COMBINING SIMULATION AND OPTIMIZATION MODELS FOR HARDWOOD LUMBER PRODUCTION

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ABSTRACT: Published literature contains a number of optimization and simulation models dealing with the primary processing of hardwood and softwood logs. Simulation models have been developed primarily as descriptive models for characterizing the general operations and performance of a sawmill. Optimization models, on the other hand, were developed mainly as analytical tools for prescribing optimal production plans but with minimal concern on real-time day-to-day operations of a sawmill. This paper describes a combined simulation and optimization model that considers both the determination and the implementation of optimal production schedules. Emphasis centers on the performance and utilization of various machine centers, including production delays, buffer decks, queue capacities, operating time, and equipment and resource utilization.

INTRODUCTION

Faced with the dual problems of dwindling sources of quality raw materials and competition from synthetic wood substitutes, the U.S. hardwood forest products must seek to improve its productivity and processing efficiency. Such improvement should be attained at various production stages; from bucking of trees into combinations of log lengths to the production and distribution of finished products. Within each production stage, a number of activities must be performed; the results of which significantly affect other downstream activities. Hence, in order to fully achieve the most efficient (not only in terms of yield but also in terms of economic returns) utilization of raw materials and the subsequent production of finished products, the entire processing and production process must be systematically optimized.

The literature contains a number of significant methodological developments focusing on primary and secondary processing of wood products, both for softwoods and hardwoods. These previous works could be categorized either as optimization or simulation models. Optimization models are in general more narrowly focused addressing specific production phases such as; log bucking (Sessions et al 1989; Pnevmaticos and Mann, 1974; Eng. et al., 1986; Briggs, 1980), log allocation (Pearse and Sydneysmith, 1966; Mendoza and Bare, 1986; Maness, 1991), and lumber manufacture (McPhalen, 1978). Simulation models, on the other hand are generally more descriptive and designed to look at sawmill-wide concerns and problems (Richards et al. 1980).

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This paper describes a procedure combining optimization and simulation models for closely examining the operations of a hardwood sawmill. The procedure takes advantage of the prescriptive nature of optimization models and the broad system-oriented perspective of a simulation model.

OPTIMIZATION MODEL

Due to the inherently rigid nature of optimization models, it is not possible to develop a generic model that could accommodate all sawmill scenarios. Hence, instead of formulating a general optimization model, a more narrowly defined but apparently typical problem faced by many sawmills is addressed in this paper. This problem involves the determination of the optimal log input mix to be processed to satisfy lumber demands. In addressed to satisfying lumber demands, the problem also includes merchandising logs to local log buyers.

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:

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

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

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

where: R = economic return

P_k = price of lumber grade k

C_{ij} = cost of processing (sawing) log grade i, of size j

m_{ik} = price of log grade i, size j sold in the market

Y_k = amount of lumber grade k produced

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

X_{ij} = amount of log grade i, of size j sawn

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

D_k = estimated production requirements for lumber grade k 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 i, size j, into lumber product k

The above optimization problem provides a production scenario that meets the limitations aggregately defined by the constraints. In a planning sense, the production scenario should be implementable. However, operationally, the optimal production scenario or schedule may require production beyond the limits of real-time production capacities such as sawing rate and trimming and edging capacities. In other words, it may be necessary to systematically balance the overall production targets with the actual operational environment of the sawmill. Under these operational concerns, the real-time process simulation model could be used to test the implementability of the production schedule. Consequently, a realistic and optimal production schedule can be generated by directly linking the optimization and process simulation models. Before presenting this linkage, the process simulation model is described in the next section.

THE PROCESS SIMULATION MODEL

The optimization model presented in the previous section formulates the sawmill activity schedule at a strategic and tactical level. Operationally, this schedule should be translated by the sawmill manager into the sawmill's daily production activity. While a multi-period production model could be formulated for this purpose, such models could not take into account the random order of inputs, stochastic nature of raw materials and machine breakdown (Sampson and Fasick, 1970). Instead, a sawmill simulator developed by Meimban, et al. (1991) is adopted as a daily scheduling tool.

The model can simulate a wide array of sawmill designs with standard processing centers. It supports, as event subroutines, the commonly employed log and lumber machining procedures. Structurally, the different processing centers with functionally similar equipment were modelled as macro-stations using the SIMAN simulation language (Pegden 1986). Each station may call a set of sawing rules which in practice depend on the dimension and grade of the log or lumber on customer order specifications. The system is equipped with a menu-driven data-entry interface which virtually insulates the user from any data manipulation or programming effort. Thru the interface, the user loads the sawmill's lay-out file and machine specifications, the current product specifications and the database file containing the log input schedule generated by the optimizer. Among the systems output include: the simulated number and volume of logs processed (by species and grade), sawmill operating time, lumber output by species, grade and volume, equipment utilization, anticipated production downtime, and status of buffer decks (queues). Previous tests of the model to simulate actual lumber production system indicate satisfactory run times ranging from 10 to 15 minutes when simulating relatively complex sawmilling set-up and operations (Mendoza, et al 1991; Meimban, et al. 1991) . This performance and the relative ease of data entry make the model useful as a real time scheduling tool.

INTEGRATED MODEL: THE LUMBER PRODUCTION SYSTEM

The lumber production scheduling system is designed to operate under the model structure described in Figure 1. On the other hand, the procedural steps involved in developing a lumber production schedule is illustrated in Figure 2. With information on log inventory and lumber demand, the log input optimizer generates a log input mix for subsequent processing. This combination of logs could be sorted and separated from the log inventory. This log mix becomes an input to the process simulation. Results from the process simulation will provide many of the significant information needed by the sawmill manager in the actual operation of the sawmill. For instance, the simulation results will help the manager identify potential bottlenecks, estimate queue lengths, and consequently determine the lumber output mix. Under these conditions, 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, the manager could plan to expand production thru over time work schedule 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 does not meet lumber demand.

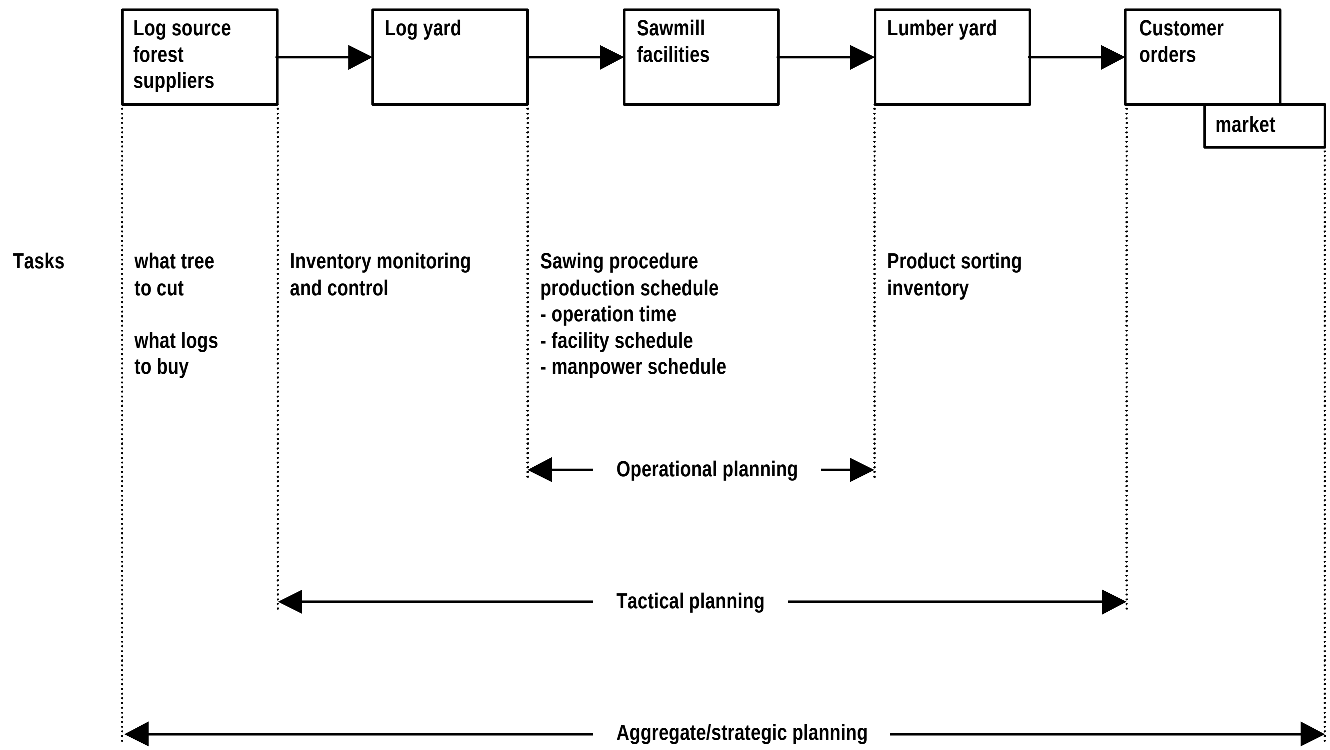

Figure 1: Phases, scope, and tasks in lumber manufacturing

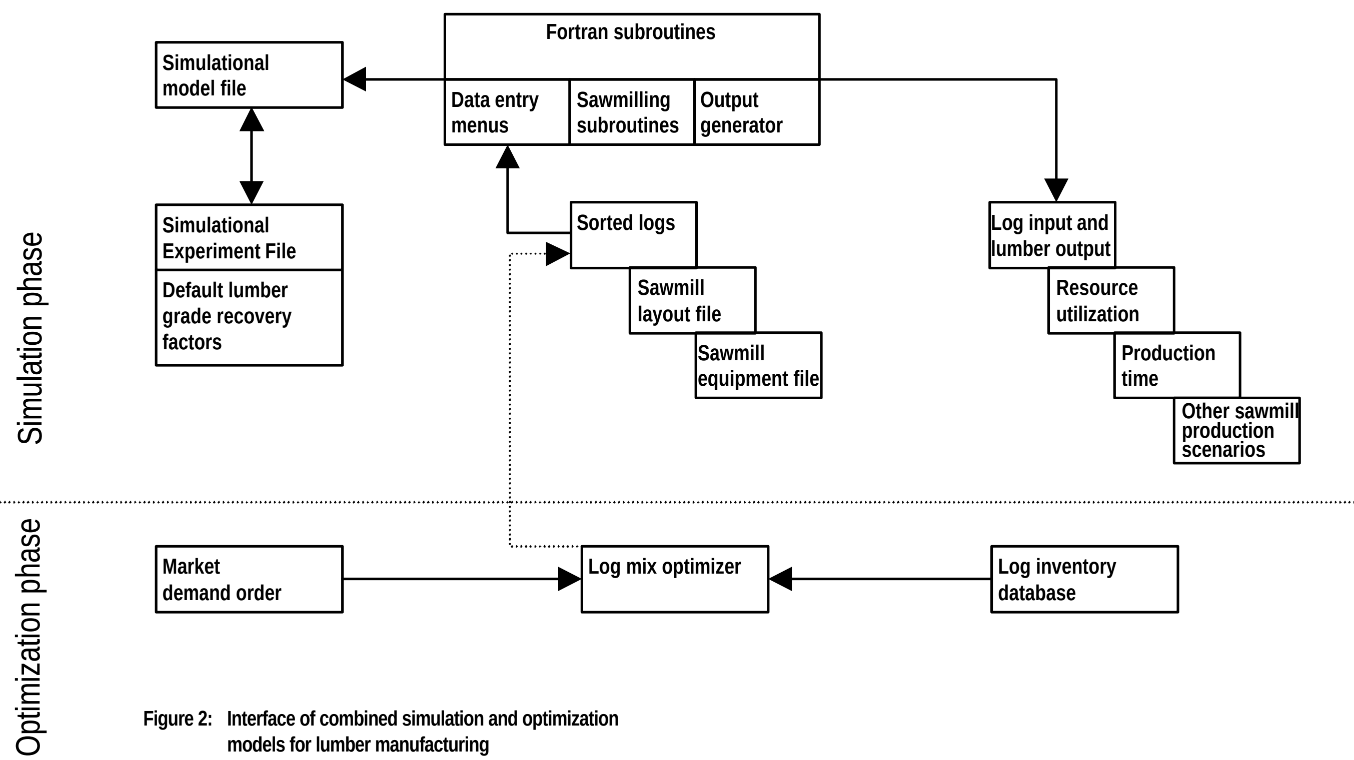

Figure 2: Interface of combined simulation and optimization models for lumber manufacturing

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 s log ($s \varepsilon S$) and update s = s + 1.
3) If 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 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 s' log and update simulation clock (T_{now}).
3) If $T_{now} < T_{fin}$, go to 2; otherwise continue.
4) List the 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.

SUMMARY AND CONCLUSIONS

A hardwood sawmill simulation model and an optimization model are combined to form an integrated model for lumber production. The simulator covers the basic facets and activities in lumber manufacturing including sawmilling logics, material flows and material data base. It can be used in a variety of ways such as: 1) to analyze log breakdown operation and sawing policies, 2) to help create look-ahead production scenarios, and 3) to design and evaluate alternative production systems. The optimization model, on the other hand, determines the optimal log input mix while satisfying lumber demand.

While both the simulator and the optimizer could be used as stand alone models, they could also be combined to form an integrated model. Combining the simulator with an optimization model enables a sawmill manager to develop an aggregately optimized production plan which is also tested for day-to-day operational feasibility. The optimization model generates a production plan based on broad company objectives and aggregately defined constraints. This optimal production plan is tested for operational implementability using the real time simulator. The integrated model could serve as a planning tool in developing not only a production schedule but the day-to-day activities of a sawmill.

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