Proceedings of the 1989 Winter Simulation Conference
E.A. MacNair, K.J. Musselman, P. Heidelberger (eds.)

AN INTEGRATED SIMULATION APPROACH FOR DESIGN AND ANALYSIS OF TIMBER HARVESTING SYSTEMS

Sabah U. Randhawa
Department of Industrial and Manufacturing Engineering
Oregon State University
Corvallis, OR 97331, U.S.A.

Eldon D. Olsen
Department of Forest Engineering
Oregon State University
Corvallis, OR 97331, U.S.A.

ABSTRACT

The paper describes a simulation environment that involves both modeling and analysis capabilities. The system provides powerful model development capabilities that would allow the user to develop and modify representations of timber harvesting system. The user would specify the characteristics of the environment to be modeled, and the system, in conjunction with appropriate data bases, would configure the models or alternative scenarios that would accomplish the user's objectives. A network-based simulation model then simulates the models or scenarios resulting from the model specification phase. The focus of this research is to develop an Artificial Intelligence-Simulation environment; the modeler declares knowledge about the system; the computer then sets up the system to be simulated, executes the system, and analyzes the results.

1. INTRODUCTION

Timber harvesting is an area of considerable importance, particularly in the Pacific Northwest. In recent years, significant changes have occurred in the log manufacturing and harvesting environment. There have been two important reasons for these changes. First, public awareness concerning forest issues has increased greatly in recent years. Protection of the environment and enhancement of the scenic values are factors that must be considered when making harvesting related decisions. Second, and perhaps most important, there has been an increase in the proportion of merchantable second growth forests now being harvested. These have greatly affected logging practices. For example, new government regulations have reduced the quantity of timber that can be extracted from logging sites. Also, the typically smaller stem sizes found in second growth forests have increased the opportunity for use of material handling systems and automatic processors.

Many simulation applications have been developed to address timber harvesting problems. These models are regarded as the first generation of timber harvesting simulators and date back to the early or mid-1970s (Wiese, 1988). Many models in this generation are outdated for several reasons. First, many of the models are oriented for individual phases of the harvesting operation rather than for the entire system. The result of analysis using these models is often suboptimization. Second, in a relatively short period of time the log harvesting process has evolved from a low level of mechanization to a level of complex material handling systems with increased automation. Existing "first generation" simulators were not designed to model highly mechanized systems.

A second problem with available timber harvesting simulation models is that they provide no development capabilities that would allow the user to develop or modify representations of the system to be simulated. The choice of equipment for any phase of the timber harvesting process is a function of multiple factors including soil type and structure, tract geometry and topography, plot size and concentration, tree stand characteristics including species distribution and log size distribution, post-harvest aesthetics, transportation availability, financial environment, and production goals. The logger or the researcher has to match these factors with available technology to determine a feasible set of equipment for a specific environment.

The objective of the research described in this paper is to develop a simulation environment for timber harvesting that involves both modeling and analysis capabilities by taking advantage of available techniques in simulation, data base management and artificial intelligence.

2. EXISTING APPROACHES

2.1 Timber Harvesting Analysis

Many simulation applications have been developed to address timber harvesting problems. These may be divided into two general classes -- phase models and tree-to-mill models (Goulett, Iff and Sirois, 1979).

In the Phase models, a certain phase of the process is modeled. Most of the simulation effort in timber harvesting has been in this class of models. Examples include simulation of the operation of a log landing for a Heli-Stat airship in old growth timber stands (Gerstkemper, 1982), simulation of a helicopter yarding system (Ledoux, 1975), loading and hauling subsystems of a logging system (Johnson, 1970), simulation of a rubber-tired feller-buncher (Winsauer, Bradley and Dennis, 1982), harvesting machines for mechanized thinning (Newnham and Sjunnesson, 1969), simulation of a timberyard (Lohman and Lehnhausen, 1983), and mechanized felling in dense softwood plantations (Winsauer, 1984).

In the phase models only a certain phase or part of the harvesting process is modeled and evaluated. Such a simulation makes no attempt at evaluating the balance of the system as a whole, which is very much the critical issue with timber harvesting systems.

In the Tree-to-Mill models, the entire process from felling until the log arrives at the sawmill is modeled. The most significant models that fall in this category include the models developed by Bussel, Hool, Leppet and Harmon (1969); Killham (1975); Bare, Jayen and Anholt (1976); Stark (1975); O'Hearn, Stuart and Walbridge (1976); Bradley, Biltonen and Winsauer (1976); Johnson (1976); and Martin (1976).

The tree-to-mill models examine the harvesting process with great variety in both function and detail. However, they are all about 10 years old, and many of the assumptions and configurations used in developing these models are no longer valid due to the evolution in the harvesting technology, and due to the requirements imposed by a changing work environment.

2.2. Timber Harvesting Modeling

Fisher, Geddes and Gibson (1984), Fisher and Geddes (1983) and Gibson, Jones, Barrett and Shih (1986) describe a prototype expert system for timber harvesting equipment selection. The knowledge base of this system consists of information derived from a small number of "experts" and from literature references. The system reasons through the rule base to make recommendations for selection of equipment about a specific phase of the process.

The choice of equipment for any phase of the timber harvesting process is a function of multiple factors including tract geometry and topography, stand characteristics, silvicultural prescriptions, post harvesting aesthetics, financial environment, and production goals. The prototype expert system reported in the above references focuses on a subset of these factors in making a selection for a specific phase. More importantly, it does not consider the entire system; thus, for example, the choice of an equipment for a phase may be incompatible with equipments prescribed for other phases of the process.

Additional considerations that need to be addressed before such a modeling system can be of any pragmatic value include:

1. Integration of the model and the user input with appropriate data bases for specific problem solving needs such as equipment characteristics and cost estimates.

2. Procedures for efficient solution of the search space resulting from combination of equipments for different work elements.

3. Procedures for handling imperfect or missing information about the system environment. The selection process must make decisions and analyze the consequences of decisions in the presence of imperfect information.

4. An effective communication protocol that would elicit from the user the characteristics of his/her environment, interact with the user to obtain feedback on the strategies selected in the modeling phase, and communicate results to the user.

5. Integration of the modeling system with an analysis module that would analyze the scenarios selected in the modeling phase.

3. TIMBER HARVESTING MODELING AND ANALYSIS SYSTEM

Our system consists of two main components: model generation and simulation analysis. We have completed the design and implementation of the simulation analysis module. We have now started working on the model generation phase. This section first describes the simulation analysis module, and then outlines the approach we plan to use for the model generation phase.

3.1 Simulation Analysis Module, LOGSIM

The objective for the development of LOGSIM was to define and build a simulation model that would overcome the problems of existing simulation models in timber harvesting, and address the changes that have occurred in forest products industry. We developed LOGSIM to provide a tool oriented toward improvement of the overall system performance. For details of the model see Wiese, Olsen and Randhawa (1988), Wiese (1988) and Moss (1989).

LOGSIM is a personal computer based network simulation model developed using SLAM II, Simulation Language for Alternative Modeling (Pritsker, 1986). LOGSIM offers three significant advantages over currently available simulation models or those developed in the past. First, LOGSIM models the entire harvesting process from the felling operation until the log arrives at the sawmill or timberyard. The process may include any of 13 harvesting operations, such as felling, delimbing, measuring, topping, skidding, loading, debarking, sorting, chipping and hauling. Each of the operations may use different type of machines, each with different processing characteristics, breakdown frequencies and repair times. In addition, the user may also specify material handling devices for transporting material between work stations. LOGSIM analyzes the system and produces output at three different levels -- the machine level, the operation level, and the system level.

Second, the model uses a front-end interface for obtaining input parameters from the user. Simulation programming languages provide a set of modeling tools which contain relatively complex structural concepts. In order to utilize the powerful capabilities of such simulation tools, the user must understand the structure, and satisfy the rules of syntax and semantics of the specific language being used. Such requirements limit the use of simulation program. The front-end interface for LOGSIM allows the input to the timber harvesting system using natural language; this input is then internally translated into the simulation language constructs.

Thirdly, a graphics utility package has been designed for LOGSIM. This package produces graphs that are useful visual aides for analyzing LOGSIM simulation results.

LOGSIM consists of three components. The simulation component is composed of a network-based model that performs the actual simulation, and FORTRAN-written functions for initializing the simulation process, for describing the statistical data sampling functions, and for computing and printing output results. The second component is the user interface for obtaining the input parameters for the harvesting system from the user. The third component is the graphics package for plotting selected simulation output.

The simulation model consists of two main components -- a main network model for modeling the harvesting process, and a machine breakdown network. The main network models the system logic based on the material flow specified by the user. The simulation program uses loads of materials as entities, and machines as resources. Conceptually, when the startup inventory level for a process is reached, a check is made on the availability of the assigned machines, and on the availability of a loader, if one is required. When the desired resources are available, the load is processed, and inventory updates are made. Maintaining appropriate inventory levels is critical in several operations of the system. During the simulation, the model automatically checks the inventory of the active processes each time an inventory transaction is performed. If the minimum inventory of the current operation is reached, the machines of the current operation are deactivated. If the maximum specified level is reached, the machines of the previous operation are deactivated. The appropriate processes are reactivated when the restart levels are reached. At the end of processing, the volume of load is added to the next process's inventory, the machine load is released, and the cycle starts over again.

The user may specify the use of a loading device to feed any machine with material. It is possible to specify the same loading device to be shared between different machines, as is not uncommon in the log harvesting practice. The user can specify capacities, time delays, costs and breakdowns for the loading machines just as for any other machine. Based on the capacities of the loader and the processing machines to which the loader is supplying material, the program computes the number of runs required by the loader to load the machine. This number, along with the time per load, is then used to compute the total load time.

A customized output processor was designed to compute and present results to the user. Results are reported at three different levels: harvesting system statistics, process statistics and machine statistics. The harvesting system statistics describe the overall performance of the system; the process level statistics describe the performance of each process; since a process may be using more than one machine, the machine level statistics report the performance of individual machines. The machine level statistics include statistics on loading and other material handling devices used in the system.

The simulation output at each level include statistics on machine utilization, throughput times, machine productive and breakdown hours, inventory downtime (that is, the proportion of time the process is down because the inventory is either below the minimum level or above the maximum level), in-process inventory levels, and processing costs.

A front-end user interface was designed to enable the user with little or no SLAM or FORTRAN background to successfully use

LOGSIM. Together with the output processor and the graphics interface (described later), the input interface completely insulates the user from the comparatively cumbersome simulation program. The input front-end, written using Microsoft FORTRAN, may be used to define a new harvesting model, edit an existing harvesting model or to print an harvesting model for documentation purposes.

In the input mode, the user is stepped through seven input phases with the program prompting for required inputs at each phase. Inputs include: the volume of wood to be harvested that determines the simulation duration, material flow through the harvesting system using a from-to table, material distributions for the tree stand and for intermediate products, specification of the material distribution and limiting inventory levels for each process, machine specific information including the number of each type of machines used with each process, and processing times, setup times, fixed costs and variable costs associated with each machine, and distributions for machine breakdowns and repairs.

The front-end features full error trapping for data input. The program automatically recovers from errors, such as, variable type mis-match during input or editing, thus preventing loss of input or editing work. When an error occurs, an error message is displayed and the user is again prompted for input.

The graphics utility package (LSGRAPH, written in TURBO-C) for the LOGSIM mechanized timber harvesting simulator produces graphs that are useful visual aides for analyzing LOGSIM simulation results. The files for generating graphs are automatically generated by LOGSIM if the data generation options are selected while running LOGSIM. This automatic data file generation, along with the menu structure used in LSGRAPH for making selections and changing graph sizes, ensures the successful use of LSGRAPH by the user without the need to know anything about the underlying computer code. Three different graphs can be generated: net utilizations for each type of machine used in the system, costs per unit processed and cost per hour of processing. The cost graphs provide a means of visually assessing the degree of stochastic convergence realized for a simulated harvesting operation.

3.2. Model Generation Framework

Automatic model generation for simulation requires developing appropriate data representation and mapping procedures. Although a number of data base management systems are widely available (relational, tree, network), they rarely provide many of the specific capabilities needed for modeling in simulation. Research into information-based methodologies have indicated the potential of using artificial intelligence (AI) representation schemes in data bases. The two primary AI approaches that have been proposed for representing information in the simulation domain are rule-orientation and object-orientation.

The use of object-oriented approach facilitates pattern recognition and inference of properties. In a dynamically changing environment, we do not know in advance what combination of processes, or events to use to satisfy a goal. As conditions change, the change may trigger some event to behave differently. This in turn, may effect other events, and so on. Such conditions can be effectively modeled using a pattern-directed invocation, where events do not respond to a specific request, but to changing data patterns. For details on object-oriented programming, see Frost (1986), Cox (1986), Booch (1986), Stefik and Bobrow (1986), Adiga (1989), Fikes and Kehler (1985), Sowa (1984), and Borgida, Greenspan and Mylopoulous (1985).

We plan to use an object-oriented framework for representing data base information. Consider, for example, an equipment or a workstation represented as an object. Attributes for this object include:

1. Descriptive data values about the object, for example, initial purchase cost.

2. Constraints on possible values of an attribute. For example, the operating efficiency of the equipment may be a function of terrain slope. Conditions may be more complex involving multiple attributes. For example, the operating efficiency of an equipment may depend on the terrain slope and soil structure.

3. Collection of production rules representing conditional relationships that are invoked when certain attribute values are accessed.

4. Links to other objects; such links will be required to develop a network of compatible equipment for the entire process.

5. Methods that respond to messages send to the object. These messages specify the target message-responder object, and any arguments needed by the methods for this object. For example, a procedure may be attached to "equipment" that would compute a score representing the "goodness" of a match. Another procedure may be invoked if this goodness value is below some user defined minimum; this procedure may request the user to relax some constraints or provide additional alternatives.

The object-oriented technique will also be used to represent the N-dimension user vector description of the harvesting system. The matching process will determine if there is a constrained region in the data base space onto which the user vector space can be mapped. Matching involves comparing the set of values associated with the user vector, U, against the attribute values of the object, C_{11} in the data base. (For example, C_{11} may represent equipment type 1 for process 1). A match may be directly obtained between U and C_{11}. However, more often we may not be able to find a direct match between U and C_{11}. Some of the attribute values of U may not be known, others may not match with corresponding values of C_{11}, while still others may be outside the allowed range.

The system will first try matching some critical attributes, for example, terrain slope in timber harvesting. The presence of an inappropriate value for such critical attributes will set the match value to zero, and further match process will be suspended. Next a match value will be computed based on the remaining attributes. A "desirability" score will be attached to each operational level of an attribute in the data base. We plan to explore the use of two models for computing the match score.

(a) The match score will simply be the sum of individual desirability scores.

(b) The match score will be computed based on the linear additive model

$$M_j = \sum_i W_i D_{ij}$$

where M_j is the match score for equipment j, W_i is the user specified importance weight for attribute i, and D_{ij} is the desirability score for equipment j on attribute i. The method of computing match value may differ for other applications.

If the match value is high enough, the system will not look at other objects (C_{1j}, j=2,...) at this time in the search process. Otherwise, the system will consider other objects. The equipment set C_{1j} represents equipments 1,2,...,j, for process 1. The search continues until a match is obtained between the user vector and an object, j (that is, compatibility score exceeds some minimum threshold level) or the search fails to find an acceptable match.

Due to the hierarchical structure of data representation in the data base, the match process will utilize concepts such as principles of hierarchy and economy (Cohen, 1982). Since lower objects constitute subclass of higher objects (for example, "equipment" objects are subclass of the object "process"), the properties of objects are not repeated for each object at which they apply, but at the highest possible object above all the subclasses to which the property applies. The properties of subclasses can then be inferred from the superclass objects at which they are stored.

Rather than to go through an exhaustive search, the current object (C_{11}) will be used to identify relevant objects. For example, if some of the attributes were satisfied, then the search will look for another object C_{1j} in which the similarity relationship of C_{1j} with C_{11} can be exploited. This solution process can be formalized as a graph search process.

The object selected for the first stage of the process, along with the user vector, U, will then be used to find a match for the next step in the process. If the current process is the last process in the system, then the network is complete; that is, a directional path between the first and the last process representing a feasible combination of individual processes has been found. For each path, a "compatibility" score will be computed based on a multiplicative model (i.e., reliability of components in series). A match score for each process (or phase of the system) is not sufficient for selecting the best path in the network. The match score will reduce the number of choices for individual phases; the compatibility score will find a more exact match for the entire system. The path with the maximum compatibility score will be selected as input to the simulation analysis phase.

The implementation procedure for the simulation modeling framework in timber harvesting is shown in Figure 1. This involves the following steps:

1. Develop a complete list of factors for timber harvesting in the western United States. Constraining the implementation effort to the western United States is to keep the problem within a manageable size. The factor set includes slope, soil structure, user's concern for erosion, post-harvest aesthetics, crew skill level, partial or clearcut, underbrush, plot size, stand density, log size distribution, site drainage capability, species distribution, weather, travel distances and transportation.

2. For each factor on the list identified in task (1), develop a set of operational levels. For example, operational levels for soil structure may be (a) gravel, (b) fine sand, (c) silt, (d) clay, and (e) organic (peat and muck).

3. Develop a user-computer interface to enable the user to define the factors and their operational levels for the user's harvesting environment.

The result from steps (1)-(3) is a N-dimension vector defining the user harvesting environment.

4. Currently, there are a wide variety of machines available for each step of the logging process. Define each of these machines in terms of the attributes identified in step (1), and in terms of their costs, and their compatibility with other machines. The modeling process then involves matching the N-dimension user vector (steps 1-3) with the technology data base (step 4).

The final step in our system is the integration of the modeling phase with the simulation analysis module, LOGSIM, so that the alternatives from the matching process can be analyzed. Thus, the pattern matching capabilities of object-oriented representation will be combined with the powerful capabilities of procedural simulation language.

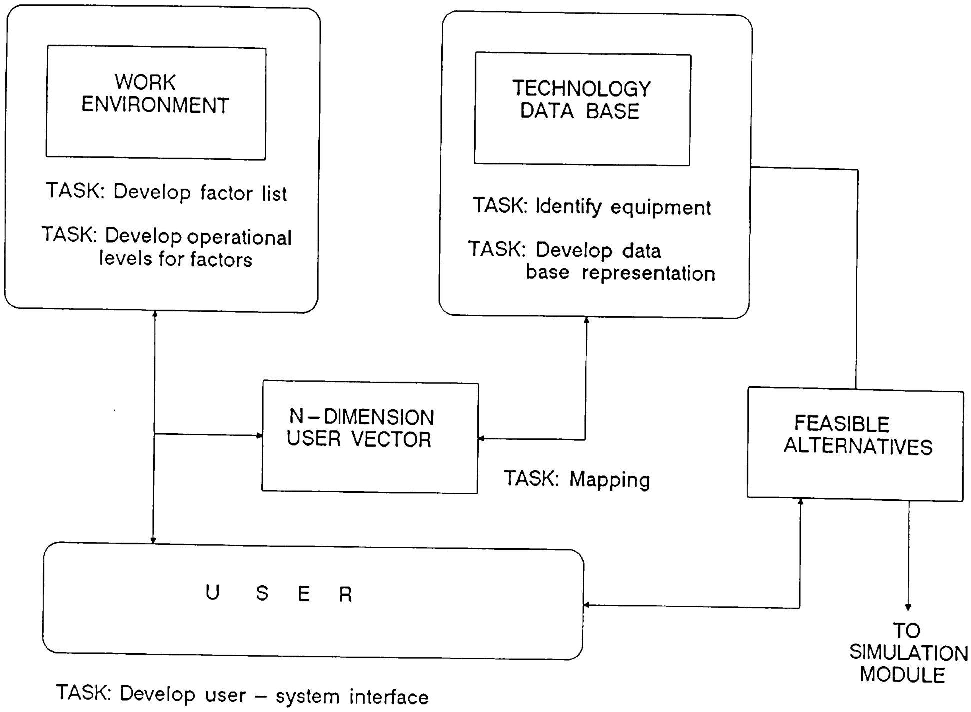

FIGURE 1. APPLICATION OF MODEL GENERATION FRAMEWORK IN TIMBER HARVESTING

4. CONCLUSIONS

We have described a simulation modeling and analysis system for the design and evaluation of mechanized timber harvesting systems, a problem that has economic as well as societal relevance. No previous work has provided a design and evaluation tool in this important area of application.

The lack of automatic model generation techniques in timber harvesting reflects the state-of-the-art in simulation research. "Simulation model development has remained a relatively unchanged technology for some 15 years" (Nance, 1984). It is an accepted notion that a facility for automatic model generation will greatly enhance the user acceptability and utility of simulation. However, there is very little implemented work available in this area. Our model generation framework is structured to be applicable to a wide variety of applications.

REFERENCES

Adiga, S. (1989). Software modeling of manufacturing systems: a case for an object-oriented programming Approach. Annals of Operations Research 17, 363-378.

Bare, D.B., Jayen, B.A. and Anholt, B.F. (1976). A simulation based approach for evaluating logging residual handling systems. USDA Forest Service Report PNW-45, Portland, OR.

Booch, G. (1986). Object-oriented development. IEEE Transactions on Software Engineering SE-12, 2, 211-221.

Borgida, A., Greenspan, S. and Mylopoulos, J. (1985). Knowledge representation as the basis for requirements specifications. Computer 18, 4, 82-91.

Bradley, D.P., Biltonen, S.A. and Winsauer, S.A. (1976). A simulation model for full-tree chipping and trucking. USDA Forest Service Research Paper NC-129, St. Paul, MN.

Bussel, W.H., Hool, J.N., Leppet, A.M. and Harmon, G.R. (1969). Pulpwood harvesting system analysis. Report to the Southern Executive Association, Auburn University, Auburn, AL.

Calu, J., Wael, L.D., Esmeijer, E. and Kerckhoffs, E.J.H. (1984). "Knowledge-base aspects in advance modeling and simulation," Pro. 1984 Summer Simulation Conf., 1247-1253.

Cohen, P.R. (1982). Semantic network models of memory: quillian's semantic memory system. In: Handbook of Artificial Intelligence, Volume III, (P.R. Cohen and E.A. Feigenbaum, eds.), William Kaufmann, Inc., Los Altos, CA, 36-42.

Cox, B.J. (1986). Object Oriented Programming: An Evolutionary Approach, Addison-Wesley Publ. Co., Reading, MA.

Fikes, R. and Kehler, T. (1985). The role of frame-based representation in reasoning. Communications of the ACM 28, 9, 904-920.

Fisher, E.L. and Geddes, L.A. (1983). An artificial intelligence approach to forest harvest planning. 1983 Winter Meeting, American Society of Agricultural Engineers, Paper No. 83-1610.

Fisher, E.L., Geddes, L.A. and Gibson, H.G. (1984). Rule-based selection of forest harvest equipment. 1984 Winter Meeting, American Society of Agricultural Engineers, Paper No. 84-1614.

Frost, R. (1986). Introduction to Knowledge Based Systems, Macmillan Publ. Co., New York, NY.

Gerstkemper, J.C. (1982). A simulation of the operation of a log landing for a helistat airship in old growth timber. Research Paper, Department of Forestry, Oregon State University.

Gibson, H.G., Jones, D.D., Barrett,Jr., J.R. and Shih, C-H. (1986). Timber harvesting equipment selection: an expert system. 1986 Winter Meeting, American Society of Agricultural Engineers, Paper No. 86-1604.

Goulett, D.V., Iff, R.H. and Sirois, D.L. (1979). Tree-to-mill forest harvesting simulation models: where are we? Forest Products Journal, 50-55.

Johnson, L.R. (1970). Simulation of the loading and hauling subsystems of a logging system. MS Thesis, Montana State University, Bozeman, MT.

Johnson, L.R. (1976). SAPLOS: documentation and use. Report to USFS Northwestern Forest Experiment Station, Morgantown, WV.

Killham, J.R. (1975). The development of a forest harvesting simulation model. MS Thesis, Auburn University, Auburn, AL.

Ledoux, C.B. (1975). Simulation of a helicopter yarding system in old growth timber stands. MS Thesis, Oregon State University, Corvallis, OR.

Lohman, H. and Lehnhausen, H. (1983). Systemanalyse eines Holzhofes durch die Simulation des Materialflusses. Forstarchiv (West Germany), 54, 6, 221-228.

Martin, A.J. (1976). A user's guide for THATS. USDA Northeastern Forest Experiment Station, Princeton, WV.

Moss, A. (1989). Performance and graphics enhancement of the LOGSIM mechanized log harvesting system simulator. MS Thesis, Department of Industrial Engineering, Oregon State University, Corvallis, OR.

Nance, R.E. (1984). Simulation modeling: two perspectives. IIE Transactions, 16, 1, 2.

Newnham, R.M. and Sjunnesson, S. (1969). A FORTRAN program to simulate harvesting machines for mechanized thinning. Forest Management Research and Service Institute Report FMR-X-23, Ottawa, Ontario, Canada.

O'Hearn, S.E., Stuart, B.W. and Walbridge, T.A. (1976). Using computer simulation for comparing performance criteria between harvesting systems. 1976 Winter Meeting, American Society of Agricultural Engineers, Paper No. 76-1567.

Pritsker, A.A.B. (1986). Introduction to Simulation and SLAM II, Halsted Press, New York, NY.

Sowa, J.F. (1984). Conceptual Structures: Information Processing in Mind and Machine, Addison-Wesley Publ. Co., Reading, MA.

Stark, J.I. (1975). A simulation model for the common pulpwood harvesting systems of the southern pine region. MS Thesis, Department of Industrial Engineering, Georgia Institute of Technology, Atlanta, GA.

Stefik, M. and Bobrow, D.G. (1986). Object-oriented programming: themes and variations. The AI Magazine, VI, 4, 40-62.

Wiese, C. (1988). Simulation of mechanized log harvesting systems. MS Thesis, Department of Industrial Engineering, Oregon State University, Corvallis, OR.

Wiese, C., Olsen, E.D. and Randhawa, S.U. (1988). A simulation model for mechanized log harvesting systems. Simulation, 51, 3, 120-126.

Winsauer, S.A. and Dennis, B.P. (1982). A program and documentation for simulation of rubber-tired feller-buncher. USDA Forest Service Research Paper NC-212, North Central Forest Experiment Station, St. Paul, MN.

Winsauer, S.A. (1984). Simulation of mechanized felling in dense softwood plantations. Paper presented at the conference COFE/IUFRO, SAF Publication No. 84-13, 175-180.

AUTHORS' BIOGRAPHIES

SABAH U. RANDHAWA is an Associate Professor of Industrial and Manufacturing Engineering at Oregon State University. He holds a B.S. in Chemical Engineering from the University of Engineering and Technology, Lahore,

Pakistan, an M.S. in Industrial Engineering from Oregon State University, and a Ph.D. from Arizona State University. His research interests are in simulation modeling, information modeling and production control. He is a member of IIE, SCS, ORSA, CASA/SME, and Alpha Pi Mu.

Sabah U. Randhawa
Department of Industrial and Manufacturing Engineering
Oregon State University
Corvallis, OR 97331, U.S.A.
(503) 737-2869

ELDON D. OLSEN is a registered professional engineer and Associate Professor of Forest Engineering at Oregon State University. For the last ten years he has conducted research in operations analysis in the harvesting of timber. He also teaches graduate, undergraduate, and extension courses in operations analysis. His publications are in the areas of computer models, cost analysis, and economic evaluations of environmental issues.

Eldon D. Olsen
Department of Forest Engineering
Oregon State University
Corvallis, OR 97331, U.S.A.
(503) 737-2192