Timber Harvesting Analyses and Design using Simulation

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Abstract

The design, evaluation and control of harvesting systems in a problem of considerable importance in the forest products industry. Modeling of timber harvesting systems include considerations such as production rates, equipment breakdown, fixed and variable costs, material flow and scheduling priorities. The resulting mathematical anaylsis is not computationally feasible. Computer simulation can be effectively used to accurately represent complex systems, such as timber harvesting, that are affected by numerous variables. The research reported in this paper developed as simulation model for analyzing the entire logging operation (tree-to-mill) in the forest products industry.

Introduction

In recent years, significant changes have occured in the timber harvesting environment. Considerable time, effort and capital is being spent to improve the value of recovery during the logging process. For nearly every step of logging process, material handling system and automatic processors have been developed. These devices have been constructed in great variety and adapted to the specific environments. The performance of these systems in terms of economics, utilization, material flow and capacities is a critical issue in the forest industry today.

The perfect system design must be based on complete information and complete process control. This requires inclusion of such factors as process flow, scheduling priorities, machine failures, in-process inventory consideration, and types of inputs and/or outputs. The resulting mathematical analysis is extremely complex to conduct because the interaction between variables are nonlinear, and difficult to model analytically. A more versatile and practical approach for developing an analysis tool is computer simulation.

Computer simulation refers to the method used to study the dynamics of the system. Simulation provides a description of system behavior as it evolves over time. The purpose of simulation is to study the effect of decision alternatives and changes to model assumptions on system output measures.

The simulation models for the logging process available in literature may be classified as either tree-to--mill-models or phase models (Goulet, Iff and Sirois, 1979). The tree-to-mill models attempt to model the entire process from felling of the tree until the log arrives at the sawmill. Examples of such models are given in Bussel, Hool, Leppet and Harmon (1969), Killham (1975), Bare, Jayen and Anholt (1976), Stark (1975), O'Hearn, Stuart and Walbridge (1976), Johnson (1976), and Martin (1976). The tree-to-tree mill models examine the timber harvesting process, with great variety in both, function and detail. However, they are about ten years old, and many of these models are obsolete. The assumptions and configurations used in these models are no longer valid due to the mechanization and automation of the log harvesting process, and due to the requirements imposed by a changing environment.

In the phase models, a certain phase or part of the process is modeled. Most of the available models in log harvesting fall in this category. Examples of these model are: Gerstkemper (1982), Ledoux (1975), Johnson (1970), Lohman and Lehnhausen (1983) and Winsauer (1984).

The objective of the research reported in this paper was to develop a simulation-based model for analyzing the entire logging operation (tree-to-mill) in the forest products industry. Using this system the user is able to define direct on-line, in an interactive session, the specific configuration of the timber-harvesting system the user would like to analyze. A network-based simulation model then performs the analysis and outputs the results in an easy to analyze and readable form. Since the environment and machine configurations change for every application, the model is built in a modular fashion, and is easy to use and adapt.

Process Description

The main work elements of the timber harvesting process are;

— Felling: all steps necessary to sever the standing

tree.
— Delimbing: removal of limbs from the merchantable log.
— Topping: cutting which severs the tree at the smallest utilizable top.
— Measuring and bucking: manufacturing the tree into log lengths to meet specifications or to maximize end value.
— Bunching: placing of trees or logs together to facilitate skidding or loading.
— Skidding: movement of trees or logs along the ground.
— Prehauling: movement of trees or logs from the stump to the landing site in a carrying vehicle without dragging.
— Loading: placement of tree or log on to a carrying vehicle such as truck, railcar or barge.
— Debarking: removal of bark from trees or logs.
— Sorting: separation of trees or logs by commercial characteristics.
— Chipping: cutting of logs into small pieces for pulping or hogfuel.
— Hauling: movement of trees or logs from the landing site to the mill or transfer yard.

Due to mechanization, machines can now combine several work elements into one workstation. Additional restrictions may be imposed by the nature of the process. For example, there can be restrictions on the inventory buffers before each process. These inventory limits can be a minimum size of inventory required to operate a certain machine, or a maximum allowable inventory level due to space constraints. Some work elements require a preliminary loading action. This loading action may be provided by the machine itself or a loading device. Also, it is possible for work elements in different stages to share the same loading device.

Any simulation model designed to analyze the logging operation should accurately describe the different components of the system and their inter-relationships, and yet be flexible enough to model the variation among the harvesting systems.

Simulation Model

The simulation model is capable of simulating a harvesting system from the felling operation until the log arrives at a sawmill or timberyard. The model can handle upto 13 processes, some of which are outlined in the previous section. Each of the processes can employ different type of machines that need to be specified by the user. In all, the simulation model can handle up to 90 machines, divided into 42 machine classes. For each machine class, the user can specify a different set of parameters through the user interface. This parameter set describes processing times, machine capacity, machine breakdowns, cost and number of each type of machine available.

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 level 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 level for 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 process are deactivated. The appropriate processes are reactivated when the restart limits are reached.

For each of the thirteen processes, the user may specify the use of a loading device to feed the machine with material. It is possible to specify the same loading device to be shared between different workstations, as is not uncomon in the log harvesting practice. The user can specify capabilities, delay times, machine costs and machine breakdowns for the loading machines just as for any other machine. Based on the capacities of the loader and the processing machine to which the loader is supplying material, the program computes the total load time.

The simulation model also contains logic for handling machine breakdowns. Based on user input during the model initialization process, two attributes are assigned to each machine: time between failures and repair times. The machines are modeled as resources; these resource levels are decreased or increased, based on the distributions specified for breakdowns and repairs.

A front-end user interface was designed to enable a user with no computer background to successfully use the model. The input interface completely insulates the user from the computer program. The input front-end may be used to define a new harvesting model, edit an existing harvesting model or to print an existing harvesting model for documentation purposes. The inputs of an harvesting system include:

1. The amount of wood to be harvested.
2. Material flow that defines the processing sequence.
3. Material frequency distributions for describ-

ing trees, logs and pulpwood pieces handled by the machines.
4. Inventory levels for each processes.
5. Indication of the use of a loading facility, and if required, the time delays associated with this machine.
6. The number of machines of each type available in the system.
7. Machine parameters including processing times, set-up times, fixed and variable production costs per machine hour, and machine capacities.
8. Machine breakdown distributions and repair frequencies.

Simulation Output

A customized output processor was designed to compute and present results to the user. This processor reports results at three different levels: harvesting system statistics, process statistics and machine statistics. The harvesting system statistics describe the overall performance of the system; each 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 process and machine level statistics include statistics on loading and other material handling devices.

The simulation output at each level include information on the following parameters:

1. Time to process a specified amount of material
2. Utilization of machines.
3. Machine productive and breakdown hours.
4. Proportion of the time the process is down because the inventory level is below the minimum level or above the maximum level.
5. Average, minimum and maximum inventory levels.
6. Processing cost per unit.
7. Processing cost per scheduled hour.

The computer code for the front end and the simulation model is too lengthy to be reproduced in this paper. Figure 1 shows the structure of the simulation model. The computer code and a detailed explanation of the model are given in Wiese (1988)

Results

The model has been thoroughly verified for accuracy. To verify the correct functioning of the simulation model, extensive test runs were performed. In these tests the behaviour of the modules and mechanisms used to control the simulation were examined by using test data that simulated the different situations possible in an harvesting system.

Also four complete harvesting systems (tree-to-mill) were simulated. Each of the four harvesting systems uses a different machine configuration with different capabilities. One of the system simulated was the traditional manual sawlog operation. This system consists of manual felling, delimbing and bucking; cable skidder for primary transport; self-loading highway log truck for secondary transport. Due to space constraints, the inputs for the system are not shown here. However, a portion of the output for a system with the above characteristics is shown in Table 1 and 2. Table 1 shows the harvesting system statistics. It took 3116.75 hours to process 255664 cubic feet of material with an overall system utilization of about 75 percent. Also shown in this table are total production costs, cost per unit of production and the cost per hour operation. Similar results are obtained for each process and each machine (including material handlers) used in the system). Figure 2 shows the utilization of the resources used in the system. The utilization of the cable skidder is very high (about 94 percent); any attempt to increase system throughput will result in this operation causing a bottleneck. Thus, an increased throughput may only be achieved by adding an additional unit of cable skidder.

Additional insights into the economics of production may be obtained by evaluating the detailed cost structure shown in Table 2. This table shows that the skidding operation contributes about 58 percent of the total cost, and another 33 percent is attributable to final

Table 1. Summary of Simulation Results

Volume Harvested (cubic feet)	255664
Harvesting Time (hours)	3116.75
Net Utilization(%)	74.61
Total Production Cost(s)	335893.40
Cost per Unit (s)	1.31
Cost per Hour (s)	107.77

Table 2. Summary of Cost Output

Process	Cost per Unit (s)
Manual Felling	0.1200
Cable Skidding	0.7647
Final Transport	0.4291

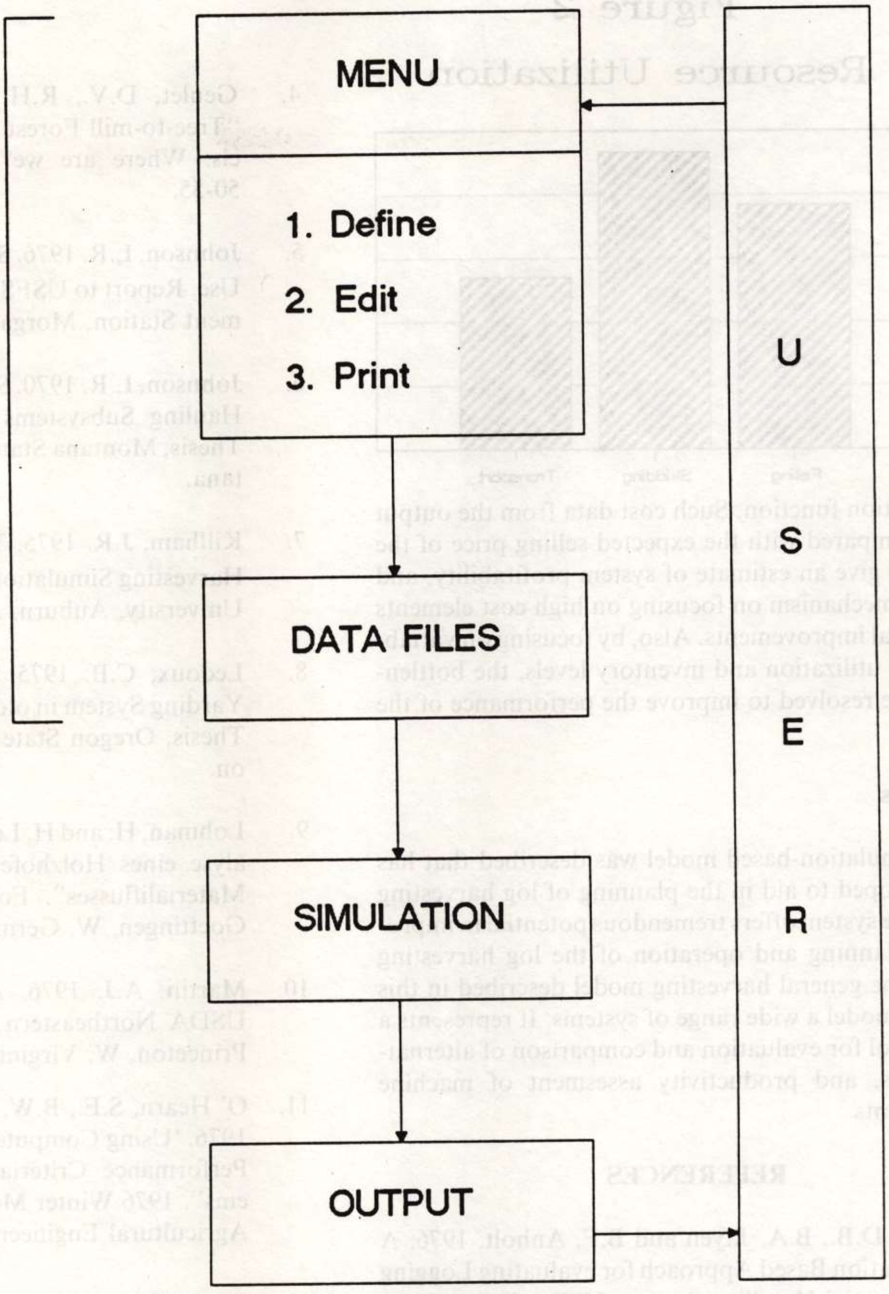
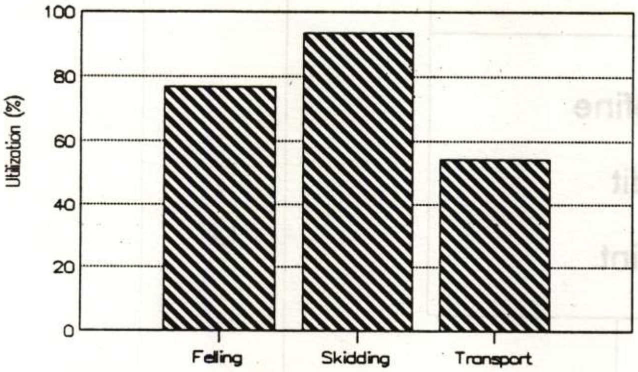


FIGURE 1. SIMULATION PROGRAM STRUCTURE

Figure 2

Resource Utilization



transportation function. Such cost data from the output may be compared with the expected selling price of the product to give an estimate of system profitability, and provide a mechanism on focusing on high cost elements for potential improvements. Also, by focusing on variables such as utilization and inventory levels, the bottlenecks can be resolved to improve the performance of the system.

Conclusions

A simulation-based model was described that has been developed to aid in the planning of log harvesting system. The system offers tremendous potential in improving the planning and operation of the log harvesting process. The general harvesting model described in this paper can model a wide range of systems. It represents a versatile tool for evaluation and comparison of alternative systems, and productivity assesment of machine improvements.

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