A Simulation Model for a Hardwood Sawmill Decision Support System

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ABSTRACT

The paper describes a sawmill simulation model developed as a component of an integrated decision support system for hardwood sawmills. Discussions focus primarily on some of the essential features of the simulator and how it can be used as a tool for designing sawmill facilities and in the evaluation of sawing policies and production plans. Further discussed are some of the discrete-event simulation modeling techniques used in developing the simulator.

Keywords: *discrete simulation, decision support, hardwood sawmilling*

INTRODUCTION

Evaluation of lumber production policies and mill design alternatives could be done using computer simulation models. A computer model can assist mill analysts in assessing a sawmill's performance under a variety of operating conditions. From a design perspective, a simulation model can be utilized to evaluate the operational feasibility and efficiency of a proposed system before it is actually implemented.

The development of simulation models that integrate the various aspects of lumber production can be extremely difficult. A number of interdependent variables need to be considered which include, among others, the relationships of material inventory, the characteristics or attributes of the materials, the mill's physical layout and equipment specifications, and sawing procedures. Attempts to develop integrated sawmill models appear in the early works of Martin [8] and Aune [1]. Martin's work can be considered a big feat at the time when simulation software has not yet flourished. His work demonstrated the difficulty of developing models that integrate the various phases of lumber manufacturing. Aune described the concept of discrete-event simulation and its potential application in modeling and analysis of sawmill processes and sawmilling productivity. He further demonstrated the complexity of the task involved in developing discrete-event simulation models even for the simplest sawmill operation.

The discrete-event simulation modeling technique used by Martin and Aune enabled the observation of time persistent variables in sawmilling. In recent years, the advent of simulation software has led to wider use of discrete-event simulation in the design, analysis and evaluation of sawmilling operations [21, 1, 4, 6]. Wagner and Taylor and Hall et al. utilized the SLAM simulation language in modeling the operation of softwood sawmills. On the other hand, Adams utilized GASP-IV in developing a design package for hardwood sawmills, while Kline and Weidenbeck utilized SIMAN/CINEMA in simulating and animating the operation of hardwood rough mills and joinery shops.

The difficulty of modeling complex lumber manufacturing systems was overcome by other researchers by developing simulation models in a piece-wise manner. Van Wyk and Eng [20] and Martin et al. [9] developed and employed specialized simulation programs at various stages of sawmill problem analysis. In using their models, one needs to select only the appropriate programs for a particular problem or tailor together a number of programs for a comprehensive problem analysis.

In the following sections, we describe a sawmill simulation model that was developed as part of an integrated decision support system for hardwood sawmills. Closely allied to the model described is the hardwood sawmill simulator DESIM developed by Adams [1,2]. However, DESIM runs only on a mainframe computer and requires a large amount of memory and a certain level of computer expertise for

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program operation. In this research effort, we tried to overcome these limitations in an attempt to make sawmill simulation more acceptable to end-users. The paper primarily focuses on a specific modeling structure that encompasses the various facets of sawmilling and management decision-making process. Furthermore, we provide some of the modeling techniques we used in developing the simulator. Constructed separately with a tree and log inventory modules, the model described in this paper can work independently as a stand-alone sawmill simulator. However, it can also be integrated with the other modules to form a single management decision support system.

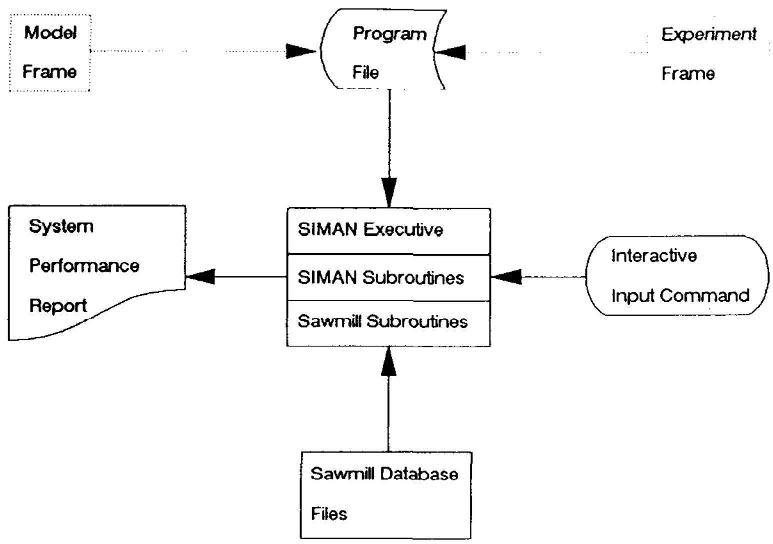

Figure 1: Overview of the interface between SIMAN and the hardwood sawmill simulator.

SYSTEM STRUCTURE

The hardwood sawmill simulation model presented in this paper takes advantage of the modeling features offered by SIMAN [14]. SIMAN is a FORTRAN-based simulation language that can model discrete and/or continuous systems that exhibit characteristics such as those typically found in many wood processing operations. The base language used offers a fundamental distinction between the system model and experiment frame. The system model defines the static and dynamic components of the system while the experiment frame defines the experiment condition under which the model is run. In this modeling endeavor, we portrayed the functional components of a hardwood sawmill and their possible interactions in the model frame. On the other hand, the sawmill attributes, material attributes, and other experimental conditions for simulation were portrayed in the experiment frame.

The simulation program is front-ended with a menu-driven data-entry interface with existing default values. This enables a user to utilize the system in analyzing various sawmill scenarios or problem areas at relative ease. Furthermore, a user can compose a desired sawmill design or analyze a sawing policy by entering the appropriate mill and sawing specifications through the data-entry interface. The interface virtually insulates a user from further program manipulation and the necessary program recompilation. The program organization of the simulator and how it works under SIMAN's modeling framework is shown in Figure 1.

Material Flow

The structure shown in Figure 1 is basically based on a discrete-event orientation, with the log breakdown and other processing logic imbedded within the model as event subroutines. The network of processing centers containing standard sawmill facilities was coded in the model frame of SIMAN. Physically, these processing centers are linked together by conveyors and transporters and a series of buffers with user-specified capacities. In the model, the processing centers define the log deck station, the headsaw area, edging and trimming stations, and the lumber sorting area.

The program treats materials (i.e., logs, boards, and lumber) as entities and machines as resources. Entity movement within the system is governed by the process model and the processing logic contained in the sawmill subroutines. Initially, a log (or mother entity) is scheduled to enter the system following a user-specified arrival rate. In the process, the basic attributes or entity characteristics, such as species, log grade and dimensions, are assigned. As the log progresses through the headsaw, it is replicated into several entities (boards) depending on the basic attributes of the log. The attributes of the offspring entities are then enhanced to include board width, volume, board grade and the next routing station. Figure 2 schematically illustrates this program logic. Note from Figure 2 that boards are produced one at a time as the log engages the headsaw. As each individual board is produced, the

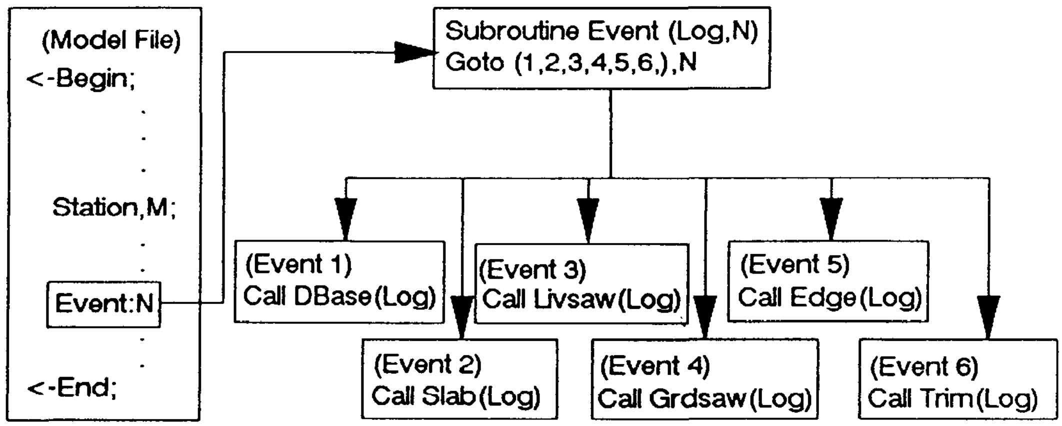

Figure 2: Overview of the interface between the sawmill material flow and the log processing event subroutines.

associated time delays are collected and treated as components of the log sawing time.

Queue capacities are associated with the lengths of buffer decks entered by a user. As a simulation run progresses, the available capacity at a given queue is updated by calculating the unoccupied space in the buffer deck. In the log deck queue, for example, a log entity occupies an amount of space equal to its diameter. By summing up all the diameters of logs residing on the log deck, the model evaluates at discrete points in time the available space for incoming entities. Note that in our model, we assume that logs and the resulting entities (boards/lumber) are stacked in queues in a single layer. In an event that a queue capacity is exceeded, the preceding operation is deactivated—creating a machine downtime condition. This system behavior, as recorded in the simulation output, will enable mill analysts to examine the sources of bottlenecks or design the appropriate buffer decks for their system.

Log Breakdown Logic

As an entity is processed during a simulation run, the FORTRAN-coded subroutines containing the logic for breaking down logs into flitches and flitches into lumber are accessed through subroutine EVENT as shown in Figure 3. This further calls the appropriate subprograms for assigning log attributes, decision routines during the log breakdown process (both for non-taper live sawing and grade sawing), face orienting, and the mathematical routines for edging and trimming.

The log breakdown subroutines are descriptive simulation routines that mimic the decisions of a sawyer in handling logs of given attributes. The live sawing model utilizes the mathematical formulations originally developed by Savsar [16] for hardwood log. Savsar's formulations assume that the logs are in the form of truncated cones and all slices at the headsaw are made parallel to the central axis of a log. Details of these formulations are also presented in Savsar and Kersavage [1] and Meimban [10].

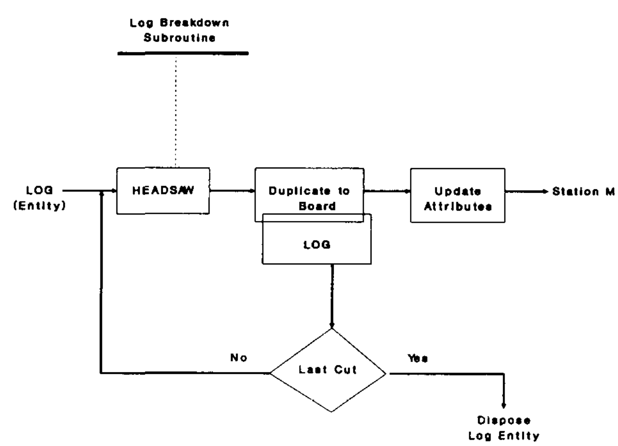

Figure 3: Schematic diagram of the simulator's log breakdown process.

The simulation of grade sawing is relatively more difficult than live sawing due to the complex characteristic of wood. The difficulty is further aggravated by the lack of information about quality variation within the same piece of log which is a major determinant in generating grade sawing decisions. While we realize that grade recoveries are dependent on a number of factors, e.g., individual milling situations, quality of log inputs, species, skill of sawyer, etc., we attempted to provide some mechanisms in the simulator to generate grades given the currently available information. In the model, lumber grades from a given log grade and species are generated by sampling from historical probability distributions. The hardwood lumber grade recovery values for different species and diameters presented in FPL No. 63 [19] were transformed into discrete distribution tables and stored in the system's experiment file. Note that these recoveries are based on industry averages and do not represent a particular sawmill. We suggest that these grade recovery values should be replaced by users if historical data from their own milling experience are available.

Initially, the grade of boards to be sawn from the four faces of the log are generated from a corresponding probability distribution. To account for the observation that wood quality generally decreases from the log surface towards the pith, the succeeding grades of boards beneath a face are generated by sampling from a truncated distribution. In this method, the grade of a previously sawn board becomes the limiting grade of a current board. Using this principle, the first two cuts are made on the highest graded face of a log where cutting progresses until the board grade drops. The log is then oriented to the next candidate face and the same decision routine is executed.

The same method of grade generation is also used in live sawing. Note, however, that sawing is done only on two opposite faces. Since the grades are generated from a truncated distribution, the grade generation process forces the recovery of high-grade lumber in live sawing to be in lower proportion than grade sawing. Previous test of the grade generation process [10, 11] confirms this behaviour while closely estimating the volume of grade recoveries as compared to an actual empirical study.

Operationally, once an entity is generated and its basic attributes defined (i.e., the species, diameter, and length), the table look-up function included in the program is used to scan the lumber grade recovery expectation tables. Grade assignments are based on species, diameter, log grade and the board's width. Currently, eight hardwood species of different diameter ranges and log grades are supported in the program's default experiment file.

In edging the boards, a modified version of the formulations presented by Kersavage et al. [5] for a conventional two-saw edger was used. Board sides to be edged are ripped half of their length. Depending on its original location in the log and the log breakdown method employed, a board may be edged on two sides, on one side only or it may also by-pass the entire edging process. In particular, boards that may by-pass the edging process are those sawn from the fourth face in an all-around grade sawing. Board trimming is based on the trimming allowance provided by the user.

SYSTEM INPUT AND OUTPUT

A menu-driven, front-end interface is attached to the system for the interactive entry of information. The required input parameters and program flow of this interface is shown in Figure 4. The data input module is coded in SIMAN's subroutine PRIME which is automatically activated at every program execution. Besides the interactive input of information, the program has the capability to access appropriately defined log inventory data files. Such data files can be created using the input interface or by any other programs provided the input-output structure is compatible. A discussion on this data sharing methodology is presented in another section of this paper.

During the input session, the following system characteristics are defined by the user: 1) log attributes, 2) physical mill attributes, 3) processing parameters and procedures, 4) product consideration, and 5) simulation run termination method. We note that the log attributes (e.g., diameter) are assigned to log entities in several manners. As will be described later, log parameters specified from a log data file are assigned to the entities. The file may therefore be created in a way that it can represent the desired order of inputs, such as by diameter class or by species, or it may also be created to represent a random ordering of the attributes. If there is no available log data file, a user may generate the attributes by sampling from some statistical distributions (e.g., normal, triangular, etc.). In this case, it is assumed that the user knows the type of statistical distribution to be used and the values of its parameters, such as mean and standard deviation, as in the case of a normal distribution.

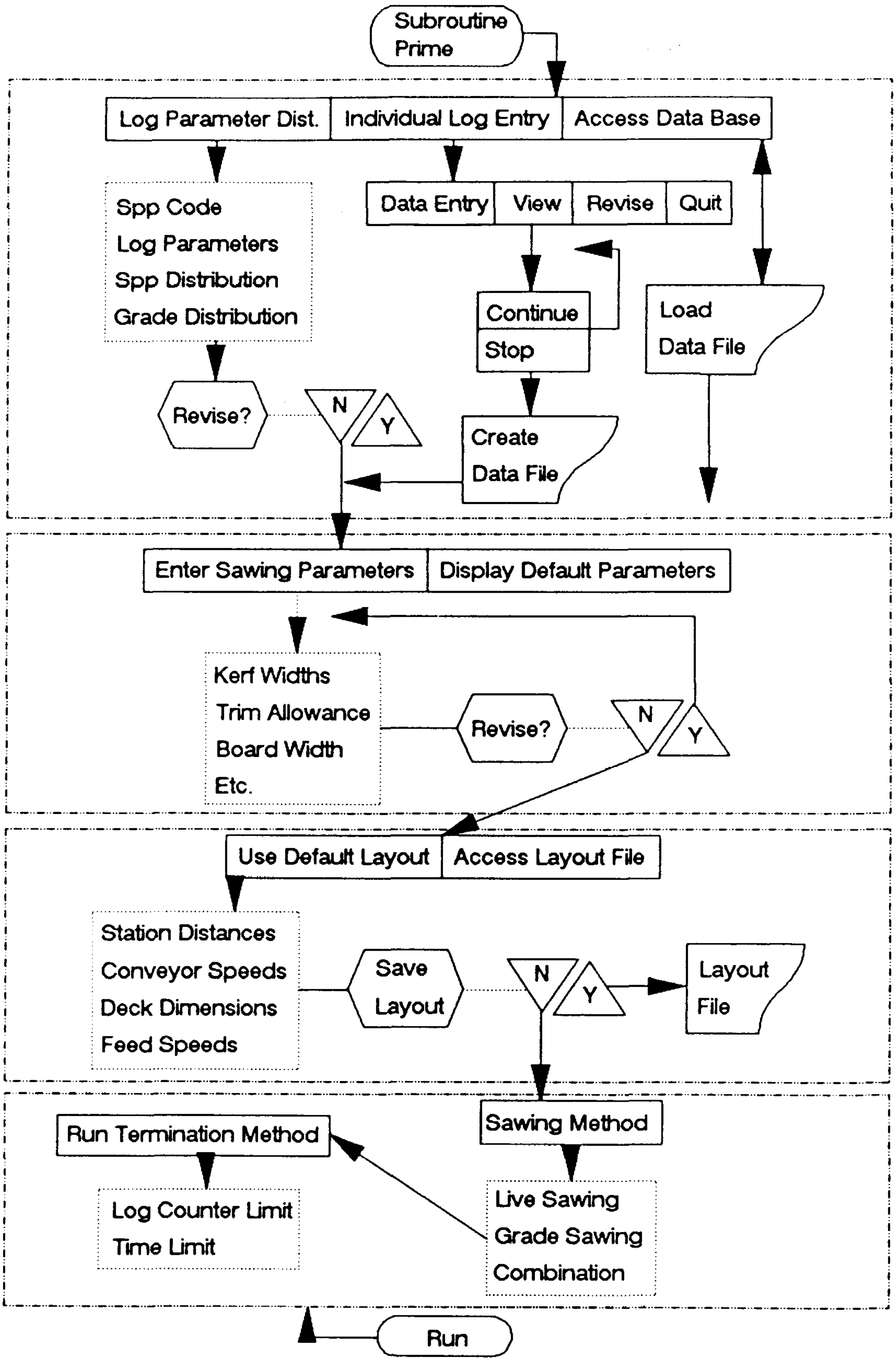

Figure 4: Program flow of the data-entry interface.

Except for the log attributes, default values for other parameters are provided in the program. These default values are contained in the program's experiment file and the data block of the subroutines. Once a user opted to override the default values, e.g., log arrival rate, the program changes the appropriate value in the default parameter set. In some cases, it overrides the default values originally specified in the program's common variable array.

To avoid the repetitive entry of enormous amounts of data, a user can save the information as data files. Thus, he can configure his sawmill's layout only once and use it for different log sawing schedule scenarios. Similarly, he can store a set of logs for sawing and experiment on different layout configurations.

At the end of the data entry session, the user is prompted for the method of terminating his simulation experiment. Two methods are currently defined in the program: 1) Log counter limit, and 2) Sawmill operation time limit. In the first method, the user specifies the number of logs he wants to process. The model then activates a log counter and the simulation run is terminated after sawing the last log. In the second method, the user enters his planned period of operation, e.g., 480.0 minutes or one day. Simulation run is automatically terminated upon reaching this time limit.

The model has a customized output processor which computes and writes the results in an output file. The summary report includes, among others, the following information: 1) total volume and number of logs processed, 2) total volume of lumber produced, 3) total sawmill operating time, 4) average sawing time of logs, 5) utilization of machines, 6) queue/buffer statistics, and 7) lumber volume by grade and species.

Depending on what particular aspect of sawmill operation the user wants to investigate, he can interpret the results from several vantage points. For example, if one specified the log counter limit as his run termination method, the model provides him the sawing time required to process all the logs. Likewise, he can record the queue length comparisons for several sawmill layouts or the utilization of resources from different log breakdown policies.

For purposes of illustrating some of the capabilities of the simulator, we present in Tables 1 and 2 the results of simulating a generic hardwood sawmill. Table 1 presents some output statistics while Table 2 shows a summary of some of the input and output of materials. In this example run, we simulated a live sawing process corresponding to 400 minutes of sawmilling operation.

It is important to note at this point that the interpretations of the simulator's output, such as those shown in the Tables, are subject to proper simulation output analysis. Sawmilling operations can be regarded as non-terminating systems where there is no natural basis for choosing the starting condition or length of simulation run. Sawmill simulation analysts are often interested in a steady-

Table 1: Output statistics from the hardwood simulator

Parameter, unit	Average	Std. Dev.	Minimum	Maximum
Headsawing Time (min/log)	1.42	.17	1.04	1.95
Log deck queue (pcs of logs)	29.44	1.82	0	30.0
Edger deck queue (pcs of lumber)	6.31	4.11	0	18.0
Headrig utilization	.78	.42	0	1.0
Edger utilization	.99	.06	0	1.0

Total time of simulation = 400.0 minutes state behaviour of the system or the system response over a long period of time. In Table 1, for example, the average queue lengths and utilization of machines can be misleading as they include observations from an empty and idle state. A number of methods are available in order to reduce the initial condition bias in analysing non-terminating systems [7, 15]. To accommodate future analysis of simulation results, we provide an option in the simulator for specifying the number of replication experiments that an analyst may want to gather and, as noted earlier, an option for specifying the length of the simulation run. In addition, some of the time-persistent variables such as queue lengths and headsawing time are written in separate output files which can be subjected to analysis using SIMAN's output processor. Furthermore, we note that the headsawing time value in Table 1 can be interpreted properly without regard to the steady-state condition of the system. The headsawing time value represents the sum of the elemental time components of processing the log, starting from log loading into the carriage and ends with the unloading of the dog board. In the model, headsawing time is collected independent of the queue status on the log deck and the status of other downstream operations. It largely depends on the log attributes, sawing methods, and feed speeds.

Table 2: Sample input and output of materials simulated for a generic hardwood sawmill.

Input Materials:	
Total log volume, cu. meters	51.39
Number of Aspen, logs	108
Number of Red Oak, logs	65
Number of Basswood, logs	98
Log Grade No. 1, logs	4
Log Grade No. 2, logs	41
Log Grade No. 3, logs	227
Output Materials:	
Total pieces of lumber	2317
Total volume of lumber, cu. meters	31.07
FAS volume, cu. meters	.47
SELECTS volume, cu. meters	.61
COMMONs volume, cu. meters	30.0

The output given by the simulator is all in numerical form. While it is possible to present an animation of the system being simulated using SIMAN/CINEMA [15], we leave this option to the discretion of users. Animation truly delivers a more believable representation of the simulated system as illustrated by Hall et al. [4] and Kline and Weidenbeck [6]. It is a very valuable tool for debugging and verifying the model. However, animating a simulation model can be very expensive, not only in terms of the computing and other technical requirements but also in terms of cost of the animation software [18]. In the simulator that we developed, we intend to have a ready-to-use and stand-alone system which can be operated by users with minimum expertise and computing capabilities. Since the simulator should be able to support real-time dynamic decision making, the process can be accelerated by presenting the results in numerical rather than animated form.

AN INTEGRATED DECISION SUPPORT SYSTEM

As previously mentioned, the simulation model can be integrated with other modules to form an over-all computer assisted, decision support system for hardwood sawmills. In the earlier work of Mendoza et al.[12], a material inventory system called CEASaw was developed. The CEASaw module specifically monitors and keeps record of the log inventory in a log yard. Operationally, an analyst may want to examine in advance the overall system behaviour if he processes the logs in inventory. Thus, without physically sawing the logs, the user can run the simulator to determine the expected lumber recovery and overall sawmill performance; both vital information in sawmill production planning and management.

Figure 5 provides an overview of how the simulator is integrated with CEASaw and other similar modules. In the figure, we note that the sawmill database files are a collection of files that represent the physical and dynamic characteristics of the sawmill such as the sawmill layout and machine specifications. These files are accessed following instructions from the users in lieu of using the default specifications contained in the model's experiment frame. In the absence of any log inventory module, users can create large data files using text editors (or the model's input interface) that are capable of writing the files in ASCII form.

Operationally, CEASaw serves as a tool to monitor log inventory while the simulator serves as the "look-ahead" tool in assessing the overall sawmill performance. Functionally, the user inputs the log parameters coming into the log yard using CEASaw. The program then rewrites the data in a file which is also recognizable in terms of the simulator's input specifications. The log data base file contains the following information for each log: species code, log grade, log diameter (small and big end), and length. The simulator sequentially reads the data as logs are created and sawn and assigns them to the logs as attributes. The log data base file may contain random mixtures of logs. For better decision making purposes, log data may be entered or arranged in certain sequences to represent desired sawing schedules.

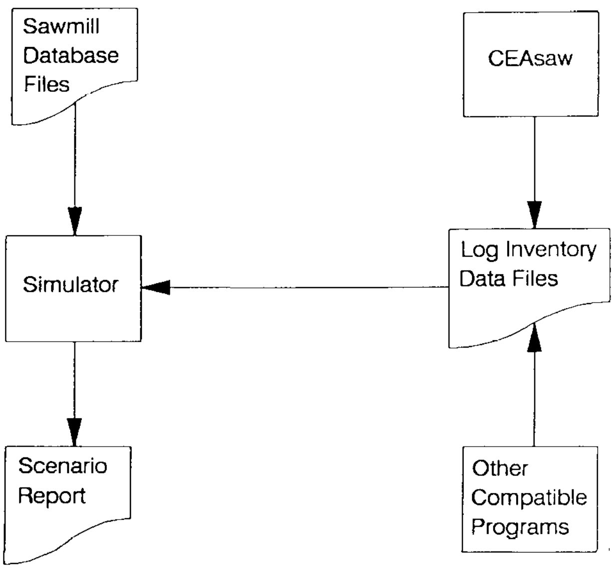

Figure 5: Simplified block diagram of the information flow in a decision support system.

With its ability to estimate processing time, the simulator could be used in formulating time-based production schedules to meet projected demands of lumber products. In the recent work of Mendoza et al. [13] for example, a linear programming-based production planning model was developed to determine the optimal mixture of logs that would satisfy a given demand. The simulator was then used to estimate the required sawing time of the logs in order to establish the work and sawing schedules of a sawmill.

CONCLUSION AND REMARKS

In this paper, we described some of the essential features of a simulation model which can be integrated within a management decision support system. The simulator combines the basic facets of hardwood lumber manufacturing including the integration of sawmilling logic or sawing policies, material flow system, and the characteristics of raw materials and lumber products. Initial validations of some of the components of the model indicate satisfactory performance [10, 11]. In these validations, the performance of the model was compared to the DESIM system [2] by utilizing similar input information. The simulator was found to have the capability to estimate within an acceptable level of accuracy the sawing time of logs, the piece-count and volume of material inputs, and the volume of the resulting lumber products. At present, work is still being done for actual implementation of the system in a real-life lumber production setting. In this proposed implementation, we plan to integrate both the CEASaw module and the simulator and determine if they can realistically represent the operation of a real hardwood sawmill and evaluate their utility in terms of aiding mill managers in a real-time decision making environment.

Some components of the simulator were developed using the SIMAN simulation language while the other components (the sawing logic subroutines) were coded using FORTRAN 77. The block diagram model of the simulator consists of 90 block elements while the experiment file occupies more than 24 KB of memory. The event subroutines and the data-entry interface were written in more than 1,900 lines of FORTRAN codes. The executable form of the model was compiled to run on IBM PCs and compatible computers. Previous runs conducted indicate satisfactory computing time and largely depends on the complexity of the system being simulated. For example, the run time for a live sawing operation in a conventional sawmill (with one debarker, one headrig, one edger, and one trimmer) takes less than five minutes to simulate 480 minutes of operation on a 286 micro-processor.

ACKNOWLEDGEMENT

The authors would like to thank the reviewers for helpful comments and for bringing to our attention a number of literature related to this research.

REFERENCES

[1] ADAMS, E. L. 1984. DESIM User's Manual: A procedural guide to designing and simulating hardwood sawmill systems. USDA General Technical Report NE-94.

[2] ADAMS, E.L. 1988. Testing DESIM for designing and simulating the operation of hardwood saw mills. For. Prod. J. 38(7/8):41-45.

[3] AUNE, J. E. 1974. System simulation – a technique for sawmill productivity analyses and design. The Forestry Chronicle (50)2: 66-69.

[4] HALL, R. J., D. J. BONHAM and D. B. JEWETT. 1988. Simulation of small-log eastern Canadian softwood sawmills using a discrete event simulation language and animation. In: Society of Computer Simulation, Simulators Conference V, Orlando, FL.,Vol.19, pp 267-271.

[5] KERSAVAGE, P. C., M. SAVSAR, and R. J. MEIMBAN. 1990. A mathematical analysis to determine the volume of residues and lumber produced in the sawmill edging process. Wood Fiber Sci. 22(3): 271-282.

[6] KLINE, D. E. and J. K. WIEDENBECK. 1989. Design and evaluation of hardwood processing facilities using simulation/animation. ASAE #89-7613. 17p.

[7] LAW, A. M. and W. D. KELTON. 1991. Simulation modeling and analysis. 2nd ed. McGraw-Hill, Inc.

[8] MARTIN, J. 1971. General purpose sawmill simulator for hardwood sawmills in the Northeast. M.S. Thesis, School of Forest Resources, Pennsylvania State University, University Park, PA.

[9] MARTIN, P., A. BOUZIMEKIS, and C. SALES. 1988. Tools for aiding decision making in the European sawmills. In: Proceedings, 9th International Wood Machining Seminar. University of California-Berkely, October 10-12, 1988.

[10] MEIMBAN, R. J. 1991. Simulation of hardwood sawmilling operations. Ph.D Dissertation. School of Forest Resources, The Pennsylvania State University, University Park, PA.

[11] MEIMBAN, R.J., P.C. KERSAVAGE, T.P. HARRISON, and G. A. MENDOZA. 1991. Simulation of hardwood sawmilling operations. In: Proceedings, 1991 Symposium on Systems Analysis in Forest Resources, Charleston, SC, March 6-7 (in press).

[12] MENDOZA, G., W. SPROUSE, W. LUPPOLD, P. ARAMAN, AND R. MEIMBAN. 1991. An integrated management support and production control system for hardwood forest products. Computers in Industry 16(4): 343-351.

[13] MENDOZA, G. A., R. J. MEIMBAN, P. A. ARAMAN and W. G. LUPPOLD. 1991. Combined log inventory and process simulation models for the planning and control of sawmill operations. In: Proceedings, 23rd CIRP International Seminar on Manufacturing Systems. June 6-7, Nancy, France.

[14] PEGDEN, C. D. 1986. Introduction to SIMAN. Systems Modeling Corporation, State College, PA.

[15] PEGDEN, C. D., R. E. SHANNON and R. P. SADOWSKI. 1991. Introduction to simulation using SIMAN. McGraw-Hill, Inc.

[16] SAVSAR, M. 1982. A simulation model for sawmill operations. M.S. Thesis, Penn State University, University Park, PA.

[17] SAVSAR, M. and P. C. KERSAVAGE. 1982. Mathematical model for determining the quantity of materials produced in sawmilling. Forest Prod J. 32(11/12):35-38.

[18] SWAINE, J. 1991. Simulation software survey. OR/MS Today, October, 1991, pp 81-102.

[19] VAUGHAN, C. L., A. WOLLIN, K. McDONALD, and E. BULGRIN. 1966. Hardwood log grades for standard lumber. FPL No. 63. Madison, Wisconsin.

[20] VAN WYK, J.L., and G. ENG. 1986. Computer-aided design and evaluation. In Proceedings: Conversion Planning Conference. April 8 - 11, 1986. Rotorua, N. Zealand. FRI Bulletin No. 128.

[21] WAGNER, F. G. and F. TAYLOR. 1983. SPSM –A Southern pine sawmill model. Forest Prod J. 33(4): 37-43.