INTEGRATING ECONOMIC PERFORMANCE AND PROCESS SIMULATION MODELS IN EVALUATING SAWMILL DESIGN ALTERNATIVES

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ABSTRACT

This paper describes a simulation study that combines an economic performance measure and a process simulation model. This integrated approach is capable of capturing the operational and cost behavior of a sawmill system over time by taking into consideration the effects of the stochastic occurrence of machine breakdowns and other processing delays. The method is demonstrated using an actual design problem involving a profiler chipper-canter mill.

Keywords: Process simulation, machine breakdown, economic performance.

INTRODUCTION

The potential throughput level of sawmill systems is considerably reduced because of processing delays originating mainly from mill design features and machine breakdowns. Some of these delays can be eliminated, whereas other isolated cases occur by chance under normal mill operations. It is not uncommon to find a high-rated capacity headrig underutilized because of delays that could have been avoided during the mill design stage. The delay could be due to an insufficient number of logs at the in-feed storage deck due to slow debarker or slow log-deck processing. It could also be caused by material storage blockage at the succeeding in-line storage or waiting decks because of slow processing downstream or insufficient surge area before the next machine.

Few sawmill design methodologies have been developed that consider the potential effects of processing delays. The problem was approached by Carino and Bowyer (1979, 1981) using queueing theory combined with a direct search algorithm that determines the least cost solutions of several design alternatives. The design simulator (DESIM) developed by Adams (1984) for hardwood sawmills is capable of describing accurately the operating performance of various mill setups. However, this design simulator still lacks the capability to assess the overall economic performance of the system it is trying to simulate.

FIG. 1. Flow diagram of the sawmill subsystem studied.

Various economic analysis methods have been used to evaluate design options. However, traditional economic evaluations cannot capture some significant cost factors that are directly related to manufacturing strategies such as equipment utilization, product inventory, and system throughput rate (Boer and Metzler 1986). These factors have been imbedded in economic evaluations before. However, these previous evaluations lacked the mechanism to estimate the above factors accurately partly due to their stochastic nature (e.g., the delays due to machine breakdowns).

One way of obtaining a sound evaluation of various design alternatives is to integrate an economic performance measure within a process simulation model. The integrated approach has the advantage of capturing the operational and cost behavior of the system over time. This paper demonstrates some approaches to modeling delays in a sawmill and then describes a method of integrating a throughput rate-dependent cost function within the process simulation model. For illustrative purposes, the profiler chipper-canter mill used by Carino (1979) will be utilized as a demonstrative example.

PROCESS FLOW OF THE MILL

To illustrate some methods of modeling delays and the notion of a combined process simulation-economic performance model, a discrete-event simulation model using the SIMAN (Pegden 1986) language was developed based on a simplified section of the profiler chipper-canter mill illustrated in Fig. 1. A more detailed description of the process is included in Carino and Bowyer (1981).

Debarked sawbolts arrive to the infeed buffer deck in front of the headrig (Chip-N-Saw). The sawbolts on the 97-ft-long buffer deck are usually stacked two to three bolts high and are converted into cants and/or lumber at the headrig on a first in–first out basis. From the headrig, the material then proceeds to an edger by way of roller conveyors and cross transfer chains (14 ft) which also serves as the waiting deck before the edger. Table 1 summarizes the arrival and service rates at each stage and the sizes of bolts processed by the mill.

TABLE 1. *Data input assumptions of the profiler chipper-canter mill.*

	Mean, minutes		
Arrival and service times			
Interarrival time at debarker	0.206		
Headrig service time	0.151		
Edger service time	0.088		
	Minimum	Mode	Maximum
Material input assumptions			
Diameter, inches	6.0	8.44	14.0
Length, feet	6.0	8.43	10.0

The sawmill operates one regular shift a day (450 min) and 250 days a year. To attain the desired daily throughput, the sawmill has to be operated beyond the regular workshift in order to fill the sawbolt buffer deck in preparation for the next day's operation. The debarker is operated at capacity during the regular workshift. A 20-min break is regularly taken at noon, which is also utilized for regular workshift maintenance. Table 2 summarizes the initial equipment cost outlay of the mill. These cost estimates were obtained from Carino (1979) and were based on the prices prevailing at that time. For its design problem, the mill is considering two alternatives: 1) replacing the current debarker with a new and faster model, and 2) extending the current logdeck area.

MODELING DELAYS AND MACHINE BREAKDOWNS

Aune and Lefebvre (1975) estimated the industry average for unavoidable delays associated with profiler chipper-canters to be about 19.6% of the time. These unnecessary delays

TABLE 2. *Initial equipment cost outlay of the mill.*

	First cost	Capacity
Debarker	$ 51,500.00	4.86 bolts/min @ 100 fpm
Log deck	38,000.00	91 ft, max 300 bolts
Chip-n-saw	330,000.00	6.62 bolts/min @ 90 fpm
Cross transfer chain	7,840.00	14 ft, max 10 bolts
Edger	53,500.00	11.36 bolt/min @ 120 fpm
Alternative debarker	65,000.00	7.29 bolts/min @ 150 fpm

may be caused by any one or a combination of machine breakdowns, conveyor system breakdown, and operational policies such as changing saws or knives.

In order to accurately model equipment breakdown, it is necessary to have pertinent information on: frequency of a machine breakdown, service times for the machines, types of breakdowns, and frequency of occurrence over a given period. Consider a system with no mechanical machine breakdown—that is, machine downtime depends only on the capacity of the buffer decks and the regular noon break schedule of the mill. Under this situation, one can examine the performance of the mill with perfect machine conditions. In this condition, it is estimated that the edger buffer deck can accommodate a maximum of 10 cants while the log deck queue can handle 300 bolts.

Developing a simulation model for this system using the SIMAN system is quite straightforward. SIMAN is a state-of-the-art real time simulation language that has been used in several business applications. Its modeling orientation and framework make simulation modeling a lot easier and have the ability to run on mini or mainframe computers, especially personal computers. The language includes in one format the event scheduling mode, the process mode, and a statistical analysis system. In addition, the SIMAN system also allows simulated processes to be computer-animated through its CINEMA system.

In the SIMAN simulation language, the process model consists of a series of QUEUE and SEIZE blocks with restriction on the capacity of the queues. For instance, when the log deck is filled to its limit, a sensor automatically signals the debarker and halts its operation. Logs are represented in the model as entities and the machines as resources. The noon break schedule of the mill is modeled by the creation of a "delay" entity. At the specified start of noon break, the delay entity seizes all the machines. This machine preemption has the effect of taking away the productive activity of the machine from a log entity, thereby creating a time delay. The duration of the time delay was set at 20 min to represent the daily noon break schedule.

Table 3 shows the simulated operation of the mill both with the debarker operating at regular workshift and at overtime. It is evident from the table that there is capacity imbalance between the machines. The debarker capacity is obviously too slow for downstream machines. This capacity imbalance results in the underutilization of the headrig and edger even without any machine breakdown. For consistency and clarity, it is important to define the

TABLE 3. *Simulated operation of the mill with debarker operating at regular schedule and with an overtime.*

	Regular schedule	Overtime
Bolt throughput	2,219	2,371
Bolt volume, cf.	9,042.3	9,921.3
Debarker utilization, %	100.0	100.0
Headrig utilization, %	76.3	79.5
Edger utilization, %	45.5	48.5
Logdeck queue, bolts:		
Average	9.2	33.5
Maximum	63	177
Edger queue, cants:		
Average	0.5	0.6
Maximum	7	9

utilization referred to in the table as the amount of time the equipment is engaged in actual cutting over the total time it is intended to operate. Thus in column two of Table 3, the headrig is engaged in actual sawing for about 79.5% of the time.

Approximately 3% increase in machine utilization and 4% increase in the volume of bolts processed can be achieved with the mill's policy of operating the debarker beyond the regular workshift. The 30-min overtime of the debarker, however, is not enough to fill the log deck to capacity. Further simulation runs conducted showed that about 30 min more of debarker operation (for a total of 1 h overtime) is needed for that purpose.

Consider now the system that is also limited by machine breakdowns. For purposes of illustrating and simplifying the analysis, it is assumed that the system is limited by headrig downtime. This situation is commonly treated by other analysts by averaging the total production downtime delays into each workshift. While it is relatively easier to model this approach, it is more illustrative to spread the machine breakdowns stochastically within the production period. The advantage of this change in modeling approach is that one can easily trace the possible sources of bottlenecks and the consequences of a delay to the size of queue formed at the buffer deck. The formation of excessively long queue directly affects the operation of the preceding machine and consequently the system throughput. If a more dedicated design evaluation model is to be developed, this change would determine the sizes of queues that would be expected from the system and consequently the appropriate sizes of the buffer decks.

For illustrative purposes, it was assumed that delays due to machine problems occur once in half a day for the headrig. A machine breakdown scheduler was created such that delays can occur anytime within a given period. The stochastic delay arrival was coded by generating a random number between zero and one and multiplying that number by the total hours in the workshift. At each occurrence of a machine breakdown, the scheduler entity is delayed following the service time of the machine, which is typically modeled using the Erlang distribution.

TABLE 4. *Simulated operation of the existing mill with machine breakdowns.*

Bolt volume, cf.	9,645.37
Mill throughput, bolts	2,098
Headrig utilization, %	71.5
Edger utiliztaion, %	41.6
Debarker utilization, %	94.0
Average logdeck queue	129
Average edger deck queue	0.5

The values in Table 4, which were collected after the system had attained a steady state condition, show the simulated performance of the existing mill. The delays due to the headrig downtime alone further reduced the operational time of the already low-capacity debarker by almost 6%. The average queue in the logdeck also increased substantially. Without considering first the economics of design, it seems appropriate that the buffer deck should be extended to accommodate the production loss due to machine downtimes. The economic performance evaluations of the sawmill's two alternatives are presented in the next section.

COST ASSESSMENT

Sawmill facilities are capital intensive and the impact of economically unsound decisions can be very significant. Traditionally, "static" engineering economic approaches are utilized to evaluate design alternatives. However, as stated earlier, these methodologies do not reflect the realistic operation of the underlying system.

In this study, the incremental method of cost analysis was employed—that is, only the costs that significantly vary with the design of a given mill were assessed. For instance, the cost of the debarker, headrig, edger, and the buffer decks are significantly relevant as far as design comparisons are concerned. For the profiler chipper-canter mill, the annual operating cost outlay was determined using the method sug-

TABLE 5. *Performance comparison of the two sawmill design alternatives.*

	New debarker	Extended logdeck
Bolt volume, cf.	10,359.92	9,345.26
Mill throughput	2,510	2,286
Headrig utilization, %	85.3	75.7
Debarker utilization, %	63	96
Average logdeck queue	288	217
Average edger deck queue	0.7	0.6
Unit cost/1,000 cf., $	208	227

gested by Coolidge and Pfeiffer (1956) and later simplified by Carino (1979) as follows

$$\text{Total Annual Operating Cost} = \\ = 0.092 \cdot \text{FRSCOS}$$

where

FRSCOS = installed process equipment costs.

The cost conversion factor (0.092) can always be updated to reflect current price ratios. The total cost outlay for a given mill design is determined by taking the sum of the equipment initial costs contained in Table 2 and the annual operating cost outlay. The unit cost outlay is calculated by dividing the total cost outlay by the annual log input volume. The main difference in this case study compared to the previous calculations of Carino and Bowyer (1981) is that the log input volume is simulated reflecting the occurrence of delays and bottlenecks as discussed in the previous section.

The above performance measure was integrated into the process simulation model with calculations carried out after the end of the simulated year. The results of simulation runs comparing the system with extended buffer deck (11 ft) and a system with a faster type of debarker installed are shown in Table 5. To ensure a common experimental condition for the two alternative systems, common integer seed values were utilized for both runs, resulting in the same sequence of random samples for each run. It is estimated that it costs $423.00 per foot to expand the current buffer deck and will result to an additional increase of 30 bolts to its capacity. As reflected in the obtained values in Table 5, a significant reduction in the unit cost outlay from $227 to $208 per 1,000 cubic feet log input is achieved by replacing the debarker with a faster model.

SUMMARY AND CONCLUSION

The effects of queues resulting from buffer deck limitation and machine breakdowns were considered in modeling the operation of a profiler chipper-canter mill. The model takes into account the stochastic occurrence of processing delays and their effects on the utilization of the sawmill's equipment. Imbedded within the process simulation model was an economic performance measure that determines the unit cost outlay of given design alternatives. This combined approach renders a more realistic performance of the system without sacrificing the ability to calculate economic performance measures. Further application of this modeling approach can be extended beyond the evaluation of design alternatives (e.g., the integration of operational and financial planning models for a given mill set-up).

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