

Planning of logging sites and follow-up

General views

Before work can start on any logging site a detailed plan of the forthcoming operation must be completed. This plan is followed during the work on the site. Is there really any need for such a plan and what is it used for?

The routine is primarily aimed at the forest ranger (= supervisor) *and* the individual work gang. They will together try to lay down guidelines and goals for the future work on the site. These goals must be expressed in terms which can be measured, otherwise it is impossible to compare achieved results with the goals. Discrepancies must be analysed and the discussion between supervisor and work gang must form a basis for suggestions and corrections. It is very simple both for the forest ranger and the work gang to monitor work in progress, with the aid of a routine for continuous follow-up. Corrective measures can therefore be taken before anything goes astray. The follow-up information is also used to update the one-year plan.

The situation today

In Swedish forestry today a plan for the logging site of the kind described previously normally exists. There is however practically no organised follow-up activity, mainly due to the fact that all of this work is done on forms, which are processed manually by the supervisor. Wages are based on the information from these forms and they are consequently sent further up in the hierarchy of the company. It takes a long time for the amalgamated information to return and the work gangs have therefore lost most of their interest in the production figures when they finally arrive. The supervisor's task in this is tedious and not very rewarding since his main activity is correcting and putting his name on the incoming forms and forwarding them. He also keeps some of the information for his own use but summaries are difficult to make, since most of the data-flow is oriented towards the wage system.

The Institute's interest is to improve this manual system and to simplify the situation for the supervisor and to make him more efficient in his work. It is also important to give the workers accurate production figures while still working on the site. It is however at this point important to stress that the routine is still being developed and minor changes may be made.

Planning and follow-up in logging sites: a solution

The main component in the chosen technical solution is a portable computer kept in the site hut, which is used by the work gang to register their current activities. The screen is used as a form with the same layout as the old paper ones. When data are entered on to the computer they are processed and results are immediately available in the form of summaries, etc.

The first step before a new logging site is opened is to load the computer in the site hut with current inventory data. At the same time the basis for fixing the work rates from the one-year plan is also loaded. Following this, a plan for the logging site is drawn up by the supervisor and the work gang working together. This is done with the help of the computerised routine, which displays a form to be completed on the screen, as can be seen in Figure 14.7. Work on the logging site is now ready to start.

At the end of each day during work on the logging site each member of the work gang enters data on how his wage (= production data) and other remuneration (= use of own car, etc.) are to be calculated. This is done on the screen with the help of a form, which looks very much like the one the worker used in the manual system. An example of this is shown in Figure 14.8.

The production data, which are entered in such a way on to the computer, are continuously used to update the plan. This means that at any time during the operation the supervisor *and* the work gang can examine the results of their labour. It is thus possible at any time to update the plan for the future work. The follow-up is now also an integrated and practical part of the work of the supervisor. The production figures (= volume), calculated in the routine from the processed numbers of trees or logs, are not always accurate. It has however been judged more important to present approximate figures than to wait for the arrival of the scaling report. Most of the wood in Sweden is scaled at the mill gate and these reports are therefore late to arrive. The accumulated production figures are always available in the plan of the logging site (see Figure 14.7).

When work at the logging site is finished or at end of the month the result is sent by the work gang to the supervisor. Most of the controls have now already been carried out by the computer and the data are essentially correct at this stage. The only thing the supervisor has to do after a summary control is to send the wage basing information onwards. With the production data readily available on his own computer it is very simple for him to analyse the material further either with the help of standard or tailor-made programs of which the latter are included in the routine.

The exchange of data between different computers at different locations is intended to be done with the help of diskettes manually carried from one location to the other. In the near future, however, most of this traffic will be transmitted by radio. The Institute is also involved in developing work in that area.

A routine like this opens numerous possibilities but also a few problems for the organisations and for the people involved. In the following, some of these have been listed and it is important to consider each of them before introducing local information systems of the kind described in this paper.

1. There is a great need for education, not only for work gangs and supervisors but also for managers further up in the companies.
2. With the routine, the work gangs will get more precise information of the work process at an earlier occasion. This means that their involvement and influence in the planning of the logging sites will increase. In the long run it is also possible that they will to a greater extent also influence the one-year plan.
3. The computer routines used at the site hut must be simple otherwise they are not going to be used. It is definitely possible to make comparatively complex operations simple. It is interesting to compare this with cash dispensers, which many people use today to obtain their cash using a computer routine.
4. It is of major importance that everyone involved is motivated and understanding, since otherwise it is very simple to disturb the routine and its yields. It is also important to make clear that the main aim of the routine is to support the company and make it more profitable and flexible.
5. The supervisor will become more efficient at his work. The parts of his administration and management, which earlier consisted of fairly simple tasks, are exchanged for more complex and rewarding analyses. The total time spent will probably not be less but definitely more profitable.
6. The company as a whole will have a much better base for its decisions and the awareness of the economic realities will be much greater all through the organisation.

Field data collection

General views

Most of the activities described in this paper would be pointless without access to data from the forest. That is particularly true in the case of operational planning since careful calculations are no more than an armchair exercise if they are not based on accurate information. Otherwise many of the activities will resemble the situation in Figure 14.9.

Field data collection is unfortunately an expensive operation and it is therefore necessary to co-ordinate the different needs to one inventory in the future logging site. It is important to find means and methods which can supply accurate data at the 'right' cost and to use the same set of data in different routines.

The same set of data (logging file) is used both in the one-year planning and in the planning of the logging site as can be seen from the diagram of the local information system (Figure 14.2). Data collection routines have been devised which can be used to meet the demands of variable accuracy in different sites. For small or less valuable sites, it is often sufficient to use data from the stand file sometimes followed by a field inspection. Objective methods are however recommended for larger or more valuable sites, where it is important to produce accurate and trustworthy data. An important principle, sometimes overlooked is that the borderlines of all future sites must be fixed at this moment since area errors are one of the greatest sources to lack of consistency between calculated and harvested volume.

A practical solution

The inventory in the local information system is carried out with the help of a hand-held computer. The computer is connected to an electronic caliper and the diameters are registered automatically. It is of course also possible to use a common caliper. Due to the big screen of the computer (40 * 8 characters) it is simple for the program to guide the user through his work.

The first step of the inventory is to mark the borderline of the future logging site. As a second step the operator, who carries out the inventory has to answer some general questions from the program concerning region (for volume calculations), choice of caliper, inventory method, etc. Each inventory method in the routine is based on sample plots. On each plot data (species, diameter and height) from a few sample trees are collected. Following this, all or some of the diameters of the trees on the plot are measured and these data stored in the computer. The total number of trees per species on the sample plot is also collected. If an error is made during collection the user is alerted and the error can easily be adjusted.

The result of the inventory can be calculated at any time during the work, which can be studied in Figure 14.10. This summary contains information for each species and also a total for the site. If objective methods have been used during the inventory the mean error is also calculated. This can be seen as a quality declaration of the collected data. If the error is too high to be acceptable it is simple to add more sample plots in order to improve the result.

Connections to administrative routines

The ongoing decentralisation in Swedish forestry as described earlier means an enlarged responsibility not only for operations but also for the economic outcome of the activities. In order to be able to manage a district or ranger district efficiently the manager needs tools especially made for him. The economic management aids available today are normally not adapted for use on local level and there is obviously a great need for better and more versatile tools.

The Institute has not done any research in this area. The following passage should therefore be seen as a recommendation and as an outline for how the economic system of the company can be incorporated in our local information system.

An important role in economic management is played by the budget. The budget shall be seen as an *undertaking* to fulfil certain economic goals. The consequences of this is that the budget must be drawn up as a joint venture between the district and ranger district manager for example. As was the case with the operational planning and follow-up, the current outcome of the budget (= the economic plan) must also be followed closely and discrepancies analysed and reported in order to avoid surprises at the end of the budget year.

In Swedish forestry today there is practically no budget work done at ranger district level. The budgets at district level are in most cases fairly rough and based on the results from past years. A much better way to produce a budget is to go by way of the one-year plan, where accurate data are available on individual logging sites, for example the calculated costs and gains. The follow-up of the logging sites can be used for preliminary and fast controls of the economic development. This fast feed-back gives the manager a tool with which he really can manage and not only follow the activities. The final control of the budget over a certain period must, however, wait until accurate information has been received from the scaling and other economic reports.

Introduction of forest computer systems: experiences

The SKOGPLAN 84 system is today an integrated part in the planning work of some of our Swedish companies. There are however many lessons to be learned from the introduction of microcomputer-based systems. In the following some of these will be touched upon without any ranking of their individual importance.

The introduction of a big system takes a long time (1-2 years). During this time good system support is vital and must be readily available. Otherwise there is a great risk that the prospective user's interest and commitment will fade. The introduction therefore costs a lot of money, often more than the cost of the program, something which is worth knowing in advance.

The user must at least have an interest in computers since one of the consequences of obtaining a microcomputer is that the user has to be in charge of such dull things as backups, etc.

It is necessary for someone at each computer installation to learn not only the current programs but also a little about the rest of the computer environment (hardware and software). Otherwise every fault, and they will come, will create a major obstacle.

It is important, especially when the user lacks previous computer experience, to make certain that the programs are adapted to the user's world. That is the user must be accustomed to the questions asked by the program. The solutions given by the program must also match the user's problems.

Programs *must* make use of the user's native tongue. This is a real problem in small countries such as Sweden, where misunderstood questions from programs can lead to disasters.

The system must be user friendly. It should however, be remembered that a tool which offers many uses is often somewhat complex in itself.

Education is an important factor and must be adapted to the level of the intended users. It is also vital to present the system in a logical sequence or the pupils will forget most of the material presented if a course is run on a single occasion on the entire system.

REFERENCES

ERICSON, O. (1986). *Modern routines for planning of logging operations.* The Forest Operations Institute of Sweden, Results No. 4.

ERICSON, O. and WESTERLING, S. (1985). *Skogplan 84 – a modern planning and follow-up system for forestry* (in Swedish with English summary). The Forest Operations Institute of Sweden, Report No. 4.

WESTERLING, S. (1986). A modern forestry planning system. In *Computers in forestry*, 65-73, eds. W. L. Mason and R. Muetzelfeldt. Proceedings of a Conference on the Applications of Computers to the Management and Administration of Forests, the Harvesting and Marketing of Timber and to Forestry Research. Institute of Chartered Foresters, Edinburgh.

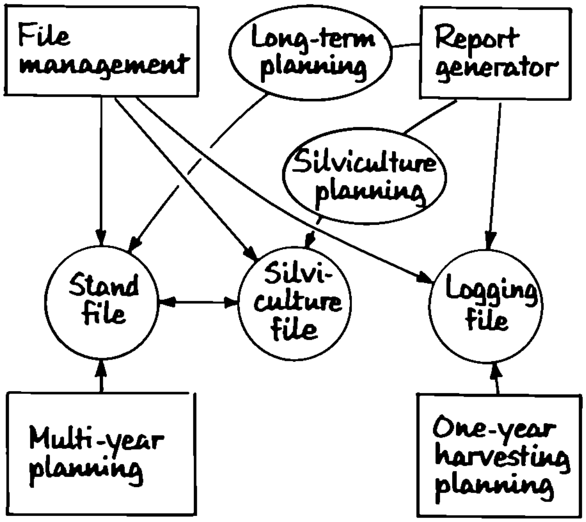


Figure 14.1 Flow chart for SKOGPLAN 84.

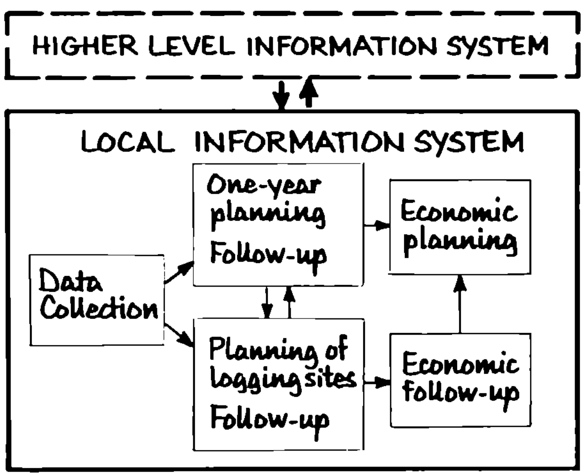


Figure 14.2 The local information system.

Alt. ->		1		2	3	4	5
Assortm.	cm	m^3	cm	m^3			
Sawlogs P	20	188	19	210			
S	23	53	22	56			
Σ		241		266			
Smallwd P	0	0	0	0			
S	0	0	0	0			
Σ		0		0			
Pulpwd P		80		56			
S		8		5			
H		68		68			
Σ		155		129			
Value kkr		106		105			

Enter min. top diameter

Alt3	Sawl	Smwd	Pulp
Pine	16	0	5
Sprc	14	0	5
Hwd	0	0	5

<u>Site data</u>

Trarea	2
CG-Bas	2
GC	1
GR	1
Sl	1
Roadst	1
SiteCL	120
Area	1.0
Pdist	7
Sdist	2
Hdist	1
Extdist	2
P-US%	50
S-US%	60
Age	105
Stem	933
DiamA	27.5
Height	26.7
Basare	37
Thin%	0
Totvol	414
Error	19
(%) :	0

```
Continue with next bucking alternative or amend ?
Choose alternative. Answer (0..5) :  3 ( 0 => to choice)
Rng.Dist. :  1 Map   :  2 Site   : 8001 Treatm.  : FiFe Thinning
```

Figure 14.3 *Analysis and selection of bucking-policy option (P = pine; S, Sprc = spruce; H, Hwd = hardwood).*

Assortm.=> m^3	Sawlogs (1)	Smallwood (2)	Pulpwoo (3)	D E T A I L O F (1) Pine	Spruce	Hardwood	NHwd
Season : Sprn							
Result	1234	0	11	433	801	-	0
Frame	1000	0	9	500	500	-	0
Difference	234	0	2	-67	301	-	0
Season : Summ							
Result	2445	0	29	1080	1365	-	0
Frame	2100	0	30	1000	1100	-	0
Difference	345	0	-1	80	265	-	0
Season : All							
Result	23780	0	112	6576	17204	-	0
Frame	20500	0	108	5500	15000	-	0
Difference	3280	0	3	1076	2204	-	0

```
Choose alternative. Answer (0..3) :  1 ( Details of assortment ?)
Rng.Dist. :  1 Map   :  0 Site   :   0 Treatm.  : All  Thinning      (%) :  0
```

Figure 14.4 *Comparison between results and frames (NHwd = noble hardwood = oak, beech, etc.).*

VOLUMES m^3		RESULT	Season : Summ	FRAME		RESULT	Season : All	FRAME	
Sawlogs	Pine	1365		1000		6576		5500	
	Sprc	1080		1100		17204		15000	
	NHwd Σ	0	2445	0	2100	0	23780	0	20500
Smallwd	Pine	0		0		0		0	
	Sprc	0		0		0		0	
	NHwd Σ	0	0	0	0	0	0	0	0
Pulpwd	Pine	1067		1200		3890		4000	
	Sprc	1538		1600		6903		6000	
	Hwd	305		200		912		800	
	NHwd Σ	0	2910	0	3000	0	11705	0	10800
	ΣΣ		5355		5100		35413		31300

ECONOMY	Result	Kkr	kr/mmd	kr/m^3	ONE-YEAR PLAN	Kkr	kr/mmd	kr/m^3
Revenue		1012	1834	189	1988-05-19	8491	3854	239
Cost		498	904	93		3264	1482	92
Contr. profit		514	930	96	Rng. Dist. : 1	5227	2372	147

Do you also want resource results ? No

Figure 14.5 *A typical end-document from the one-year plan.*

The Forest Company Ltd Page : 6
1988-05-19

RESULT - ONE-YEAR PLAN, BASIS FOR FIXING THE WORK RATES

Identity						Inventory data					
Rng.Dist	1	Map	2	Treatm	1	Surveyor	1	Pltarea	100	Pltnum	15
Trarea	2	Site	8039	Thin%	0	Idate	8606	Relfact	0	Error	12
Parish	1					Imethod	1				

Site data	
Areal	5.7
Vol	227
Totvol	1294
Stem	341
P-US%	45
S-US%	50
Trans%	0
DiamA	28.4
Extdist	4
GC-Bas	2
GC	1
GR	1
SL	1

Diameter distribution

	-8	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46+	Σ
PINE		2		11		31		58		82		95		92		71		38		8		
	0		5		20		44		70		90		96		83		55		21		1	975
SPRUCE		1		9		25		46		65		76		74		57		30		7		781
	0		4		16		35		56		72		77		67		44		17		1	
HWD		0		2		6		11		16		19		18		14		7		2		194
	0		1		4		9		14		18		19		17		11		4		0	
																					ALL	1949

Result	PINE	SPRC	HWD	ALL
Min.diam cm				
Sawlogs	15	12	-	
Smallwd	0	0	-	
Pulpwd	5	5	5	
Top diam. cm				
Sawlogs	24	25	-	
Smallwd	0	0	-	
Volume m^3				
Sawlogs	509	468	-	977
Smallwd	0	0	-	0
Pulpwd	117	53	103	273
ALL	626	521	103	1250

Method and season

Method MomF (1)
Season Wint (2)

Man/Machine days

Cutt	Forw
94	13

Average stem	PINE	SPRC	HWD	ALL
Vol m^3sk	.66	.69	.55	.66
Diameter cm	30	30	30	30
Height m	21	21	21	21
Stem tot	975	781	194	1949

Economy	Tot (Kkr)	kr/m^3
Revenue	352	281
Cost	103	83
Contr. profit	249	199

Figure 14.6 *The basis for fixing the work rates.*

The Forest Company Ltd PLAN OF LOGGING SITE Date: 88-04-20

SITE DATA

Site: 1 5712	Rng.Dist.: 5	Cou./Mun.: 1266	Par.: 7
Work gang: Charles Chaplin's	Treatm.: 1	Res.types:	1 Cutter
			2 Forw
Area, ha: 10.6	Method : 2 PmeF		3 LimBuck
			0
Extr. dist, m 200	Season : 2 Wint		0

Terrain GB,G,R,S: 1 1 1 1

The site is amalgamated from stands

Cutting class: 8

Stand	23	28	0	0	0	0
Area, ha	8.4	2.2	0.0	0.0	0.0	0.0
Sitecl	236	230	0	0	0	0

GOALS

	PERFORMANCE Goal	Result		TOTAL TIME CONSUMPTION Goal	Result
FELLING	11	0	trees/h	193	0 h
CONVERTING	23	0	trees/h	96	0 h
FORWARDING	13	0	m^3/h	190	0 h

WORK QUALITY	Goal	Result
damagefreq.	0	0 %
strip road		
- distance	0	0 m
- width	0	0 m
- area	0	0 %

Figure 14.7 Plan of logging site (part).

The Forest Company Ltd PRODUCTION REPORT - MOTOR MANUAL
Site : 101 200 Groucho Marx 490315-0037 May 1988

Date	Note	Production (by the piece)								
		Saw logs Pine	Saw logs Sprc	Pulp wood Pine	Pulp wood Sprc	Pulp wood Hwd				ALL
1	<Free sunday>									
2		12.0	8.0	34.0	50.0	6.0				110.0
3		8.0	6.0	47.0	59.0	16.0				136.0
4		15.0	10.0	61.0	36.0	12.0				134.0
5		11.0	6.0	78.0	42.0	15.0				152.0
6		6.0	8.0	46.0	58.0	32.0				150.0
7	<Free saturday>									
8	<Free sunday>									
9										
10										
11										
12										
	Total month:	52	38	266	245	81	0	0	0	682

Figure 14.8 Example of production report.

Figure 14.9 *Lack of information.*

PLOTS: 16	PINE	SPRUCE	HWD	ALL	ERR%
STEM/ha	304	788	50	1142	8
BAAR/ha	15	15	1	31	9
VOL/ha	118	110	5	232	10
AV.STEM	387	139	103	204	12

MAP: 11 SITE: 7541

Figure 14.10 *Inventory result presented in the forest (BAAR = basal area; AV.STEM = average stem volume, dm^3).*

Paper 15

A Methodology for Machine Selection using Harvest System Simulation/Cost Analysis

J.F. ***McNeel****, Assistant Professor, Extension Forestry Department, University of Georgia, Tifton, Georgia, U.S.A. and* **T.W. Reisinger,** *Assistant Professor, Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana, U.S.A.*

Abstract

A method for testing new harvesting equipment through simulation of production and cost factors is examined in this paper. A microcomputer based harvesting simulation/cost analysis program was used to estimate the effect of introducing a sawhead feller-buncher into an existing harvesting system. Production equations for the Bell Model T sawhead feller-buncher were developed and used in the Auburn Harvesting Analyzer to determine what impact this machine had on system productivity and cost. The analysis indicates that individual cost efficiencies associated with the Bell may not exist when the machine is evaluated in a system environment. The study suggests that simulation analysis can be used for evaluating the effect of various system changes without incurring the high costs associated with field study and analysis of harvest systems.

Introduction

Evaluation of new harvesting equipment often involves machine analysis using time and motion studies. Typical examples in the United States include studies by Landford and Sirois (1983), Greene and others (1984), and Ashmore and others (1987). The resulting cycle or functional equations provide a good estimate of machine productivity based on field observations of a single machine independent of system constraints.

However, the actual performance of a machine depends substantially on its interactions with other equipment in a productive setting. These interactions can have tremendous impact on both system productivity and unit production costs. Determining these effects has often been a 'hit and miss' affair, where a machine is actually placed in a productive environment and observed over time. This approach is time consuming, costly, and not always accurate. In many cases, computer simulation is a less costly and faster method of analysis.

Several new harvesting simulation programs have been developed in recent years that take advantage of advances in microcomputer technology (McNeel, 1986; Reisinger *et al.,* 1987). These programs allow potential users better access to harvesting systems at lower cost and provide relatively accurate results.

This paper examines the use of a microcomputer-based simulation/analysis program to assist in testing new harvesting equipment under system constraints. To evaluate this methodology, a microcomputer-based harvest simulation/cost analysis program, the Auburn University Harvest Analyzer (Tufts *et al.,* 1985), was used to analyse production equations for two different felling devices using similar system constraints. Simulation was used to determine the impact on productivity and cost when replacing a conventional shear-head feller buncher with a new saw-head felling machine. In addition, comparisons were made over a range of stand and stocking conditions to determine the impact of outside variables on changes in the harvesting system.

Methods and procedures

Southern harvesting operations have traditionally used shear-type felling equipment to fell and bunch standing trees. Recently, emphasis has been placed on the replacement of shear-type feller-bunchers with newly developed saw-type machines to alleviate problems with shear-related damage in the butt log of felled trees (Greene and McNeel, 1987).

***Figure 15.1** The Bell Model T sawhead feller-buncher.*

The Bell Model T sawhead feller-buncher is one of the first saw-type felling units introduced into the southern U.S. on a widely commercial basis. The Bell, first available in 1986, is a three-wheeled unit equipped with a sawhead felling device capable of felling trees up to 100 cm in diameter (Figure 15.1) Field studies indicate that the machine is very productive in large diameter stands of timber (i.e. 40 to 60 cm DBH), although the studies suggest that production declines in small diameter stands (i.e. less than 30 cm DBH). Production studies of the Bell Model T have analysed individual machine performance in terms of production and cost (McNeel and Greene, 1987; Greene and McNeel, 1987). The total cycle equations developed from these analyses incorporate both tree diameter and between tree distance as the dependent variables:

$$TC = 0.5792 + 0.0135 * DIST: \text{IF } DBH <= 43 \text{ cm}$$

and

$$TC = -2.0394 + 0.0012 * DIST + 0.0032 * DBH^2: \text{If } DBH > 43 \text{ cm}$$

where:

TC = total cycle time in minutes per cycle
DBH = diameter at breast height (cm)
DIST = average between-tree distance (M).

Cost analysis of the Bell indicates that it can be extremely cost efficient over a wide range of stand conditions, costing less then \$0.60 per m^3 in stands averaging 41 cm DBH (McNeel and Greene, 1987). However, the machine has not been examined in a system environment to determine if the cost efficiencies could be extended to total system costs.

The Auburn Harvesting Analyzer (Figure 15.2) was used to compare a conventional system using a shear type feller-buncher with a system using the Bell sawhead machine. The conventional system, termed the 'Hydro-Ax System' in later discussions, was comprised of a Hydro-Ax 511 feller-buncher, two Timberjack 380 grapple skidders, a Prentice 210 knuckleboom, and four Mack haul trucks. The modified system, termed the 'Bell System' in later discussion, was comprised of similar machines, with the Hydro-Ax 511 being replaced with a Bell Model T sawhead. System parameters used in the analysis are detailed in Table 15.1, while parameters for the Bell and the Hydro-Ax feller-bunchers are detailed in Table 15.2. Major differences between the two units include purchase price, insurance and tax costs, fuel consumption, maintenance and repair costs, and the equations used to estimate machine productivity.

Stocking and average stand diameter were modified to cover a range of stand conditions. To determine how changes in tree size affect system costs when using the Bell, stand parameters were varied to reflect a range of stand diameters. In addition, stand density was modified to allow for analysis at several levels of stand volume. System comparisons under these differing conditions were used to determine what system advantages might be derived from using the new sawhead technology. The two systems were compared in stands with average stem diameters ranging from 17 cm DBH to 51 cm DBH and stocking

```
                    AUBURN HARVESTING ANALYZER
                    --------------------------
 SYSTEM:  Bell Model T, Timberjack 380, gate, Prentice 210, Mack Truck
========================================================================
 --STAND & STOCK TABLE-- ----------------GENERAL INFO------------------
  DBH  T/Ac Cd./T Cd./Ac Hours/Day=     9  Tract Size=  250   Acres
------------------------ Days/Week=     5   Move Time=    5   Hours
   6      0 0.050  0.00  Weeks/Yr =    48  Home Dist.=   35   Miles
   8      0 0.083  0.00
  10      0 0.164  0.00 Support--                 Roads to be built--
  12     12 0.225  2.70     2 Pkup:  0.18  $/mi.    Type    Miles  $/mi.
  14     30 0.341 10.23    Foreman:  1500  $/mo. Main haul:  0.00 10000
  16     64 0.431 27.58   Overhead:   500  $/mo. Secondary:  0.00  3000
  18     34 0.527 17.92     2 Saws:   600  $/ea.  Push-out:  1.25  1050
  20     10 1.083 10.83
------------------------ Arth. Mean DBH=  16.00  Truck Hrs/Day=   12.00
 TOTAL  150        69.3  Quad. Mean DBH=  16.13  Quota (Cd/Wk)=    999
========================================================================
------FELLING----- ----SKIDDING----- -----LOADING----- -----HAULING-----
------------------------Machine Productivity---------------------------
 BA/accum=  0.56  Deck-Woods=  300  TiDwn Time= 3.87        Miles Speed
-----------------  Gate-Deck=  150   Trim Time= 2.87  2ndry  0.5   3.2
 DBH  Min/T Hr/Ac Skidder Wt=17140   DBH  Min/T Hr/Ac  Main  1.1   6.8
 ---  ----- ----- Skidder HP=  136   ---  ----- ----- Grvel  2.5  19.0
   6  0.57  0.00  Tree/Cycle=  2.5     6  0.31  0.00  Paved 40.0  40.0
   8  0.61  0.00  Bnch/Cycle=  1.1     8  0.47  0.00   ------------
  10  0.62  0.00    ------------      10  0.61  0.00   Load Size= 9.80
  12  0.63  0.13  Cycles/Ac.= 60.0    12  0.74  0.15  Unload Tim=   30
  14  0.65  0.32  Cords/Cycl= 1.02    14  0.84  0.42   Load Time=25.88
  16  0.64  0.69   PMM/Cycle= 5.53    16  0.92  0.98   Trip Time= 3.83
  18  0.62  0.35                      18  0.97  0.55
  20  1.23  0.21                      20  0.99  0.16
-----------------                   -----------------
 TOTAL  --- 1.70                    TOTAL ----  2.25
 Cords/PMH= 40.63  Cords/PMH=12.53  Cords/PMH= 22.72   Cords/PMH= 2.56
--------------------------Machine Cost---------------------------------
 Pmt ($/mo)= 2139              1742              1230              1332
 I&T ($/mo)=  159               204               144               134
 F&L ($/hr)= 0.88              4.84              4.08              5.36
 M&R ($/hr)= 6.77              4.43              2.60              1.97
 Labr($/hr)= 7.50              6.50              7.50              7.00
 Fringe (%)=   36                36                36                36
 Max UT(%) =   65                70                85                90
 Number    =    1                 2                 1                 4
========================================================================
            Cords   Max   Cords/SMH   New -----Cost per SMH------  Cost
Function     /PMH  % UT   One   All  % UT Fixed  Oper Labor Total  $/Cd
------------------------------------------------------------------------
 Felling    40.63    65 26.41 26.41    30 12.77  2.31 10.20 25.28  2.06
 Skidding   12.53    70  8.77 17.54    49 21.62  9.09 16.90 47.61  3.88
 Loading    22.72    85 19.31 19.31    54  7.63  3.61  9.75 20.99  1.71
 Hauling     2.56   120  3.07 12.28   120 32.58 35.18 48.53 116.3  9.47
 Support     Pickups, Chainsaws, Foreman, and Overhead             1.18
 Road Work                                                         0.08
 Moving      5.00 hours spent moving men & equipment to tract      0.05
------------------------------------------------------------------------
                System Rate =12.28      System Cost/SMH:  210.1
  Weekly production (cords) =  553
 Days required to cut tract =  158          System Cost/Cord: 18.41
========================================================================
```

Figure 15.2 *Typical output from the Auburn Harvesting Analyzer*

Table 15.1 Stand parameters used in the Auburn Harvesting Analyzer.

General tract information:
Tract size: 101 ha
Move time: 5 hours
Home distance: 56 km

Road construction requirements:
Main haul: 0
Secondary: 0
Push-out: 2.01 km @ $652 per km

Support equipment:
Pick-up trucks: 2 each @ $0.11/km
Foreman: $1500/month
Overhead (office, etc.): $500/month
Chainsaws: $600/saw

Work schedule:
Hours/day: 9 hrs/day
Day/week: 5 days
Weeks/year: 48 weeks
Truck hours/day: 12 hours

Machine cost:[1]

	Skidding	Loading	Hauling
Unit:	Timberjack 380	Prentice 210	Mack truck trailer
Number:	2	1	4
Financing:	$1742/month	$1230/month	$1332/month
Insurance:	$204/month	$144/month	$134/month
Fuel, lube:	$4.84/hr	$4.08/hr	$5.36/hr
Maintenance:	$4.43/hr	$2.60/hr	$1.97/hr
Labour:	$6.50/hr	$7.50/hr	$7.00/hr
Fringe Rate:	30.0%	30.0%	30.0%
Utilisation:	70.0%	85.0%	90.0%

Machine productivity:[1]
Skidding:
Average skid distance = 91 m
(45.5 m — deck to gate delimber, 45.5 m — gate to woods)
Average number of trees per turn = varied from 1 to 4 trees
Average number of bunches per turn = 1.1 bunches
Maximum volume per turn = 2.55 m^3
Loading:
Average tie-down time = 3.87 minutes
Average trim time = 2.60 minutes
Hauling:
Average load size: 25 m^3 per load
Average unload time at mill: 0.50 hours
Average total trip time: 4.15 hours (includes loading times)

[1] Felling equipment data is provided in Table 15.2

conditions ranging from 173 trees per hectare to 865 trees per hectare. The average volume in these stands ranged from 130 m^3 to 470 m^3 per hectare, generally increasing with stand diameter.

Other parameters changed during analysis include changes in the skidding data to maximise skidding capacity at 2.5 m^3 or less. In larger diameter stands, the number of trees skidded per turn was set to reflect this limit. A maximum of four stems per turn was used when simulating smaller diameter (under 41 cm DBH) stands.

Analysis results

A summary of cost and production data for the two harvesting systems is provided in Table 15.3.

Table 15.2 Felling equipment parameters used in the Auburn Harvest Analyzer.

Item	*Bell Model T feller-buncher*	*Hydro-Ax 511 feller-buncher*
Financing:	\$2139/month	\$2989/month
Insurance:	\$ 159/month	\$ 298/month
Fuel, lube:	\$ 0.88/hr	\$ 1.91/hr
Maintenance:	\$ 6.77/hr	\$ 3.79/hr
Labour:	\$ 7.50/hr	\$ 7.50/hr
Fringe rate:	36.0%	36.0%
Utilisation:	65.0%	65.0%

Production equation used for the Bell Model T (McNeel and Greene, 1987):

$$TC = 0.5792 + 0.0135 * DIST\text{: If } DBH >= 43 \text{ cm}$$

and

$$TC = -2.0394 + 0.0012 * DIST + 0.0032 * DBH^2\text{: If } DBH > 43 \text{ cm}$$

where:

TC = total cycle time in minutes per cycle
DBH = diameter at breast height (cm)
DIST = average between-tree distance (m)

Production equation used for the Hydro-Ax 511 (Lanford and Sirois, 1987):

$$TC = 0.11 + (0.0357*DBH/DIST) + (0.0183*BA/DIST) \quad \text{If } DBH <= 46 \text{ cm}$$

and

$$TC = -0.251 + 0.0484*DBH + 0.00026*DBH^2 \quad \text{If } DBH > 46\text{cm}$$

where:

TC = total cycle time (minutes/cycle)
DBH = diameter at breast height (cm)
DIST = average between-tree distance (m)
BA = basal area (cm^2) accumulated in shear

Table 15.3 Comparison of production and cost data for the Bell and Hydro-Ax systems.

Mean stand Diameter (cm)	*17*	*20*	*25*	*30*	*36*	*41*	*46*	*51*
Bell Model T: cost/m^3 (\$)	\$18.16	\$12.33	\$9.04	\$7.74	\$7.56	\$7.22	\$7.14	\$8.49
Weekly production (m^3/week)	423.1	690.7	1118.9	1348.3	1378.9	1409.5	1447.7	1088.3
Hydro-AX 511: Cost/m^3 (\$)	\$10.65	\$9.16	\$8.05	\$7.71	\$7.51	\$7.32	\$7.36	\$8.94
Weekly production (m^3/week)	909.9	1088.3	1312.6	1348.3	1378.9	1409.5	1447.7	1088.3

The Bell system produced substantially less wood per week in smaller diameter stands, i.e. average stand DBH of 25 cm or less. Poor production levels for the Bell in stands with a mean DBH of 17 cm reduced system production to 423 m^3 per week. In contrast, the Hydro-Ax system produced an average 910 m^3 per week in similar stand conditions, a difference in production of more than 115 per cent. The graph in Figure 15.3 illustrates production differences for these two systems across the range of diameters analysed.

As noted, the Bell system produced less wood per week than the Hydro-Ax system in stands with an average diameter of 25 cm DBH or smaller. When average stand diameter increased beyond 25 cm DBH, the Bell system matched the production level of the Hydro-Ax system. However, production for the Bell system never increased in stands of 30 cm DBH and larger, as was suggested in previous single machine analyses. Other components of the system, particularly the skidding and trucking functions, affected production in large diameter stands and minimised the impact of the Bell feller-buncher on total system costs.

As a result, unit production costs for the Bell system in larger timber were marginally better than those costs associated with the Hydro-Ax system. The simulation results suggest that costs for the Bell system range between \$7.14 and \$18.16 per m^3. The Hydro-Ax system illustrated a substantial cost advantage in smaller timber, with total system costs ranged between \$7.32 and \$10.65 per m^3 (Figure 15.4). These cost differences decrease as stand diameter increases and shift in favour of the Bell system in 41 cm DBH stands (Figure 15.5). However, even in larger timber, the unit differences favouring the Bell system are small and suggest little financial incentive for including the sawhead machine in the system being simulated.

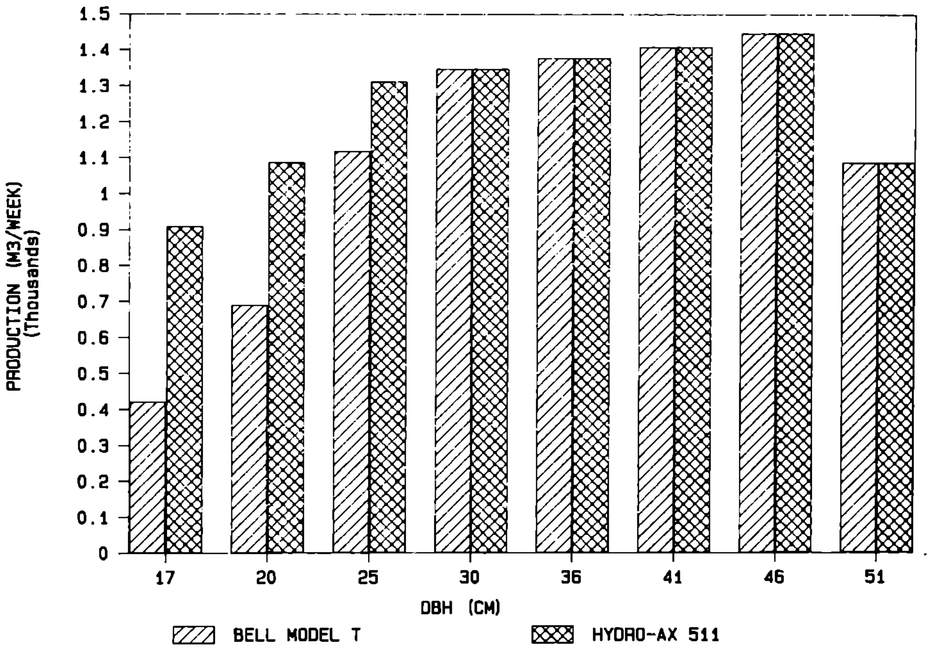


Figure 15.3 Production comparison for the Bell Model T and Hydro-Ax 511 systems.

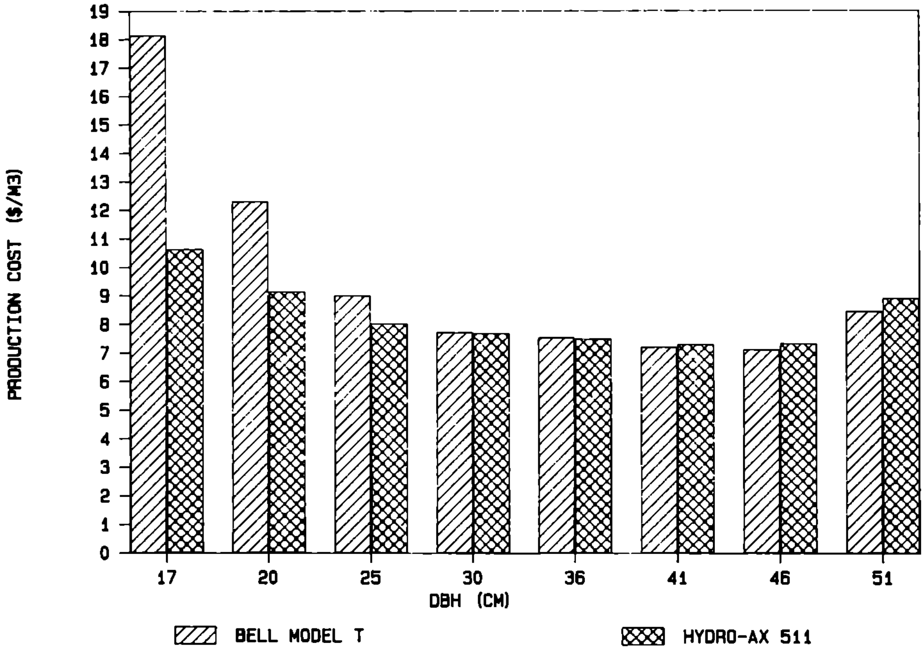


Figure 15.4 Unit cost comparison for the Bell Model T and Hydro-Ax 511 systems.

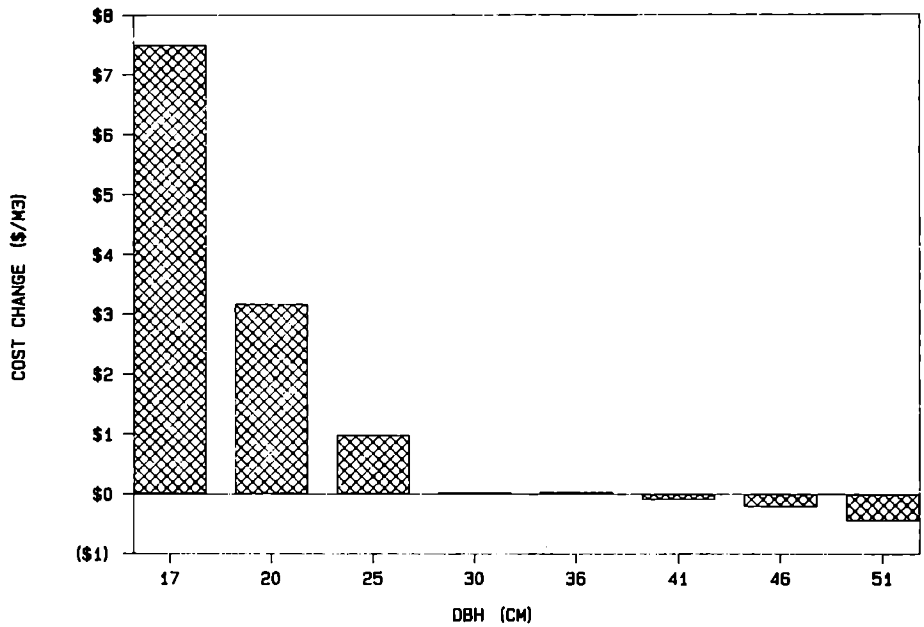


Figure 15.5 Change in cost per cubic metre when adapting system to include Bell Model T sawhead feller-buncher.

A more quantitative method of estimating the financial gains or losses associated with system modification, termed the opportunity cost, also proved useful for this analysis. The opportunity cost in this case is defined as those costs associated with not modifying the system to account for new harvesting technology and is specifically defined in the following equation:

$$OC = [(Rn*Pn)-(Cn*Pn)]-[(Ro*Po)-(Co*Po)]$$

where:

- OC = opportunity cost (\$/week)
- Po = production for old system (m^3/week)
- Pn = production for new system (m^3/week)
- Cn = cost per unit of production - new system (\$/m^3)
- Co = cost per unit of production - old system (\$/m^3)
- Rn = gross revenue per unit - new system (\$/m^3)
- Ro = gross revenue per unit - old system (\$/m^3).

In this study, the Bell system is defined as the 'new system', while the Hydro-Ax system is defined as the 'old system'. In addition, the value for R gross revenue per unit) is an assumed constant of \$19.62 per m^3 for both systems. Application of the opportunity cost equation to the systems under study yielded opportunity cost values ranging from −\$7,544 when operating in an average 17 cm diameter stand to \$490 when working in a 51 cm diameter stand. These costs are graphed against average stand diameter in Figure 15.6. In stands averaging 36 cm DBH and less, the opportunity cost is negative, suggesting that no financial incentive exists to adopt the Bell system. In contrast, a logger operating in 41 to 51 cm diameter stands should expect some opportunity cost if the Bell system is not adopted. Depending on the average stand conditions, this cost could range between \$133 a week to \$490 a week for the described system (Table 15.4).

Opportunity cost factors can be used to quantify the financial advantages of any new

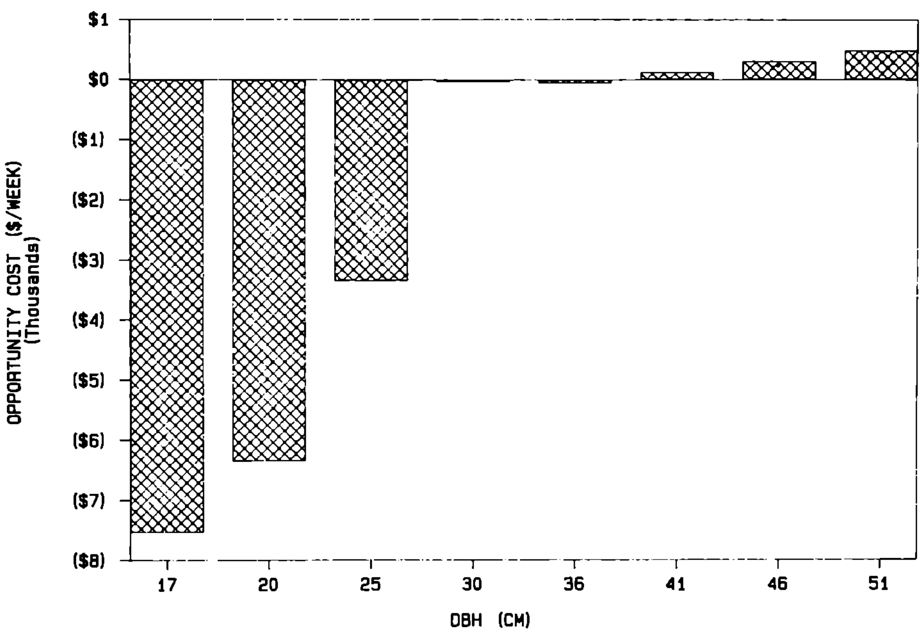


Figure 15.6 Opportunity costs associated with not changing system to include Bell Model T sawhead feller-buncher.

Table 15.4 Potential changes associated with adopting Bell Model T sawhead feller-buncher into existing system.

Mean stand diameter (cm)	*17*	*20*	*25*	*30*	*36*	*41*	*46*	*51*
Cost change ($/m^3)	– $7.51	– $3.17	– $0.99	– $0.03	– $0.04	$0.09	$0.22	$0.45
Prod change (m^3)	– 486.8	– 397.6	– 193.7	0.0[1]	0.0	0.0	0.0	0.0
Opportunity cost ($/wk)	– $7,544	– $6,348	– $3,349	$40	$69	$141	$319	$490

[1] No change in productivity indicates that other components of the system have reached their maximum productive capacity. To rectify this problem, further system changes are required that go beyond the scope of this paper.

harvesting system relative to an existing system. In addition, computer simulation techniques facilitate rapid computation of opportunity costs for decision-making purposes. In this case, opportunity cost analysis identified stand conditions where the modified system would be economically advantageous and quantified the 'cost' associated with not adopting the new system. Such analysis techniques can be refined and used to match harvesting systems with stand conditions that ensure adequate financial return.

Conclusions

System analysis is an appropriate method for defining the advantages and disadvantages of new harvesting equipment and provides a somewhat more realistic approach than single machine analysis. Adapting the concept of opportunity costs to harvesting system analysis in this case provided a quantitative measure of the impact associated with system modifications. In addition, this analysis tool could be applied to other harvesting analysis situations, assuming that: 1) simulation/cost programs are available to model the harvesting system being analysed; 2) production equations have been developed that define individual machine performance; and 3) accurate cost and revenue data for the harvesting system is available.

System analysis can help to define the potential of harvesting technology and identify harvesting parameters that will enhance system productivity and minimise system costs. Computer analysis techniques, such as that illustrated in this paper, can improve the scope of harvesting analysis and reduce analysis cost substantially.

REFERENCES

ASHMORE, C., STOKES, B.J. and LANFORD, B.L. (1987). *Performance and cost of the Boreal 20-inch circular saw.* USDA Forest Service Research Paper SO-238. (6 pp.).

GREEN, W.D. and McNEEL, J.F. (1988). Productivity, costs, and levels of butt damage with a Bell Model T feller-buncher. *Forest Products Journal* **37**(11/12), 70-74.

LANFORD, B.L. (1983). Productivity and cost of the Timberjack 30 feller-buncher. *Forest Products Journal* **33**(1), 62-66.

LANFORD, B.L. and SIROIS, D.L. (1983). *Drive-to-tree, rubber-tired feller-buncher production studies.* USDA Forest Service General Technical Report SO-45. (14 pp.).

McNEEL, J.F. (1986). *Microcomputer-based harvest cost analysis programs.* American Pulpwood Association Technical Release 86-R-83. (2 pp.).

McNEEL, J.F. and GREENE, W.D. (1987). *Non-shear felling heads for southern pine.* ASAE Paper 87-1529. American Society of Agricultural Engineering, St. Joseph, MI. (18 pp.).

REISINGER, T.W., GREENE, W.D. and McNEEL, J.F. (1988). Microcomputer-based software for analyzing harvesting systems. *Southern Journal of Applied Forestry* **12**(1), 37-41.

TUFTS, R.A., LANFORD, B.L., GREENE, W.D. and BURROWS, J. (1985). Auburn Harvesting Analyzer. *COMPILER* **3**(2), 14-15.

Paper 16

Prototyping: A Tool for Needs Analysis

E.W. ***Robak****, Department of Forest Engineering, University of New Brunswick, Canada*

Abstract

Once the general objectives have been established for a proposed forest operation planning system, the next major step in its development is the determination of the users' needs that the system must address. Based upon the planning decisions that the system will be used to support, the designer/developer must determine what information will be required and how it should be presented in order to facilitate managerial decision making. Unfortunately, needs analysis may seem so obvious and trivial that it may be taken for granted: system developers may feel that the needs analysis process is accomplished once the users have been asked what they want. Although this may be an improvement over the countless systems that have been built without the benefit of the eventual users opinions, experience has shown that managers and other users of information systems often have great difficulty in understanding or articulating their informational needs. This is not a trivial problem since poor needs analysis is often cited as a cause of system development failures.

Most forest operation planning systems developers are more likely to be proficient in computer systems design and development (or, at best, knowledgeable about system development and forest operations) than in psychology or the cognitive sciences. Therefore it would be very helpful if some simple method were found for helping developers elicit the informational needs of forest operation managers. It would appear that prototyping (the conscious development of a system through iterative, evolutionary development steps) may be a partial solution to this problem. Since much of the managerial decision-making function is as intuitive as it is analytical, managers often find it much easier to criticize a prototype than to describe and justify their informational needs to non-managers (or even to themselves). As well, other benefits of the prototyping approach are that useful working models or partial systems may be made available to managers sooner, and managers' interest is maintained in the design and development process.

Introduction

A fundamental and necessary part of the design and development of a forest operation planning decision support system (DSS) is the analysis of the current and projected needs of the eventual users. This might seem to be essential in the design of any information system, but reviews of the electronic data processing (EDP) and management information system (MIS) phases of recent information technology history indicate that users' needs were usually not emphasised in EDP and MIS development projects (Kanter, 1977). Although this may be understandable for EDP projects given EDP objectives and the technology of the 1960s, it is more difficult to excuse for recent MIS projects. After all, one would think that an information orientation should be synonymous with a user orientation.

It may well be that MIS developers had good intentions but misunderstood managerial decision making. Most MIS developers probably assumed a purely rational model of decision making, and so they could be forgiven for believing that the needs analysis was complete once the objectives of an intended information system were established. If that assumption were true then it would simply be necessary to get users (or upper management) to describe what the system was intended to do, and the system design could follow logically, with no further need of input from users.

It may not come as a surprise to developers, however, that the managers for whom their systems are designed often do not apply rationally-based models of decision making (Kunreuther and Schoemaker, 1982). That might explain, after all, why managers often reject the developers' perfectly logical system designs, often without being able to offer rational reasons for their rejections. Research conducted by students of behavioural and organisational decision making offers considerable evidence that, besides ignoring 'logical' models that are made available to them, managers are often shown to make 'irrational' decisions (for reviews see Connolly, 1977 and Simon, 1979). Furthermore, this 'irrationality' cannot be attributed solely to human fallibility, or to instances where managers have been subjected to conditions that force them beyond their 'bounds of rationality' (as defined by Simon, 1960). Rather, there is empirical evidence that human decision processes themselves often do not follow rational models (Schweder, 1977). In fact, Chestnut and Jacoby (1982) have shown that managers often use only a small portion of the information available to them, even when it appears that the unused information would be necessary for good decision making. This motivated them to suggest that it was managerial attention, not information, which is the scarce resource.

These research results could be used to illustrate the futility of attempting to satisfy users' (managers') informational desires. If, as some researchers suggest, the results prove that 'humans are such poor and unsystematic decision makers' (Kunreuther and Schoemaker, 1982), then basing system designs on managers' perceptions of their needs could well be a waste of effort. The developer's time would be better spent on ensuring that system designs are a rational extension of the systems' objectives, and then justifying these designs to the eventual users.

However, a close look at these and other research results might lead to an entirely different conclusion when it is considered that these systems are to be used in real-world situations. According to (Huber, 1982), the rational model is only one of at least four valid, empirically-based general models of decision making, each of which might be found acting in actual decision environments. Mintzberg (1982) also makes a good case for a fifth model called intuition, since some research has shown that in complex decision environments managerial decision making based upon limited information, experience and intuition may yield better results than purely rational models.

The fact that some managerial decision processes do not follow rational models does not mean that these processes should be labelled 'irrational'. Instead, these may be processes which act at such deep levels of human consciousness that they cannot be modelled by contemporary decision analysis methods. Although it is always tempting to dismiss processes which are not understood as being illogical or irrational, Mintzberg goes on to suggest that "It is we theorists who are poor decision makers. . . so intent are we on promoting our own perspective that we blind ourselves to reality".

In fact, although current rational models may not accurately portray real-world decision-making situations, in my own experience I have found that managers appreciate the good information that can be derived from logically-designed information systems. However, system design approaches that ignore or are unable to incorporate the heuristic methods that managers have developed to cope with their complex decision environments are much more likely to fail. Whereas this may be occasionally true for EDP or MIS development projects which tend to deal with more routine situations, it is almost always true in the design and development of the most recent generation of information systems, DSS.

Decision support systems

Definitions and characterisations of DSS abound in contemporary information system and operations research literature. For this reason, and since I have previously described the relevance of DSS to forest operation planning (Robak, 1984) this paper will not include a thorough explanation of DSS theory and practice. It is necessary, however, to discuss those DSS concepts and research findings which are relevant to the issues of needs analysis and prototyping.

The label 'decision support system' was first used by Keen and Morton (1978) to describe computerised systems that:

- are aimed at the kinds of ill-structured problems that managers face;
- combine modelling with traditional database management functions;
- support all phases of decision making;
- employ features which make them appropriate for interactive use by 'computer illiterates';
- are flexible and adaptable to changes in the problem environment and the decision-making approach of the user.

Watson and Hill (1983) described DSSs as interactive systems that provide the user with easy access to decision models and data in order to support semi-structured and unstructured decision-making tasks. Huber (1982) suggests that a DSS is that portion of a manager's broad-based decision-making support system (which might include decision rules, policy manuals, recollections, and advisors) that utilises a computer to retrieve and manipulate data. In general DSS refers to a structure that includes a set of models, a model management system, databases, a database management system and a dialogue component. However, the DSS approach implies more: it refers to a philosophy of design, development and application which considers the manager an integral part of the needs analysis process.

There are many aspects to and implications of the DSS design and development philosophy, but the following might be considered to be most relevant to the topic of needs analysis:

1. the intended DSS user must be involved in the DSS design and development process (Alter, 1980; Sprague and Carlson, 1982);
2. the design and development of a DSS is an iterative, adaptive process (Keen and Morton, 1978);
3. the DSS design must respect the primacy of managerial judgement (Prasad, 1985) - the goal of the system must be to improve managerial decision-making effectiveness rather than to generate solutions;
4. changing decision-making processes or modifying organisational goals can be valid design objectives (Sprague and Carlson, 1982);
5. in those complex situations where many users depend upon the system for decision support, system integration becomes a factor. Integration can be accomplished through a process of analysis, training, installation and evaluation (Sprague and Carlson, 1982);
6. according to Sprague and Carlson (1982) users must be trained to identify applications, discuss design and development strategies, and adapt existing DSSs to new problems. This implies, again, that users are members of an on-going system design and development effort.

Implications for needs analysis

Since DSS are described to be structurally and philosophically distinct from MIS, it stands to reason that the needs analysis requirements may also differ. In that case, the highly structured and linear methods of needs analysis, design and development that have traditionally been advocated for EDP and MIS projects (Sroka and Rader, 1986) might not be appropriate for DSS.

DSSs are user-oriented systems designed to deal with complex, ill-structured decision environments so that spending a great deal of time attempting to elicit detailed design specifications from managers from a 'cold start' could be fruitless. As Rolph (1979) indicated, decision-making processes are not well understood by managers themselves and, since managers act as information filters (Mintzberg, 1975), analysts are prevented from adequately modelling the problem. At the same time, the lack of structure in the decision environment means that developers are not usually able to assume that there is a normative model of the solution around which they can design a system by themselves.

The evolutionary nature of DSSs would not support analytical approaches that rely upon a detailed pre-design strategy. One study revealed that, even for normal EDP and MIS development projects, over 80 per cent of program errors uncovered at the acceptance/testing stage of information system development were caused by incorrect specifications (Harrap, 1985). If, as Keen and Morton (1978) contend, competent managers will improve the way that they use the system and make decisions, inflexibility in the system design could be highly counter-productive. This contention is supported by a study of DSSs in many organisations which found that excessive pre-specification was impractical because DSSs are not static (Major, 1984) and may be especially valid where the project involves the development of integrated, multi-user DSSs (Meador *et al.*, 1986).

When a sequential design and development approach is used, the problem for system developers becomes one of determining when the specification or preliminary analysis and design has become excessive. The DSS focus on users' needs and on the ill-structured problems that such systems are intended to help solve implies a requirement for more, rather than less, needs analysis. What is required, then, is an approach that depends less on structured specification, but results in a higher degree of satisfaction of user needs. Although these objectives appear to be contradictory, many system development researchers and practitioners have begun to advocate a philosophy that may provide solutions to this dilemma.

Evolution of the prototyping approach

In the late 1970s and early 1980s, some experts began advocating new approaches to analysis and design that called for more user participation in the system design process (Lasden, 1980). At that time there was little empirical evidence upon which to judge the relative effectiveness and efficiency of alternative needs analysis techniques, although an assessment by King and Rodriguez (1981) did suggest that participative design produced positive results.

A paper by Wetherbe (1982) suggested that such participation could be achieved by employing a prototyping approach consisting of an iterative analysis, design, development, evaluation and refinement cycle. It was felt that prototyping should be considered appropriate when traditional analytical techniques aren't able to elicit users' needs or when system designers are confronted by significant ambiguity or uncertainty (Asner and King, 1981). Appleton (1983) went so far as to predict that prototyping would replace functional decomposition as the dominant mode of developing and maintaining end-user systems.

Early proponents of DSS who elaborated on the importance of needs analysis in the DSS design and development process suggested that a prototyping approach might prove much more successful than traditional analytical approaches (Sprague and Carlson, 1982). The prototyping methodology, which is considered most appropriate for complex, evolving end-user applications, seems most suitable for DSSs that are flexible and adaptive, developed iteratively, and that are meant to grow and change as organisational objectives, decision-making processes and problem environments evolve. Current literature suggests that prototyping is becoming the preferred method of information system design and development, especially for DSSs and Expert Systems (Huffaker, 1986; Gilhooley, 1987; Fordyce *et al.*, 1987; Cerveny *et al.*, 1987).

Applying prototyping

Pointing out the philosophical consistencies between prototyping and DSS does not, however, explain how prototyping can actually be used to help identify users needs and ensure that they are incorporated in the system design. Advocating prototyping doesn't mean justifying a blind trial and error approach, nor is it meant to constitute the entirety of the needs analysis function. Instead, prototyping should be considered a strategy which helps to ensure that needs analysis tactics are used to full advantage.

Many DSS researchers and builders propose that system requirements be established by following rigorous, structured analysis (Sprague and Carlson, 1982; Sen, 1983; Meador *et al.*, 1986; Hughes, 1986). Some have proposed methodologies that would retain the advantages of a rigorous analysis, but would utilise prototyping to improve the needs analysis and design phases of a development project. In fact, several proponents of prototyping have gone to great pains to emphasise that prototyping is meant to complement, not replace, good analysis (Hughes, 1986; Smith, 1986). For example, Decision Support Analysis (DSA) combines structured interviews, decision analysis, data analysis, technical analysis, and a managerial orientation with prototyping (Major, 1984), an approach which Meador *et al.* (1986) have reported may be specially advantageous in complex multi-user DSS situations.

What is being advocated is a rigorous, goal-oriented analysis within the framework of a flexible prototyping approach where basic user requirements are identified, then prototypes are designed, developed, implemented and re-designed in an iterative manner. Weisman (1987) suggests that, even when artificial intelligence (AI) technology is being used as a development tool, a relatively formal structure to the prototyping project may be advantageous. The difference is that the prototyping approach demands that "problem definition, analysis, design and implementation become concurrent processes" (Cerveny *et al.*, 1987).

Prototyping requires that, once a conceptual design is produced using a formal systems analysis method, a prototype is quickly built and implemented (while managers are still interested and remember what their original design objectives were). As managers work with the prototype and return to the developer with complaints and suggestions, improved versions should be provided within days, hours or even while the manager waits (perhaps helping to re-design interfaces or reports). This would obviously require very powerful development languages and specialised, dedicated hardware. Until relatively recently, such technology has not existed or has been prohibitively expensive. However, recent developments in computer hardware and software have redefined the technological and economic environment of information systems development. Extremely powerful microcomputers, relational database management systems, fourth-generation languages, application generators and other development tools are making it possible to produce and modify applications and databases at a rate that makes prototyping feasible (Whieldon, 1984; Cerveny *et al.*, 1987). Current literature and personal experience would suggest that, in order to be able to prototype successfully, the following tools should be made available to the system developer.

1. **Relational database management** - It will usually be necessary to restructure a prototype's databases quickly and often in order to be able to change the information presented to users and/or attempt to increase speed and efficiency. A relational (or pseudo-relational) database management system (DBMS) that enables developers to make changes to one database while all other relevant ones are automatically up-dated (without danger of data corruption) is essential. It is also very helpful to developers and users if the DBMS has a natural language interface.

2. **Modelling and model management** - Although the first DSSs that many users will wish to have may not require particularly sophisticated algorithms, this should change with time. Prototyping and DSS development are learning experiences: as managers learn more about how to access and manipulate data to provide better information for decision making, the models that they demand could become more elegant. Forest operation managers, for example, might graduate from simple harvesting cost models to integrative DSSs that include linear and dynamic programming routines. It would be unfortunate if the developer were not able to provide more powerful tools to those managers who have finally become interested in using them.

3. **Dialogue management** - How information is presented is an important factor in the decision-making process. Development tools that unduly restrict how information is presented or limit how managers can interact with the system will, in the long run, be unacceptable. This means that the development 'arsenal' must be able to produce menus, windows, charts, tables and other interfaces without requiring much programming. If prototyping is to be carried out as effectively as possible, it must be possible to 'paint' screens and show the effects to the user almost immediately.

Although some software companies claim to have developed applications generation environments that satisfy all of these requirements (usually called fourth-generation languages or 4GLs), the great variability of needs that developers are faced with when constructing integrated applications would imply that such tools may actually be a few years away. However, the move towards compatibility that many tool developers are aiming for has recently begun to yield results. It is becoming much easier to develop applications using various separate software languages and tools that are tied together in a 'shell' or applications environment.

Prototyping case studies

I have been involved in several small and medium-sized DSS and MIS development projects where the prototyping approach has been applied. It has shown itself to be very useful in all phases of development and has been especially valuable in assisting in the determination of user needs, even in relatively uncomplicated situations.

In one case, the use of a prototyping methodology in the development of a teaching forest inventory software package for a technical school resulted in a product that was substantially different from what was originally envisaged. Although the general objectives of the project didn't change, the instructors' perceptions as to how the system could be best used as a teaching tool evolved as they were presented with successive draft prototypes and then again as students began working with the package. One important lesson that was learned from this venture was that it is important to have users understand that prototyping is intentionally being employed and that it is 'OK' to demand changes. The development of the software was significantly delayed by the fact that the instructors did not understand their rights and responsibilities with respect to the development of prototypes. They did not place themselves at the disposal of the developers often enough and sometimes did not avail themselves of the opportunity to criticise prototypes until considerable subsequent work had been (improperly) completed.

In another situation, the amalgamation of two separate forest product companies into one necessitated the development of an entirely new budgeting system. There was a considerable time constraint associated with the project as the new budget had to be ready within 2 months. Complicating matters was the fact that the underlying accounting structure was also being re-designed simultaneously. When the new company's accounting and computer department admitted that they were not able to solve the problem, outside consultants were asked to develop a microcomputer-based 'stop-gap' system. Using spreadsheet technology a system was developed which allowed managers to produce a 12 month budget (with monthly details) for each of the company's 29 operations and consolidate those into one company-wide budget. This system was developed on time and at a low cost despite the fact that:

1. two quite different budgeting approaches had previously been used by the managers involved;
2. many changes in requirements were called for by the operating managers, accounting department and head office as their perceptions of needs changed or as their requirements were affected by changes in other parts of the organisation;
3. none of the operating personnel had been closely involved with a software development project in the past or, for that matter, with computers at all.

In this example the users seemed quite comfortable with the fact that many prototypes were to be created, perhaps because it was generally acknowledged that there was no existing 'correct' design and everyone involved was at the learning phase. At the time of writing, the 'stop-gap' budgeting system has been used for 3 years and is now integrated with a cost analysis and planning system.

General case study findings

These experiences revealed that, in some circumstances, prototyping may not only be helpful but may actually be essential. This agrees with the message put forward by management science researchers (Kauber, 1985) who have found that successful organisations take on an experimental perspective and stress learning rather than knowing. Certainly, where the problem is more ambiguous or where time is of the essence, prototyping appears to be the only approach that stands a reasonable chance of success. As well, it was found that users appreciated that the prototyping methodology allowed them to respond to rough models, rather than requiring them to define their needs immediately. This allowed them to be certain that the system developed actually met their requirements, and also helped them to understand how these requirements were eventually put in to operation. Users gave the impression that the prototyping approach allowed them to be more creative, since they did not feel as much pressure to be right the first time.

It should be understood that developers must beware of potential problems that can be associated with the prototyping approach. For instance, developers must guard against allowing prototyping to degenerate into direction-less trial and error sessions that are expected to 'magically' result in useful systems. As well, since most managers are busy people, it may be difficult to get them to take the time to work on defining needs for the original prototypes or evaluate progressive versions. Although this problem may be less severe for prototyping than for traditional approaches, it should be recognised as a potential impediment to efficient and effective system development.

Developers must moderate their natural tendencies to 'lead users to the right answers', especially when they are obviously foundering or when the 'right answer' is obvious. There may be times when the expertise of the system builder should become paramount, especially concerning questions of system technology. None the less, except where builders will also be on-going users of the system, they should be careful not to impose their beliefs upon users. Although this may occasionally lead users to perceive that the system builders (the experts) are not providing adequate direction, the client must be made to understand that the design criteria must originate with users while the system builders' expertise is used to help users articulate needs and then create an efficient and effective system based upon those needs.

Future prototyping projects

A major forest operation planning DSS, called OP-PLAN (see Robak, 1984 for a description), was originally designed for a particular forest products company, but the original system's design and installation shortcomings resulted in incomplete implementation (Robak, 1986). Nevertheless, the limited prototyping that was undertaken for that project did result in the formulation of better design and performance specifications for the DSS. These, along with recent hardware and software innovations, have enabled the developers to produce a second demonstration version of OP-PLAN that will be used as the basis of a new project.

As a result of previous successes with prototyping and experience with new microcomputer hardware and software technologies, the design, development and installation of the new version of OP-PLAN for another Canadian forest products company will depend heavily upon a prototyping methodology. The company has asked that the demonstration version of OP-PLAN be installed at their forest operations office, even though it is acknowledged that the system must be considerably changed before it can be fully implemented. The development language being used is called Clipper, a product of Nantucket Corporation. Clipper is actually a compiler for the database management system and programming language, dBase III+ (Ashton Tate Ltd.). Although dBase III+ is itself a relatively powerful development language and has had many development tools developed for it, the use of a compiler such as Clipper means that these capabilities can be combined with the advantages of modelling tools developed using the 'C' or assembler languages.

One of the major problems to be overcome in this project is the fact that the installation site is in a relatively isolated area of Quebec, quite far from the home-base of the developers. Ordinary prototyping, to be done properly, would require that the developers and/or forest operation managers meet frequently to ensure that needs are being met in progressive system designs. In this case this would be expensive and would tend to discourage managers from evaluating prototypes and articulating needs, and certainly would discourage them from being creative. The developers will pioneer an innovative technique that will couple the use of a very fast (9600 baud) modem with special communication software (called Close-Up, by Norton Lambert Corp.). Once the developers have installed the demonstration version of OP-PLAN and have taught managers how to use it, there should be little need for face to face contacts between users and developers. Close-Up will allow the developers and managers to demonstrate ideas interactively, discuss needs and designs and redevelop the system even while they are a thousand kilometres apart. The new generation of 9600 baud modems will allow this to happen without long pauses or risk of data corruption.

Conclusion

The evidence of empirical and anecdotal studies of information system development projects suggests that traditional design and development methods are often unsuccessful in the development of decision support systems and complex management information systems, in large part because of the inadequacy of current needs analysis procedures. Moreover, more time spent employing orthodox needs analysis methodologies does not appear to be a valid solution since their sequential nature does not allow managers' and developers' perceptions of the problems and needs to evolve. In other words, conventional techniques do not allow the participants to learn and to incorporate the results of this new knowledge in the information system design in an efficient manner. Recent literature suggests that prototyping, coupled with some of the better standard analytical techniques, should be conducive to the efficient development of more functional systems. Personal experience confirms that, although prototyping is not a panacea, it may be the best way to ensure that forest operation managers' needs are met when information and decision support systems are developed for them. Prototyping may be the only way that systems can be developed which enable managers to employ poorly understood but valuable intuitive skills.

Current hardware and software technologies are making it easier to apply the prototyping approach successfully. More powerful development languages and computer hardware of the near future, including some that allow the inclusion of artificial intelligence technologies, may make prototyping the methodology of choice for all but the most trivial system design projects.

REFERENCES

ALTER, S.L. (1980). *Decision support systems: current practices and continuing challenges.* Addison-Wesley, Reading, Mass.

APPLETON, D.S. (1983). Data-driven prototyping. *Datamation* **29**(11), 259-268.

ASNER, M. and KING, A. (1981). Prototyping: a low-risk approach to developing complex systems. *Business Quarterly (Canada)* **46**(3), 30-34.

CERVENY, R.P., GARRITY, E.J., HUNT, R.G., KIRS, P.J., SANDERS, G.L. and SIPIOR, J.C. (1987). Why software prototyping works. *Datamation* **33**(16), 97-103.

CHESTNUT, R.W. and JACOBY, J. (1982). Behavioural process research: concept and application in consumer decision making. In *Decision making: an interdisciplinary inquiry.* Kent Publishing, Boston, USA.

CONNOLLY, T. (1977). Information processing and decision-making in organisations. In *New directions in organisational behaviour.* St. Clair Press, Chicago, USA.

FORDYCE, K., NORDEN, P. and SULLIVAN, G. (1987). Review of expert systems for the management science practitioner. *Interfaces* **17**(2), 64-77.

GILHOOLEY, I.A. (1987). Productive systems development with prototyping. *Journal of Information Systems Management* **4**(2), 15-22.

HARRAP, K. (1985). DP should not shun new ideas. *Computerworld* **19**(7), 47-57.

HUBER, G.P. (1982). Decision support systems: their present nature and future directions. In *Decision making: an interdisciplinary inquiry.* Kent Publishing, Boston, USA.

HUFFAKER, D. (1986). Prototyping business applications within the traditional life cycle. *Journal of Information Systems Management* **3**(4), 71-74.

HUGHES, J.R. (1986). Moving out of the Middle Ages. *Infosystems* **33**(10, Part 1), 76-79.

KANTER, J. (1977). *Management-oriented management information systems* (2nd edn.). Prentice-Hall, New Jersey, USA.

KAUBER, P.G. (1985). Prototyping: not a method but a philosophy. *Journal of Systems Management* **36**(9), 28-33.

KEEN, P.G.W. and MORTON, M.S.S. (1978). *Decision support systems: An organisational perspective.* Addison-Wesley, Reading, Mass.

KING, W.R. and RODRIGUEZ, J.I. (1981). Participative design of strategic decision support systems: an empirical assessment. *Management Science* **27**(6), 717-726.

KUNREUTHER, H.C. and SCHOEMAKER, P.J.H. (1982). Decision analysis for complex systems: integrating descriptive and prescriptive components. In *Decision-making: an interdisciplinary inquiry.* Kent Publishing, Boston, USA.

LASDEN, M. (1980). Games played between users and providers. *Computer Decisions* **12**(10), 72-86.

MAJOR, M.J. (1984). Approaching DSS. *ICP Business Software Review* **3**(6), 41-44.

MEADOR, C.L., GUYOTE, M.J. and ROSENFELD, W.L. (1986). Decision support planning and analysis: the problems of getting large-scale DSS started. *MIS Quarterly* **10**(2), 159-177.

MINTZBERG, H. (1975). The manager's job: folklore and fact. *Harvard Business Review* **53**(4), 49-61.

MINTZBERG, H. (1982). Comments on the Huber, Kunreuther and Schoemaker and Chestnut and Jacoby Papers. In *Decision making: an interdisciplinary inquiry.* Kent Publishing, Boston, USA.

PRASAD. A.P. (1985). *Forest operation planning using decision support systems: a design for the 1990's.* MScFE thesis, University of New Brunswick, Canada.

ROBAK, E.W. (1984). Toward a microcomputer-based DSS for planning forest operations. *Interfaces* **14**(5), 105-111.

ROBAK, E.W. (1986). Forest operation planning education: a microcomputer-based decision support approach. *Proceedings of the 18th IUFRO World Congress,* Ljubljana, Yugoslavia.

ROLPH, S. (1979). A study of decision makers. In, DSS: an executive mind support system, Keen, P.G.W. and Wagner, G.R., *Datamation* **25**(12), 117-122.

SCHWEDER, R.A. (1977). Likeness and likelihood in everyday thought: magical thinking in judgments about personality. *Current Anthropology,* No. 18.

SEN, A. (1983). Decision support system: an activity-oriented design. *Journal of Information Science,* No. 7, 23-30.

SIMON, H.A. (1960). *The new science of management decision.* Harper and Row, New York, USA.

SIMON, H.A. (1979). Information in processing models of cognition. *Annual Review of Psychology,* No. 30.

SMITH, H.A. (1986). Get your requirements right! *Canadian Datasystems* (Canada) **18**(10), 66-71.

SPRAGUE, R.H. Jr. and CARLSON, E.D. (1982). *Building effective decision support systems.* Prentice-Hall, New Jersey, USA.

SROKA, J.M. and RADER, M.H. (1986). Prototyping increases chance of systems acceptance. *Data Management* **24**(3), 12-19.

WATSON, H.J. and HILL, M.M. (1983). Decision support systems or what didn't happen to MIS. *Interfaces* **13**(5).

WEISMAN, R. (1987). Six steps to AI-based functional programming. *Datamation* **33**(15), 71-72.

WETHERBE, J.C. (1982). Systems development: heuristic or prototyping? *Computerworld* **16**(17), SR14-15.

WHIELDON, D. (1984). Prototyping: shortcut to applications. *Computer Decisions* **16**(7), 138-147.

Paper 17

A Systems Approach to Planning and Control of Tree Harvesting Operations in the Tropical High Forests

S.A. Dada, E.B. Lucas and F.O. Olorunniwo, Faculty of Technology, University of Ibadan, Nigeria[1]

Abstract

Efficient tree harvesting which is the key to optimal utilisation of the forests, has been an elusive objective in the tropical high forests due to a myraid of conflicting factors. These range from the multiplicity in tree species in the forest to the climatic conditions and the fast deterioration and frequent spoilage of the equipment and machinery available for tree harvesting. Another serious problem is posed by the absence of an appropriate management tool that can be used for maintaining a practical and economic balance of the various input materials that would minimise operational costs of tree harvesting in the tropical high forests.

The increasingly complex market structure, heightened consumer awareness, steadily increasing labour costs and prices for timber and other raw materials and the decreasing timber supply capability of the forests in the tropics have created a need for greater production economics in the forest products industry located in this area of the world.

This paper reports the application of an operations research approach that was used to evaluate the tree harvesting operations of a timber company situated in the high forest zone of Nigeria. In the study, a linear programming model was used to simulate tree harvesting operations of the firm. The analysis included the effect of changes in manpower available for tree harvesting operations on company's profit, and the expected economic impact of importing wood from the open log market on company's profit.

Introduction

In view of the diminishing wood resources base available to the forest products industry in Nigeria and the developing countries in general there is a need for the development of strategies and methods that would promote efficient use of the forest resource. Effective control of tree harvesting operations in the tropical high forest zone of Nigeria has been an elusive objective solely because of the complex and ever-changing quality and quantity of the available wood-fibre, factors relating to production, equipment and financial resources, and transportation facilities.

The increased demand for forest products due to increased population growth in recent years has resulted in an increase in the number and size of forest products firms operating in the country. It has also resulted in an increase in tree harvesting activities in the nation's high forest reserves.

[1] This project was partially supported by the Senate Research Grant, 2/SRG/80/06 and 2/SRG/81/30, University of Ibadan, Nigeria.

Tree harvesting is a difficult and costly operation. Its efficiency influences the quality and quantity of end-products recovered from the tree, as well as the market prices obtainable for manufactured end-products. The degree of forest utilisation is also influenced by the efficiency of tree harvesting operations carried out in the forests.

The increasingly complex market structure and increases in labour and equipment costs and other inputs caused by the recent Government economic adjustments programme have made the control of tree harvesting operations very essential for any firm involved in tree harvesting in Nigeria.

Several other factors also influence tree harvesting operations in the tropical high forests. They are the unplanned nature of the tree species in the forests involving mixed stands of both the economic and the uneconomic wood species; and the long rainy season which very frequently makes skidding and log transportation exceedingly difficult if not impossible for most of the season.

It is therefore evident that the success of any firm engaged in tree harvesting in the country is measured not only by how well it can stack up against the above stated conditions and other competitive timber extractors, but how it can effectively maintain a practical and economical balance of the various input materials that would minimise operational costs of tree harvesting in its forest.

This paper reports the use of an operations research technique to analyse the tree harvesting operations of a forest products firm in Nigeria.

Basically, operations research is a technique for developing a strategy of control by measuring, comparing and predicting probable behaviour through a scientific model. Linear programming, amongst several other techniques has been used to study practical problems in forest harvesting operations (2, 3, 5, 6). However, most of the studies have dealt with problems and situations specific to operations in temperate forests.

The demonstration company

The forest product company used for the study is situated in the high forest zone of Ondo State in Nigeria. The company's major products are lumber and plywood. The mill is situated at a distance of about 80 km from its forest concession which is also within Ondo State. The mill location is connected to the forest reserve and other state capitals by a good network of roads.

The major operations in tree harvesting in Nigeria are felling, bucking, skidding, loading and transportation. The felling and bucking are carried out with chainsaws while the skidding and loading are by means of rubber-tyred tractors fitted with pulled arch. In certain areas of the country, especially the forest areas having steep hills, cable yarding has a potential.

The harvested trees are retained in a concentration area (landing) in the forest pending their transportation to the mill yard. Loading of logs on to trucks at the landing is carried out by front-end-loaders, usually a 980 class caterpillar. Not all the wood skidded to the landing in a particular month is transported to the mill yard in that month. This may be due to limitations imposed by the loading and transportation facilities, over-production in the preceeding period and a number of other factors. Log transportation from the forest landing to mill yard is by means of 30 ton trucks fitted with pole trailers with tandem axles.

The company operates no conventional log grading system; wood species are classified into three major groups based on their end use potentials. The groups and their respective wood species are as follows:

group 1 - afrormosia, African walnut, iroko, mansonia and mahogany;

group 2 - cordia, opepe, pterygita, red sterculia, antiaris and obeche;

group 3 - white ajara, white sterculia and red bombay.

The wood species listed under group 1 are for processing into sliced veneer and/or lumber, but not into peeled veneer. The wood species listed under group 2 are either processed into peeled veneer or lumber production. Those in group 3 are for the production of lumber and peeled veneer; they are not for sliced veneer production.

Occasionally, the mill buys logs from the open log market to smooth out the log supply situation. The quantity and quality of wood input to the mill from the forest and open log market have been based on the mill's rule-of-the-thumb experience on market demand for logs of various wood species and the demand for the mill's finished products. The log input to the mill is always influenced by a company policy that places a limit on the quantity of wood to be purchased from the open log market. This policy was seriously questioned when it was discovered that the mill was losing money due to wide fluctuations in the log input from the forest and the uncontrollable high increases in prices of logs from the open log market.

The company lacks the necessary tools for determining the optimum quantity of each input resource that would minimise the cost of wood input to the system under various market and mill log supply situations. The study was formulated and conducted to resolve the following questions asked by the company's management.

1. What is the optimal schedule for cutting, buying and transporting wood in order to minimise the total cost of delivering the necessary amount of wood to meet the mill's requirements for a planning horizon?
2. What is the effect of changes in manpower available for tree harvesting operations on the company's profit?
3. What economic impact can changes in company policy on wood import from open log markets have on the company's profit?

Modelling procedure

A linear programming model was used to provide solutions to the management's problems. The formulation used was:

$$\text{Minimise } Z = \sum_{t=1}^{T} \sum_{i=1}^{W} \left[(f_{it}+y_{it}+N_{it})A_{it}+c_{it}B_{it}+\bar{h}_t L_i \tau_t+\Sigma_{it} V_{it} \right] \qquad \ldots (1)$$

subject to the following restrictions.

Company's policy on wood purchase:

$$\frac{\sum_{i=1}^{W} B_{it}}{\sum_{i=1}^{W} A_{it}} = \alpha_t \quad (t=1, 2, \ldots, T) \qquad \ldots (2)$$

Minimum millyard requirement:

$$A_{it}+B_{it} \geqslant M_{it} \quad (i=1, 2, \ldots, W;\ t=1, 2, \ldots, T) \qquad \ldots (3)$$

$$A_{it}+B_{it} \geqslant M_{it} \quad (i=1, 2, \ldots, W;\ t=1, 2, \ldots, T) \qquad \ldots (4)$$

Harvesting manpower capacity:

$$\sum_{i=1}^{W} \lambda_{it} A_{it} \leqslant \bar{M}_{it} \quad (t=1, 2, \ldots, T) \qquad \ldots (5)$$

Material balancing at the landing:

$$A_{it}+L_{it}-V_{it} \leqslant L_{i,\,t+1} \quad (i=1, 2, \ldots, W;\ t=1, 2, \ldots, T) \qquad \ldots (6)$$

Non-negativity:

$$A_{it},\ B_{it},\ V_{it},\ L_{it} \geqslant 0$$

where

Z = optimum cost per unit volume (₦/m³) of wood species i brought to mill yard from company's forest and free areas in period t, [₦1.0 = $0.25 = £0.20];

A_{it} = volume (m³) of wood species i, cut from the forest in period t;

B_{it} = volume (m³) of wood species i, purchased from free areas during the period t;

L_{it} = volume (m³) of wood species i, retained in landing at the beginning of period t;

V_{it} = volume (m³) of wood species i, that is to be transported to the mill yard from forest landing in period t;

α_t = maximum value of the wood that should be purchased from free areas in period t, expressed as a ratio of total wood procured from company's forest during that period;

c_{it} = cost per unit volume (₦/m^3) of wood species i, purchased by mill from external sources in period t;

f_{it} = felling and bucking cost per unit volume (₦/m^3) of wood species i, in period t;

y_{it} = skidding cost per unit volume (₦/m^3) of wood species i in period t;

$\bar{h}_t$ = holding cost per unit volume (₦/m^3) of wood in inventory at the landing period t;

M_{it} = minimum volume (m^3) of wood species required at the mill yard in period t;

$\overline{M}_t$ = maximum manpower (expressed in man-hours) available for harvesting during period t;

N = stumping cost per unit volume (₦/m^3) of wood species i in period t;

T = number of discrete time periods;

τ_{it} = transportation cost per unit volume (₦/m^3) of wood species i from forest landing to mill yard in period t;

w = number of the different types of wood species;

λ_{it} = man-hours required to harvest a unit volume of wood species i in period t; the unit is man-hours/m^3.

The cost of harvesting indicated in equation 1, includes the cost of road construction, felling, bucking and cost of skidding of logs to landing.

The input-data required for the linear programme includes the following: harvesting, holding and transportation costs of logs of each wood species in each period under consideration; cost of wood purchased by mill through external sources; ratio of wood purchased by mill through external sources to that obtained from company's forest; minimum volume of various woods required at mill yard at each period; man-hours required to harvest wood species by period; maximum manpower available for harvesting in each period.

The volumes of wood input into the programme was determined using the Smalian formula (5).

Computer solutions for model

The model was solved on an APPLE II plus microcomputer using an LP software (1) developed by the Holding-Day Inc., Oakland, California. The data used for the computer analysis were for a 3-month production period. The first, second and third periods being January, February, and March, respectively.

The estimates for the harvesting and transportation costs of the various wood species for production period under study are contained in Table 17.1. The cost of retaining wood at the forest landing (holding cost) and the cost of wood procured from external sources during the production period are also shown in Table 17.1. Table 17.1 also indicates the estimates for the minimum mill yard requirement of wood species during each production period. The estimated maximum manpower production requirements for the first, second and third periods were 8400 m^3, 6160 m^3, and 5040 m^3, respectively. The company's wood import policy ratio for the current production condition was estimated to be 7.0 per cent during the first production period, while it was 10.0 per cent each for the second and third production period. The estimates for the quantity of each wood species at landing at the beginning of each production period is given below:

$L_{11} = 400,\ L_{14} = 400$ m^3
$L_{21} = 560 = L_{24}$
$L_{31} = 680 = L_{34}$

Above estimates of input data were determined from company supplied information and data obtained in a separate study conducted on company's forest and mill operations (4).

The computer analysis was conducted in three phases. The first phase was carried out to reflect the current harvesting conditions in the

Table 17.1 Summary of production cost items and minimum mill yard requirements for wood by species group and period.

Wood species group	Production period	Cost items (₦/m³) Harvesting cost	Transportation cost	Cost of wood from external sources	Holding cost	Minimum mill yard requirements for wood (m^3)
	1	13.0	5.0	24.0	0.34	1900
1	2	14.0	8.0	27.0	0.37	1800
	3	16.0	9.0	29.0	0.44	2400
	1	11.0	5.0	22.0	0.34	2800
2	2	12.0	8.0	24.0	0.37	2200
	3	14.0	9.0	26.0	0.42	2400
	1	10.0	5.0	21.0	0.34	2600
3	2	11.0	8.0	23.0	0.37	2800
	3	12.0	9.0	25.0	0.42	2400

forest and the current company's policy on wood input from external sources. This analysis was carried out in order to obtain information on the optimum schedule for cutting, buying and transporting wood that would minimise cost of delivering wood to mill yard under the current harvesting conditions.

In the second phase of the analysis, the harvesting manpower production capacity available in the first period was reduced. The analysis was undertaken to find out the influence of this factor on company's profit given the fact that the company can obtain wood through external sources.

The third phase of the analysis was carried out to examine how the optimal solution would be influenced when there are changes in the company's policy on wood purchase from external sources during each of the planning horizon.

Results and discussion

The optimal schedule for cutting, buying and transporting wood in order to minimise the total cost of delivering the necessary amount of wood to meet the company's requirements for the planning period is shown in Table 17.2.

The analysis (Table 17.2) indicates that it would be more economical for the company not to buy any group 1 wood under the current conditions. Group 1 wood should be cut in periods 1 and 2, while no wood in this group should be cut in the third period. Group 1 wood retained at the forest landing in the second and third period would result in the company not harvesting and buying the wood in third period.

Details of the optimal production schedule for group 2 and 3 woods are contained in Table 17.1. The total least cost that would be incurred in supplying the mill yard with wood for the planning period is ₦424,796.72. Throughout the planning horizon, the transportation section would be very busy hauling logs to the mill yard from the forest landing.

Some computer runs of the forest model were carried out to assess the sensitivity of the results to a change in company's harvesting manpower capacity. To effect this, the harvesting manpower production capacity available in the first period was decreased to 6700 cubic metres. The results indicate that it was more profitable under this condition to devote more of the manpower available in the first period to cutting group 2 wood which is less expensive

Table 17.2 Summary of production schedule for the forest model.

Wood species		*Period*		
		1	*2*	*3*
1	Quantity of wood harvested (A_{1t})	2124	3976	0
	,, ,, ,, purchased (B_{1t})	0	0	0
	,, ,, ,, transported (V_{1t})	1900	1800	2400
	,, ,, ,, in landing (L_{1t})	0	624	2800
2	Quantity of wood harvested (A_{2t})	4356	0	1960
	,, ,, ,, purchased (B_{2t})	580	0	504
	,, ,, ,, transported (V_{2t})	2220	2200	1896
	,, ,, ,, in landing (L_{2t})	0	2696	495
3	Quantity of wood harvest (A_{3t})	1920	2184	3080
	,, ,, ,, purchased (B_{3t})	0	616	0
	,, ,, ,, transported (V_{3t})	2600	2184	2400
	,, ,, ,, in landing (L_{3t})	0	0	0
	Least total cost		**₦424,796.72**	

than group 1 wood. More group 2 wood would also be transported to the mill yard in period 1. It was also found that no group 2 wood would be purchased by the mill in the first period. This could be due to the presence of large quantity of group 2 wood harvested in the period. During the runs, the mill purchased wood from external sources only on two occasions. The first purchase occurred in the second period, when some group 3 wood was bought to supplement the quantity of wood harvested in that period. The other purchase occurred in the third period when some group 2 wood was bought. The decrease in the available harvesting manpower capacity would result in a total saving of about ₦2,963.00.

The forest model was adjusted to find out how the optimal solution would change when there are changes in the company's wood purchase index during each period of the planning horizon. When the index was increased to 8 per cent the value of the total least cost was the same as was obtained for the original model. Increasing the company wood purchase policy index to 12 and 14 per cent, respectively, resulted in a decreasing trend in least total cost as the index was increased. The quantity of group 2 wood inventoried and hauled to mill yard during the same period also decreased. The results confirm the fact that additional quantity of group 2 wood was actually purchased from log brokers in period 3 of the planning horizon. The observed reduction in the values of the total least cost of each run was probably due to the reduction in the quantities of group 2 wood inventoried and transported as the index increased.

With a 15 per cent increase in company policy index on wood purchase in the second period, the schedule for cutting, buying, inventorying and transporting wood during the run was almost the same as that obtained when the index in the third period was 14 per cent. The main differences were in the quantity of group 2 bought in the first and third periods (B_{21}, B_{23}), the quantity of group 2 wood left in landing during the second and third periods (L_{22}, L_{23}) and the quantity of group 2 wood hauled to the mill in the third period (V_{23}).

The solution indicated a least total cost of ₦424,374.76. This is a reduction of about ₦422.00 from that of the original forest model.

Summary and conclusions

A systems approach to planning and control of tree harvesting operations in the tropical high forests is presented. The approach, which involves the use of a linear programming model, will provide an optimum schedule for cutting, buying and transporting wood in order to minimise the total cost of delivering the necessary amount of wood to meet a mill's requirement for a planning period. The model was evaluated using information collected from a timber processing company operating in the south-western high forest zone of Nigeria. The model was used to evaluate the effect of changes in manpower available for tree harvesting operations on company's profit, and to evaluate the expected economic impact on company's profit due to changes in company's policy on wood import from open log market. The total least cost that would be incurred in supplying the mill yard with wood through company's forest and external sources for a planning period of 3 months was ₦424,796.72. Throughout the planning horizon, the transportation section would be very busy hauling logs to the mill yard from the forest. A decrease in the company's manpower production capacity available in the first period to 6700 cubic metres would result in a total saving of about ₦2,963.00 to the company. Changes in the company's wood purchases index have an impact on total least cost.

The use of such a model would eliminate the current rule-of-thumb or guess-work in decision making pertaining to the schedule of production that optimises quantity of wood to be procured from forest concessions of mills and external sources. The model would be useful to the management of the mills especially during the rainy seasons when most of these mills usually find it difficult to obtain enough wood supply through their forest concessions. Using the model, mill management can evolve a suitable production schedule that would ensure adequate wood supply to the mill yard during the rainy season at minimum cost.

REFERENCES

ANONYMOUS (1985). *Microsolve/operations research: an introduction to operations research with microcomputers.* Holden-Day Inc., Oakland, California, USA.

BENGSTON, S.J. (1966). *A mathematical model for optimum timber allocation.* Unpublished M.S. Thesis, Oregon State University, USA. (43 pp.).

CORCORAN, T.J. (1964). *Operations research and management in wood-using business.* A.P.A., Quarterly Reports Paper, 61-65.

DADA, S.A. (1987). *A process analysis model for an integrated wood utilization system applicable to mixed tropical high forests.* Ph.D. Thesis, University of Ibadan, Nigeria (223 pp.).

FREESO, F. (1973). *A collection of log rules.* General Technical Report FPL1, pp. 17, 48. USDA Forest Service, Forest Products Laboratory. Madison, Wisconsin, USA.

KOGER, J.L. and WEBSTER, D.B. (1986). *Maximizing profit of ground based harvesting systems. Forest Products Journal* **36**(2), 25-31.

WIMBLE, A.W. (1969). *Application of a linear programming model to analyze pulpwood procurement scheduling.* M.S. Thesis, University of Maine, Orono, Maine, USA. (149 pp.).

Paper 18

Closing Address

E.K. Arthurs, Forestry Commission, 231 Corstorphine Road, Edinburgh EH12 7AT, U.K.

Introduction

Ladies and gentlemen it is my privilege to summarise the proceedings of this symposium. In doing this I do not intend to dwell on the specific examples of *A systems approach to forest operations planning and control* so eloquently presented by speakers over the past week but rather to attempt to draw out the main themes arising from these and the discussion they have generated.

Generally speaking there has been agreement that forestry has been late in using computers and the systems approach for planning compared to other industries. Various factors have been put forward to explain this delay, but whatever the reasons there is no doubt that forestry now needs to obtain and use more relevant information in order to cope with increasing economic, ecological and political pressures. I think it almost goes without saying that there is general agreement among those attending this symposium that the most practical way in which this need can be met is to employ computers and a systems approach to planning.

Complexity and uniqueness of forestry operations

Throughout the symposium a recurrent theme has been the complexity of forest operations in information terms, with special emphasis on the unique aspects of forestry which require a different systems approach from that employed in administrative and manufacturing environment. Obviously there are some aspects of forestry operations where these same principles can be applied to the more mechanistic sub-systems in isolation from the whole and it is in these areas that we are seeing the most rapid introduction of computer technology. While some countries are ahead of others in development of systems to meet the unique requirements of forestry it is going to take a lot of time and effort before we see the ideal of totally integrated systems. In order to meet this long-term ideal the proposal has been made to define the overall forestry system and subsystems in broad terms and to establish various systems standards at an early stage. The objective of this process of definition and standardisation is of course, to reduce data capture and information redundancy to a minimum and facilitate the transfer of compatible information formats between subsystems.

Designing the right systems

During the symposium it has been stressed that the researcher should ensure that the information needs of managers are correctly identified by their close involvement in the development process. In addition the researcher must have a major commitment to user education and support and perhaps most important to production of systems that are easy to use and which present information in such a way that it is easily assimilated as a knowledge base for action. Mention has been made of the use of prototyping, expert systems, graphics and animation in this context and it is in the use of these techniques that perhaps we see that most exciting prospects for future development. Responsiblities do not end with development however and the researcher must also check the system when implemented in order to make any adjustments needed to optimise practical operation. In this way the systems produced by researchers should be acceptable to managers and their staff engaged in operations and as such are most likely to be used properly and to best advantage.

Modelling and planning systems and reality

Turning to modelling and planning systems themselves there has been much discussion about the merits of detailed modelling for short term planning of individual stand management operations and the need for underlying assumptions to be based more firmly in the reality of overall production results. It would appear that it may be some time before we see the possibility of integrating what some see to be conflicting, and others see as separate requirements. What does emerge however is a reiteration of the point that systems do not end with production of the plan. Feedback mechanisms must also be in place to measure attainment against plan so that planning assumptions can be validated and if necessary recalibrated to provide revised plans with a better fit to reality. Managers must also be made very aware that computer systems should be used as a support and not as a substitute for their own management of operational planning.

Future co-operation

Perhaps one of the major conclusions to be drawn from this symposium is that while the emphasis on different aspects of forestry operation systems planning may vary from country to country there are obviously common problems. Clearly IUFRO has an important role to play in promoting the transfer of ideas and information. Various mechanisms have been proposed to strengthen and facilitate this role and members of Working Group S3.04.01 have indicated that these will be taken away for further consideration within IUFRO. Hopefully this will lead to a reduction in duplicated and wasted effort in the enormous task of producing systems that can be introduced to the benefit of all involved in forestry operations.

Farewell

Finally I should like to return to the remarks made at the opening of this symposium by Gwyn Francis, Director General of the Forestry Commission. He expressed the hope that this would be an enjoyable and productive week for all concerned. May I say on behalf of my colleagues that we from the UK have thoroughly enjoyed your company and your contributions to this symposium. From what you, our guests, have said both in public and in private we feel certain that you have enjoyed yourselves and that you consider this to have been a successful symposium from which you will take away many concepts for further consideration and development. We look forward to seeing you again at Montreal in 1990 and hearing how you have taken these and other ideas forward. Thank you and goodbye.

List of Delegates

Mr E.K. Arthurs	Forestry Commission 231 Corstorphine Road Edinburgh EH12 7AT UK
Mr A.J.A. Betts	Forestry Commission Forest Surveys Branch Alice Holt Lodge Wrecclesham Farnham Surrey GU10 4LH UK
Prof. H.O. Canham	Faculty of Forestry College of Environmental Science & Forestry State University of New York Syracuse New York 13210 USA
Mr L. Carbonnier	Interforest 63 Lincoln's Inn Fields London WC2A 9JX UK
Prof. T.J. Corcoran	University of Maine Department of Forest Management 263 Nutting Hall Orono Maine 044669-0125 USA
Mr J. Dirkman	Maine Forest Service Station 22 Augusta Maine 04333 USA
Mr G.J. Francis	Forestry Commission 231 Corstorphine Road Edinburgh EH12 7AT UK
Mrs W.C.G.Harper	Forestry Commission 231 Corstorphine Road Edinburgh EH12 7AT UK
Dr W. Heij	Department of Forest Technique & Forest Products Agricultural University PO Box 342 6700 AH Wageningen The Netherlands
Prof. T.E. Howard	Department of Forest Resources University of New Hampshire Durham New Hampshire 03827 USA
Prof. P.M. Joyce	Department of Forestry University College Dublin Belfield Dublin 4 Eire
Prof. I. Kolenka	University of Forestry & Wood Technology (USDL) 96001 Zvolen ul Marxova Czechoslovakia
Mr V. Kolman	Maine Forest Service State House Station 22 Augusta Maine 04333 USA
Mr A.K. Korpilahti	Metsäteho Box 197 00130 Helsinki Finland
Dr J. McNeel	Extension Timber Harvesting Specialist University of Georgia College of Agriculture PO Box 1209 Tifton Georgia 31793 USA

Dr E.S. Miyata	USDA Forest Service PNW Research Station 4043 Roosevelt Way Seattle Washington 98105 USA
Dr R.M. Newnham	Canadian Forestry Service Petawawa National Forestry Institute Chalk River Ontario KOJ 1JO Canada
Dr M. Nieuwenhuis	Department of Forestry University College Dublin Belfield Dublin 4 Eire
Mr S. Northway	MacMillan Bloedel Ltd. Wood Services Division 65 Front Street Nanaimo British Columbia Canada V9R 5H9
Mr N. Novak	ROS Slavonska suma SLUZBA 2A IS & AOP 54000 Osijek VJ. B. KIDRICA 14/G Yugoslavia
Dr W. Patzak	Lehrstuhl fur Forstliche Arbeitswissenschaft und Verfahrenstechnik der Universitat Munchen Hohenlindener Strasse 5 8000 Munchen 80 Federal Republic of Germany
Mr M.A. Pritchard	Forestry Commission Redford Hamsterley Bishop Auckland Co. Durham DL13 3EN UK
Prof. E. Robak	Department of Forest Engineering University of New Brunswick PO Box 4400 Fredericton New Brunswick Canada EB3 5A3
Prof. A. Roeder	Forest Research Institute Rheinland Pfalz Schloss D-6751 Trippstadt Federal Republic of Germany
Mr D.T.J. Rutherford	Forestry Commission 231 Corstorphine Road Edinburgh EH12 7AT UK
Dr M.S. Shiba	c/o Lehrstuhl fur Forstliche und Arbeitswissenschaft und Verfahrenstechnik der Universitat Munchen Hohenlindener Strasse 5 8000 Munchen 80 Federal Republic of Germany
Dr R.B. Tennent	Ministry of Forestry Forest Management & Resources Division Forest Research Institute Private Bag Rotorua New Zealand
Prof. S. Tomanic	Faculty of Forestry The University of Zagreb Simunska 25 41000 Zagreb Yugoslavia
Mr S. Westerling	Forskningsstiftelsen Skogsarbeten Box 1184 S-16422 Kista Sweden
Dr A.G.D. Whyte	School of Forestry University of Canterbury Christchurch 1 New Zealand

Printed in the United Kingdom for Her Majesty's Stationery Office
Dd 291256, 4/89, C16, 3385/2, 16268

HMSO BOOKS

HMSO publications are available from:

HMSO Publications Centre
(Mail and telephone orders only)
PO Box 276, London, SW8 5DT
Telephone orders 01-873 9090
General enquiries 01-873 0011
(queuing system in operation for both numbers)

HMSO Bookshops
49 High Holborn, London, WC1V 6HB 01-873 0011 (Counter service only)
258 Broad Street, Birmingham, B1 2HE 021-643 3740
Southey House, 33 Wine Street, Bristol, BS1 2BQ (0272) 264306
9-21 Princess Street, Manchester, M60 8AS 061-834 7201
80 Chichester Street, Belfast, BT1 4JY (0232) 238451
71 Lothian Road, Edinburgh, EH3 9AZ 031-228 4181

HMSO's Accredited Agents
(see Yellow Pages)

and through good booksellers

£12.00 net

ISBN 0 11 710272 5