COMBINED LOG INVENTORY AND PROCESS SIMULATION MODELS FOR THE PLANNING AND CONTROL OF SAWMILL OPERATIONS

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ABSTRACT

A log inventory model and a real-time hardwood process simulation model were developed and combined into an integrated production planning and control system for hardwood sawmills. The log inventory model was designed to monitor and periodically update the status of the logs in the log yard. The process simulation model was designed to estimate various sawmill performance parameters taking into account the different static and dynamic features of a sawmill. Besides the log inventory and simulation models, the system also has a front-end spreadsheet-based optimizer for determining optimal log input mix. Thus, the integrated system has the capability to determine the optimal lumber production schedule (including log input mix) which is also operationally feasible on real-time.

BACKGROUND

The operations and decision-making complexities involved in a saw-milling company are no different from other manufacturing enterprises. From the felling of trees in the forest to the distribution of lumber products, the raw material undergoes various stages of processing. In the forest, a tree is selected based on its quality and age and marked for felling. A felled tree is then bucked into commercial lengths and transported to the mill log yard. Based on customer demand specifications, logs are selected and scheduled for processing.

The nature of customer demand specifications, the quality and volume of logs in inventory and the processing limitations of the mill constitute some major challenges to a mill manager. In the sawmill industry, customers place orders according to species, volume, grade and dimensions of lumber. To meet these customer specifications, a mill manager has to select what logs to process, decide on the sawing procedures and schedule production to meet the demand on time and at a minimum cost.

Figure 1 illustrates a few of the decision tasks involved in lumber manufacturing. At the aggregate or corporate planning level, over-all production goals are set based on the expected market demand, mill capacity and supply of raw materials. At the lower level, tactical plans are set and production schedules are determined based on company goals. The major activities cover a wide range -- from maintanance and monitoring log inventory to the development of sawing schedules that meet anticipated demands.

Most of the day-to-day action takes place at the operational level. The sawmill manager initiates production to meet the schedule specified at the corporate and tactical levels. He schedules the kind and amount of logs to saw, communicates the product specifications to the sawyer, or suggest possible work overtime and other schedule revisions. Critical to this operational plan are the details of log conversion and lumber cut-up operations. Depending on the sawyer's procedure and the log grade, each log may or may not produce the demand volume and mixture of lumber grades. The sawyer has to decide, on-line, the cutting patterns by taking into account the potential trade-off between the resulting lumber quality, volume, and production time.

In this paper, we present a system to facilitate the planning and control of sawmill operations. The tools that we developed focus on the tactical and operational level of production planning. Comprising the system are program models for log inventory, an optimizing component to determine the combination of logs for sawing and a simulation system to assess the sawmill scenario and schedule adjustments.

SYSTEM STRUCTURE

The discussion presented above describes the information needs, tasks, and key decisions at various phases of the sawmilling process. Integrating all these information into a comprehensive production schedule involving a variety of inputs and outputs is a difficult but strategically significant task. A poorly designed production schedule could result in significant wastes, loss in product recovery, and inefficienct allocation of time and machine resources -- all or a combination of these could result to enormous economic losses. On the other hand, a carefully designed production schedule could potentially improve the overall economic performance of the sawmill. Such a plan is almost impossible to develop without the help of some kind of information processing and scheduling tools.

This paper describes a system designed purposely to systematically analyze the entire sawmilling process. The primary objective of the system is to develop a comprehensive production schedule which is not only optimal from a broad, company or sawmill-wide perspective, but also operationally feasible. This could be achieved by combining a log inventory model with an optimization capability, and a real-time process simulation model. Operationally, the system works as follows: First, an optimization model determines the “best” log input mix to process in order to satisfy periodic lumber demand. This log mix is optimized under constraints based on average machine, human, and other resource capacities. Information on log input mix then becomes an input to the process simulation model to create production schedules and examine on-the-job performance of the various aspects and phases of the entire sawmill. A descriptive representation of this process and the overall structure of the combined log inventory and process simulation model is described in Figure 2.

The sawmill process simulation is modelled using SIMAN (Pegden, 1986). The components of this simulation model including other elements of the combined optimization-simulation model is also shown in the figure.

Log Input Optimizer

The sawmill manager is constantly faced with the problem of determining what mix of logs should be taken out from the log yard to the log deck for subsequent processing. Decisions on the type of logs (by species and grade) to be sawn on any given time depend on the demand for specific lumber types (by species and grade) and the amount of lumber stored in the inventory. This is particularly true for sawmills which is highly market-responsive.

The log input decision problem facing the sawmill manager which must operate within the corporate objective of maximizing economic efficiency can be formulated as follows:

$$\text{Maximize } R = \Sigma P_k Y_k - \Sigma c_{ij} X_{ij} + \Sigma m_{ij} Q_{ij}$$

subject to:

$$Q_{ij} + X_{ij} \leq L_{ij} \qquad \text{for all } i,j$$

$$Y_k \leq D_k \qquad \text{for all } k$$

$$\Sigma\Sigma\; r_{ijk} X_{ij} - Y_k = 0 \qquad \text{for all } k$$

where: R = economic return

P_k = price of lumber grade k

C_{ij} = cost of processing (sawing) log grade <u>i</u> of size <u>j</u>

M_{ik} = price of log grade <u>i,</u> size j sold in the market

Y_k = amount of lumber grade <u>k</u> produced

Q_{ij} = amount of log grade i, size <u>j</u> sold in the market

X_{ij} = amount of log grade <u>i,</u> of size <u>j</u> sawn

L_{ij} = amount of log grade <u>i,</u> of size <u>j</u> stored in the inventory

D_k = estimated production requirements for lumber grade <u>k</u> after adjusting for the quantity of demand and amount lumber stored in the inventory

r_{ijk} = lumber recovery rate in percent, of processing log grade <u>i,</u> size <u>j,</u> into lumber product <u>k</u>

The log input decision problem described above is a prototype log allocation problem typically found in many sawmills. One of the concerns in lumber manufacturing is what log mix should be processed to meet a lumber demand on a daily or weekly basis. It is also common among sawmills to merchandise their logs instead of processing them into lumber. Hence, sawmill managers are often faced with the problem of deciding what type of logs (by species, grade and size) should be allocated to the log market for merchandising, and what mix of log input (by grade, species and size) should be processed to meet actual and projected demands for various lumber products. For more detailed description of the log allocation prototype, readers are referred to Mendoza, et. al (1991).

A solution to the optimization problem above provides a production scenario that meets corporate objectives and is also within the limitations aggregately defined by the constraints. In a planning sense, the production scenario should be implementable. However, from an actual operational perspective, the production scenario may prove to be impossible to carry out or may require production beyond the limits of real-time production inputs such as: queue lengths, sawing rate, trimming-and edging capacities, and other actual operational constraints. In view of these operational concerns the real-time process simulation model becomes both critical and operationally significant. From a tactical planning standpoint, it is therefore necessary to systematically balance the overall production targets with the actual operational environment and real-time capacities of the entire sawmill. Before presenting this operational linkage, the simulation model is described in the next section.

The Process Simulation Model

The log input optimizing model formulates the sawmill activity schedule at a tactical level. Operationally, this schedule should serve as a guide to the sawmill manager in determining the mill's daily production activity. While a multi-period production planning model could be formulated for this purpose, such model could not take into account the random order of inputs and the stochastic nature of raw materials and machine breakdown. For purposes of developing a time-based production schedule, the sawmill simulation model of Meimban et al (1991) can be used.

The model can represent a wide array of sawmill designs with standard processing centers and sawing procedures. The process flow of the sawmill is depicted in SIMAN block diagram codes while the lumber conversion logic are modelled as event subroutines. The system maintains a list of events for cutting slabs, breaking down the slabs into flitches or boards, edging the boards into proper width, and trimming the boards to final lumber lengths. Unlike other processing facilities, a sawmill's primary saw (called the headrig) can perform a variety of log breakdown procedures. For example, a single band saw is used to live saw (continous slicing) or grade saw (around-and-around sawing). The same machine may also be employed for cant sawing or sawing relatively large rectangular blocks. Such operation flexibility are modelled by using indicator variables (the global variables in SIMAN) that dictate the type of event subroutines to be called. Once an entity (log) arrives in a processing station, the value of an indicator variable is determined based on the log's dimension and grade. This variable assignment can also be initialized by the user to suit a desired sawing specification.

In some sawmills, several headrigs are installed in parallel and perform specialized cutting procedures for higher production. To accommodate these possible mill designs, the processing centers are modelled as macro-stations. The stations comprising a macro-submodel are similar in structure but differ in the type of machine involved, queue capacities, and the governing event subroutine.

The simulation model is front-ended with a menu-driven data-entry interface. Thru the interface, a user can create and load the sawmill's lay-out file and machine specifications, product specifications, and the data base file that contains the log input schedule developed from the log optimizer. Among the model's output include: 1) the simulated number and' volume of logs processed (by species and grade), 2) sawmill operating time, 3) lumber output by species, grade, and volume, 4) equipment/resource utilization, 5) production delays, and 6) status of buffer decks (queues).

The simulation model was primarily intended to measure the performance of different sawmilling systems. However, the output variables could also be used to create activity schedule, both in the tactical and operational levels.

Previous tests of the model involving a simulation of an actual 10-hour lumber production operation indicate satisfactory run times ranging from 10 to 15 minutes on a 286 IBM PC (Mendoza, et al., 1991). This computational performance and the relative ease of data entry offer some clear indications of the model's potential as a real-time control tool.

Lumber Production Scheduling System

The integration of the models for the purpose of developing lumber production schedules is described in Figure 2. With information on log inventory and lumber demand, the log input optimizer generates a log input mix for subsequent processing.

Of particular interest in developing production schedule is the time needed to convert the log inputs, X_{ij}, into lumber products, Y_k. Given the log list in the inventory, the S set of log pieces could be sorted and separated from the log inventory. The required production period (T), which is not represented in the log optimizer, could be estimated by processing the S logs using the simulator. This schedule simulation procedure goes thru the following steps: 1) Set the simulator counter to S. 2) Process an $\underline{s}$ log ($\underline{s} \varepsilon$ S) and update $\underline{s} = \underline{s} + 1$. 3) If $\underline{s} <$ S, go to 2; otherwise continue. 4) Set $T = T_{now}$; Stop. T_{now} is the SIMAN variable that denotes current simulation time.

A variation of the above scheduling procedure may occur if the mill has enough production time to accommodate other orders. In this case, the variable of interest becomes the additional $\underline{s'}$ logs that could be accommodated in the schedule. If t is the simulated time to process the original log schedule (T or T_{now} in the previous step), one can generate the additional log set as follows: 1) Set $T_{fin} = T - t.$, 2) Process an $\underline{s'}$ log and update simulation clock (T_{now}). 3) If $T_{now} < T_{fin}$, go to 2; otherwise continue. 4) List the $\underline{s'}$ logs processed. Stop. T is the planned production period and T_{fin} is the SIMAN variable that denotes the ending of the simulation run.

Results from the process simulation model can provide many vital information needed by the sawmill manager in the planning and control of mill operations. For instance, once the required production period T is estimated, he/she can translate this in terms of daily work schedule and determine if it is within the necessary due date. On the more detailed level of operational control, the simulation results can help the manager identify potential bottlenecks, estimate queue lengths, and consequently determine the lumber output mix. Under these conditions, the simulator could be used on a daily basis, where end-of-day actual production status becomes the next day start-up conditions of the simulator. Thus, the sawmill manager can plan proactively, enabling him to rationally respond with appropriate adjustments in areas where they are expected to be necessary. For example, he/she could plan to expand production thru overtime work if simulated lumber production rate needs to be increased in response to lumber demand. Adjustments on log input mix can also be made if simulated lumber production based on a combination of log inputs does not meet lumber demand.

SUMMARY AND CONCLUSIONS

Advances in computer technology are beginning to find their way even in conservative manufacturing industries such as the lumber industry. More and more, sawmills are adopting computer-based techniques as a useful tool both in planning and in day-to-day operation of their mills. As the use of computer-based manufacturing becomes more widespread, the need to develop user-oriented software in the lumber industry has likewise become a necessity.

In this paper, a combined log-inventory and process simulation model is described. The model addresses some typical planning and decision problems faced by many sawmills. The general model structure offers a novel approach that accommodates the simultaneous consideration of broad sawmill-wide goals, as well as the day-to-day operational constraints faced by the sawmill manager.

The system was purposely designed to be user-oriented, menu driven and easy to use. It has a convenient data entry interface including a highly user-friendly optimization routine which is built within a spreadsheet environment. The system was developed with no data manipulation or programming effort required from the user. The options, conveniently described as menus, fully automates all computations and data transfers, including options, to view and edit input and output results.

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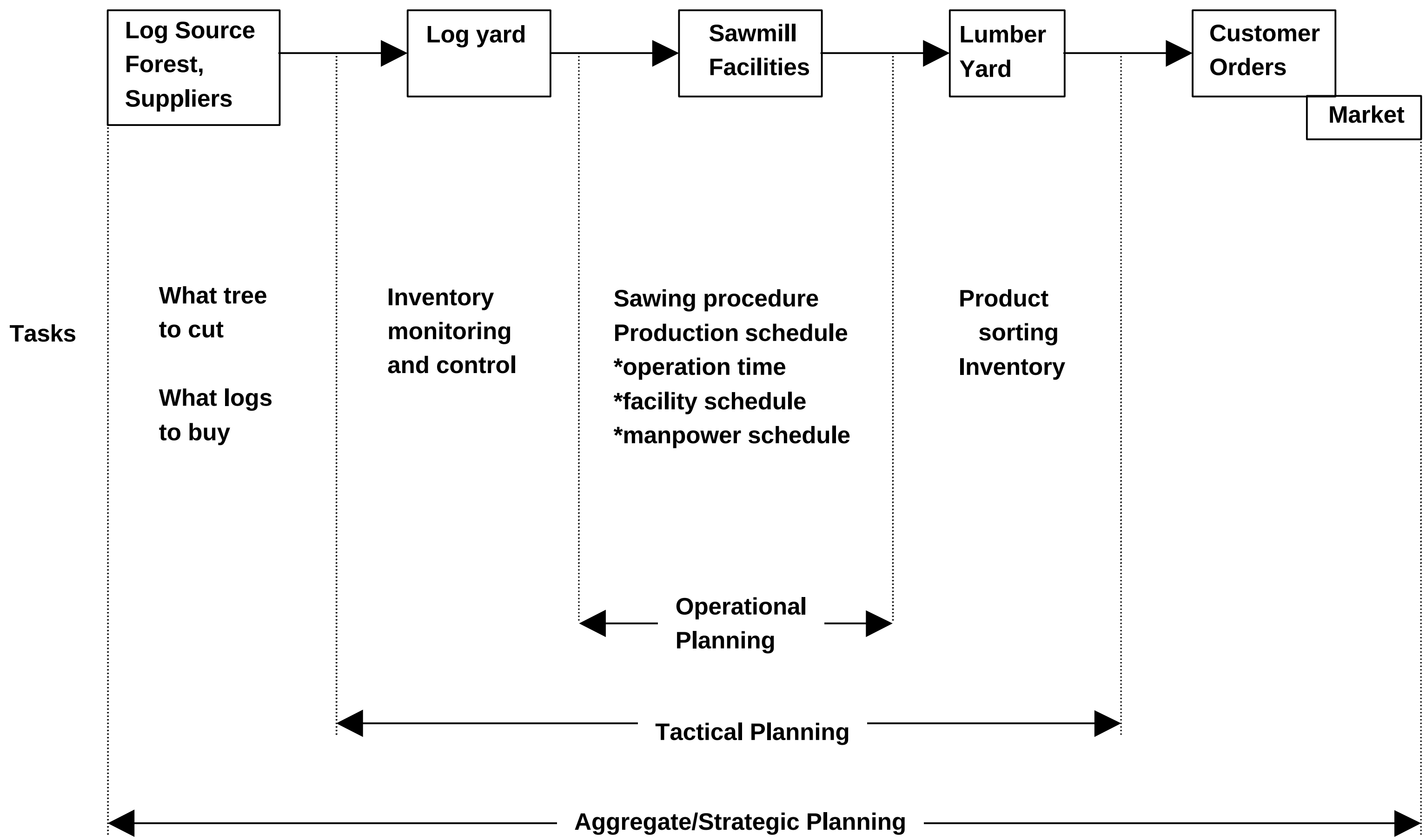

Figure 1: Phases, scope, and tasks in lumber manufacturing

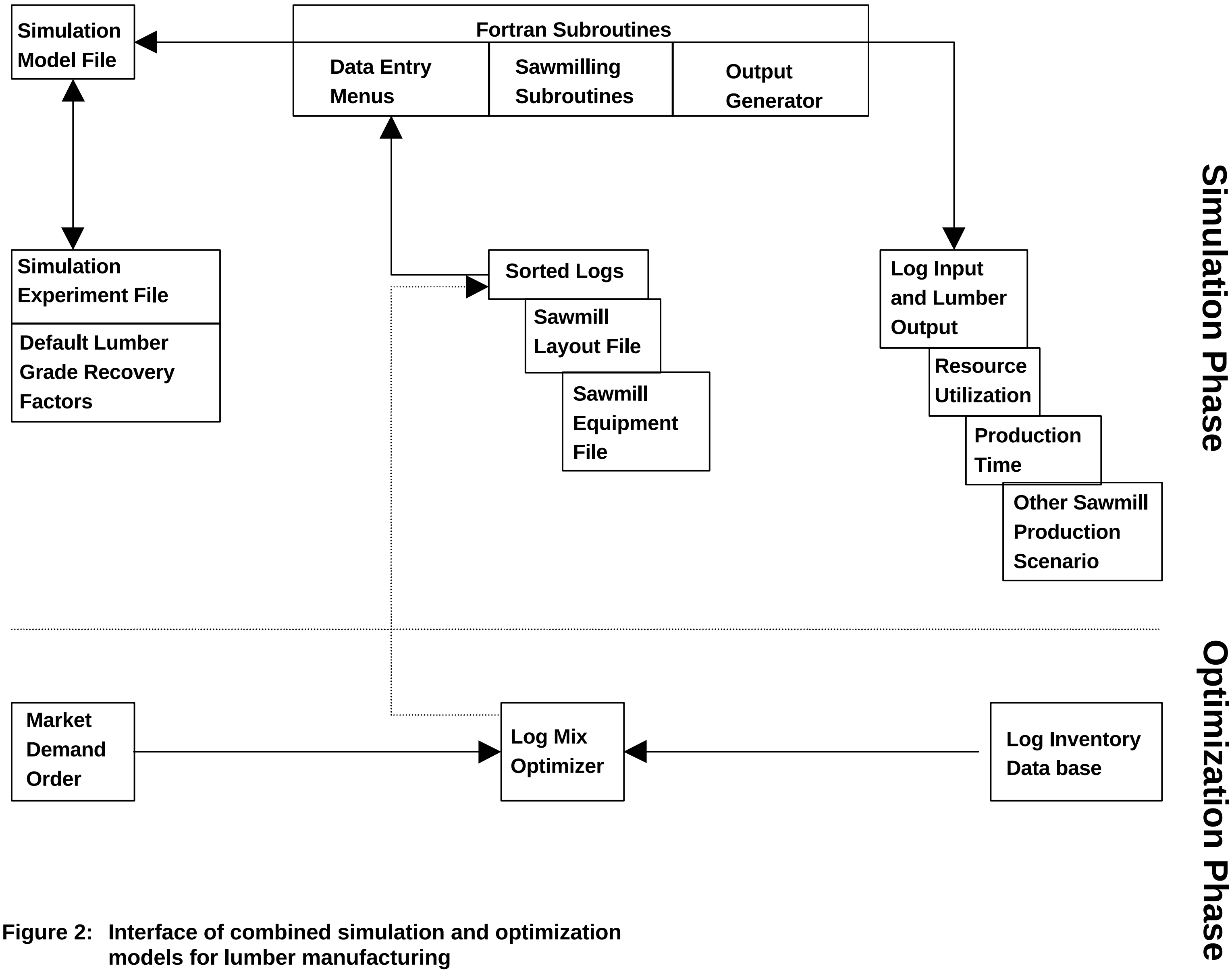

Figure 2: Interface of combined simulation and optimization models for lumber manufacturing

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