LOG YARD DESIGN USING DISCRETE-EVENT SIMULATION: FIRST STEP TOWARDS A FORMALIZED APPROACH

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Sébastien V. Robichaud, Daniel Beaudoin

FORAC and Département des sciences du bois et de la forêt, Faculté de foresterie, de géographie et de géomatique
Université Laval – Québec – Canada – G1V 0A6
sebastien.vachon-robichaud.1@ulaval.ca, daniel.beaudoin@sbf.ulaval.ca

Luc LeBel

FORAC, CIRRELT and Département des sciences du bois et de la forêt, Faculté de foresterie, de géographie et de géomatique
Université Laval – Québec – Canada – G1V 0A6
luc.lebel@sbf.ulaval.ca

ABSTRACT: *The current paper assesses a log yard design methodology. The method is derived from a procedure developed in the early 1980's and is updated using simulation software and analytic tools which allow for a more thorough evaluation of yard performance. The purpose of the proposed method is to offer a rigorous procedure for log yard design and to assist the industry in making decisions concerning log yard operation. The methodology used in this experiment is divided into six steps: (1) collecting data on resources and relevant activities, (2) modeling material flow, (3) establishing flow priorities, (4) determining the required space for each activity, (5) developing preliminary plans and (6) evaluating said plans using simulation modeling tools. The method was carried out in partnership with a forest product company which was considering options for mill yard improvements. Results indicate that the methodology is useful to guide decision makers when developing a log yard design. Moreover, integrated with simulation tools, it provides for a robust evaluation of log yard performance through investigations using sensitivity analysis. Finally, handling equipment capacity and the dynamic interaction between each activity within the yard can now be determined and observed, which was not possible with previous methods.*

KEYWORDS: *Log Yard; Design; Performance analysis; Simulation modeling; Flow analysis*

1 INTRODUCTION

The forest industry is constantly evolving to reduce cost and increase market value. For it to strive, the industry needs to be flexible and sustainable (Gautam et al., 2013). While much research has been done to optimize the industry's value chain (D'Amours et al., 2008), notably on timber harvesting, transportation and transformation, little research has been done on the operation and design of log yards. Indeed, a well-designed log yard is critical for efficient sawmill operation, and neglecting such design may lead to increased operating costs, shortages in raw material, inventory degradation, as well as significant environmental and social impacts (increased pollution, noise, and safety risks) (Demers et al., 2000, Koehncke et al., 2003). Additionally, a log yard can often perdure for decades, thus making its conception critical for reducing costs in the long run.

This paper introduces an enhancement to existing methodologies such as those proposed by Hampton (1981), and Baker and Canessa (2009). These methodologies provide a detailed understanding of the principles behind the design of log yards. However, the evaluation of the design is insufficient. Evaluating the design of a log yard is difficult since it implies complex interactions with its operation, which then leads to a multitude of sub-problems related to log yard planning (Gu et al., 2007, Rouwenhorst et al., 2000, Berg, 1999).

Indeed, the design of a log yard can be divided into the following sub-problems:

1) General structure: identification of departments, relative localization of each department.
2) Dimensioning: log yard area, department dimensions.
3) Department configuration: amount, length, width, height and direction of log piles.
4) Equipment selection: handling and unloading equipment.

These sub-problems not only interact with each other (for example, the localization and height of log stockpiles affect handling and unloading equipment selection), but they also interact with the following operation sub-problems, which creates the need for a method that allows to dynamically evaluate log yard performance.

1) Operation strategy: storage strategy (e.g. random, dedicated, First In First Out, freshness, etc.)
2) Log classes affectations: characterization of raw materials, allocating raw materials to specific departments, area allocation.

Sawmills are frequently confronted to one or several of these problems, which was also the case for the studied lumber mill. Therefore, the project pursued the objective to tackle the sub-problems of general structure, sizing and dimensioning, department configuration, equipment selection and log classes' affectation in order to improve the evaluation process of log yard design methodologies.

While some useful tools, such as Quality Function Deployment (Wasserman, 1993, Govers, 1996) and Value Steam Mapping (Irani & Zhou, 2000, Abdulmalek & Rajgopal, 2007, Pepper & Spedding, 2010), can be applied to solve some of these problems, these methods have a few drawbacks when used with log yard design. For example, VSM is insufficient in mapping several products if they do not have exactly the same process routings, or in including varying machine cycle times. Also, decision-making tools such as QFD can be very useful in prioritizing according to multiple requirements. However, in the same way than VSM does, they do not allow the user to dynamically see many time-varying aspects which are critical to log yards (machine cycle times, varying supply and customer demand, etc.).

Section 2 describes the methods used to carry out this project. Sections 3 through 7 describe the design steps and their outcomes. Section 8 presents the simulation model developed to evaluate the designs. Discussion and conclusions are presented in sections 9 and 10.

2 METHODS

For the sake of this study, a log yard design procedure developed by the proficient practitioner Charles Hampton was used and formalized (Hampton, 1981). It is divided into six steps, which are: (1) collecting data on relevant activities and resources, (2) modeling material flow, (3) establishing flow relationship diagrams in order to assess flow priorities, (4) determining required space for each activity, (5) developing preliminary plans and finally (6) evaluating said plans, but this time we used discrete-event simulation for log yard evaluation instead of using averages and wide-ranging calculations. This process can indeed be iterative from step (6), in such a way that modifications can be made according to the results observed through simulation.

Using this methodology, it is possible to obtain one or many designs which can then be compared according to key performance indicators. Discrete-event simulation provides a better understanding of the log yard's behavior on the operational level and assists in identifying bottlenecks prior to implementation.

An ongoing log yard design project from the Province of Quebec, located in Canada, was used to test the method for the purposes of the study. The lumber mill company was in the process of modernizing the facility, thus giving an interesting opportunity to carry out the research.

This medium-sized sawmill, which consumes approximately 500,000 cubic meters of spruce and fir every year, is located in a small rural area (fairly close to a residential area) and has as primary purpose to produce timber to be used for construction. It contains two main entries, one from public roads (paved road) and one from a private road (dirt road), which is maintained by the company.

Since this log yard is subject to seasonal variability and this leads to varying operation dynamics, simulation models were built for both periods with minimum and maximum resource arrivals. Maximum inflow was measured during the season with highest raw material inflow (from January until March). Minimum inflow was also measured during the lowest utilization period (from April until June). This was done in order to avoid redundant capacity.

3 DATA COLLECTION

Data collection is the first step of the studied methodology, and can be divided into four parts: obtaining information on the raw material profile, quantifying inflow data, understanding the handling activities and comparing the handling and unloading equipment alternatives. Gathering information on these four main aspects provides a clear understanding of the requirements for completing an efficient layout.

3.1 Raw Material Profile

In this step, the methodology suggests dividing raw materials in different categories based on the handling activities and processes they must undergo. Since particular categories of raw materials go through different log yard activities, resource data is most important for establishing a good design. The division of raw material profiles is done on a case by case basis and depends on the mill. In the study case, the raw materials were divided into three main categories described below: cut-to-length logs, tree-length logs and large diameter logs. The descriptions are specific to the example business, but the general approach may be used for other sawmills.

Cut-to-length (CTL) logs are a type of raw material that is bucked to specific lengths directly at the harvesting site. These logs are mainly 3.65m (12 ft.) and 4.88m (16 ft.) in length with varying diameters, and are currently mixed together inside the log yard. Other lengths, such as 2.44m (8 ft.), 2.74m (9 ft.), and 3.05m (10 ft.) are also present in the log yard but amount to an insignificant volume compared to the other products. Very small logs, categorized as "pulp logs", are directly sent to the chipper[1] and not processed through the sawmill factory production line.

[1] Chipper: machine that reduces logs to thumb-size chips.

Tree-length (TL) logs usually exceed 5.49m (18 ft.) in length and are stored in dedicated stockpiles. Contrarily to CTL logs, they are not bucked at their harvesting site and are delivered in their whole length, with branches cut off. Since they are generally harder to handle and heavier than CTL logs, some kinds of machinery cannot be used to move them. Another major difference between TL and CTL logs is that TL logs must be slashed[2] for log shortening as the mill itself can only process CTL logs.
Finally, the third main log category that is handled within the log yard is large diameter logs (LD). These logs are very similar to CTL logs since both are already sawn and do not require to be processed at the slashing station. However, they are put in a different category because of their large diameter, which is considered too large for the debarking process at the factory entry (such a log would then completely block the hydraulic debarking unit and halt production). For this reason, they must be handled in another production line. In the studied case, logs exceeding 40.64cm (16 in.) in diameter were brought to the secondary entrance in order to ensure that there would be no problems with the debarking process.

3.2 Raw Material Inflow

It is primordial to understand the inflow of raw materials because this has a significant impact on the capacity requirements inside the log yard. For example, in the case that was studied, there are two main roads from where the raw materials are delivered; public road and private road. Public roads are paved with asphalt and may be used by the general public. Trucks delivering from these roads are generally smaller and lighter in order to conform to road regulations. Private roads are often used in order to allow bigger and heavier trucks to deliver more volume of raw materials per trip. All types of logs can be delivered from both sources, though in this case most tree-length logs come from private roads and most CTL logs come from public roads.

As stated previously, the inflow of logs also varies seasonally. Figure 1 illustrates the seasonal variability by illustrating the weekly amount of delivery trucks that came to deliver raw materials for a period of a year and a half. During winter, the arrival rates from the private road entrance are at their peak during the year, and then completely stop during spring. This is due to the fact that private roads are blocked during the spring because of their poor condition after thawing. The supply from the public road stays relatively constant throughout the year, except during Christmas and New Years' time, where supply trucks operators are on vacation.

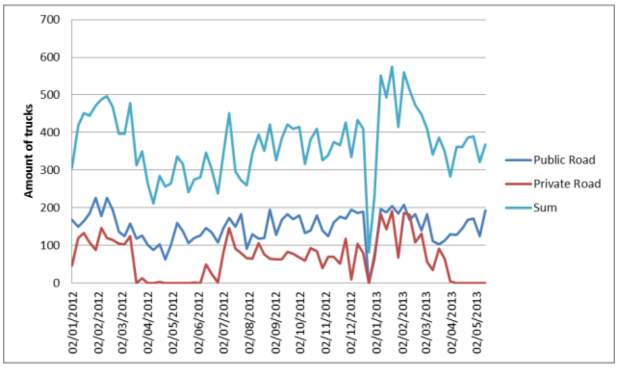

Figure 1: Seasonal variability of supply truck arrivals

Data concerning the arrival location and time of every type of delivery truck should be collected in order to later build the simulation model. This data can generally be obtained at the scaling database and converted to volume measurements. Truck loads statistics are also very useful in order to build the simulation model.

3.3 Handling Activities

Once they arrive at the log yard, different raw material types have to undergo various handling activities. This section is dedicated to summarizing the different activities that are carried out within the log yard that was studied. Since many softwood lumber mills use very similar processes for their yards, the case study may be used as an example for a typical log yard. The following Figure 2 summarizes the main handling activities within the studied log yard.

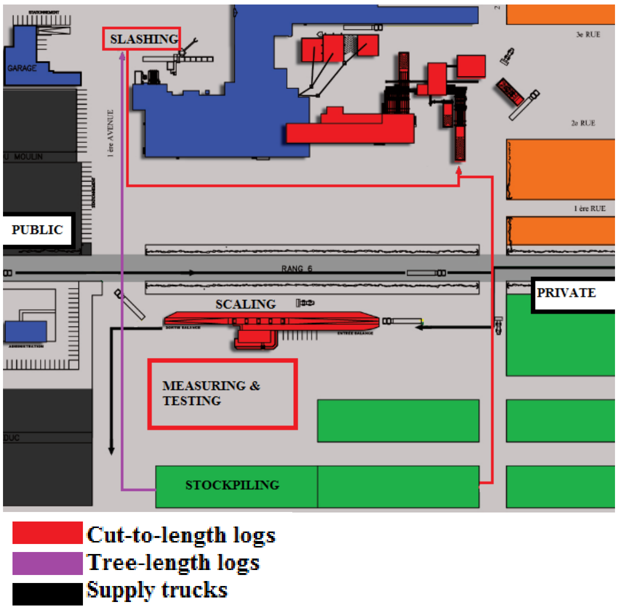

Figure 2: Handling activities

The first activity is the scaling process. Supply trucks need to be scaled at their arrival and before leaving the log yard. The data regarding nature of materials, weights, processing times and arrival rates are available in a centralized database.

[2] Slashing is a transversal cutting process to shorten logs to a desired length.

The second type of handling activity within the log yard is measuring and testing of all types of logs. This is done by systematically measuring a certain percentage of the volume that goes through the scaling process within the yard.. A measuring worker is stationed in an area intended for this purpose and measures individual log's dimensions from a truckload sample. From time to time, the worker must walk to the scaling area to measure there, due to internal regulations. For this reason, it is desirable that the log measuring areas be close to the scale.

The next activities are truck unloading and log stockpiling. Delivery trucks coming from both public and private roads are unloaded and their contents are added to same-type stockpiles. Handling machinery is used in order to unload the trucks. When emptied,, the trucks go back to the scale to be weighed again, then leave the log yard.

The final activity depends on the type of log being handled. If the logs are tree-length, they first need to be converted to CTL logs at the slashing station. The CTL logs are then brought directly to the lumber mill, where they are processed and transformed into planks. For LD logs, the process is the same as CTL logs, but they are brought to the entrance close to the slashing station.

3.4 Handling Vehicles

Many types of handling machinery exist, each with their own advantages and disadvantages. This section describes the main categories of equipment and machinery. Most of the data that was collected regarding handling machinery was obtained by reading previous studies (Tran, 2008) regarding equipment efficiency in log yards.

First of all, front-end loaders (such as the Cat IT62 and the Volvo L150) generally have very good speeds (up to 25 km/h) and versatility, thus making them ideal for supplying the sawmill with wood. This is due to the fact that they can go back and forth between the lumber mill and stockpiles in a short time. They also have very short loading and unloading times; because all they have to do is fill their small grapple. However, this also causes them to have very limited volume capacity, making them only efficient on short distances. Reducing travel distance not only reduces equipment cycle times, but also greatly reduces operating costs due to reduced fuel consumption and vehicle wear. They are also very limited in weight capacity, so they cannot handle tree-length logs. Moreover, their height reach is very limited, reaching only about 10 to 12 ft. in height. If the log pile height exceeds its range, other equipment with higher reach must divide the piles in order to make them accessible for the front-end loader.

Log loaders (such as the Tanguay LL228 and the Tanguay WL430) are much slower machinery than front-end loaders (reaching velocities between 5 and 7 km/h). However, their grapples are more delicate with the logs compared to front loaders, and thus reduce the risk of damaging the raw materials. They also have a much higher reach than front loaders, which makes them ideal for truck unloading, log stockpiling and preparing samples for measurements and testing. However, their loading and unloading times are much slower than the front-end loader. This is due to the fact that stabilizers have to be enabled every time the equipment goes from movement mode to unloading mode. They can also be used for supplying the lumber mill with logs, but only when a container is attached. This improves their handling efficiency since it ensures that the volume of raw materials transported per trip compensates for their very slow speeds. If they were to be used for supplying the mill, it would then make sense for them to carry larger volumes across a larger distance.

Finally, the third type of equipment to be analyzed in this study is the truck-mounted log loaders. They generally have very similar properties to other log loaders, but have slightly faster movement speeds (7 to 8 kilometers per hour when loaded). Truck-mounted log loaders also have containers attached to them by default, which can carry up to about 40 cubic meters of TL logs, or up to about 20 cubic meters of CTL logs. At the studied log yard, they are mainly used to supply the slashing station, or to unload trucks directly at the slashing station. Their use is very similar to log loaders, since both need stabilizers to start loading and unloading, and are more delicate with log handling compared to front-end loaders (which need to do a pushing movement on the pile to load, risking to damage logs).

As found in the previous studies regarding handling equipment efficiencies (Tran, 2008), Table 1 shows the average data for speeds, loading times, unloading times and truck unloading times (when applicable).

Equipment	Speed (km/h)	Volume (m^3)	Load Time (min)	Unload Time (min)	Truck Unload Time (min)
Front-end loader	25	8.87	0.4	0.2	N/A
Truck-mounted	7	40	7.6	5.4	11.2
Log loader 1	4	0	7.9	11.4	13.3
Log loader 2	5.2	0	1.7	5.8	15.7

Table 1: Handling equipment properties

Using all the data collected in this first phase of the methodology, there is enough understanding of the system to start modeling the material flow throughout the yard.

4 MATERIAL FLOW MODELING

Once the activities, resources and handling machinery options are known, the next step of the methodology is to map the activities occurring inside the log yard and quantify their interactions in terms of volume flow. This is used in order to identify on which handling activities the efforts should be focused while developing preliminary plans.

In the case specific to this study, the interactions between every activity are represented by a Process Flow Diagram as shown in Figure 3. The diagram reveals every flow by a percentage of the total volume. Using this as a condition to be met, the required volume movement across each activity is determined.

Figure 3 shows that the most important flow interactions are between the CTL stockpiling and processing (90.4% of total flow), as well as between the TL stockpiling and slashing (49.3% of total flow).

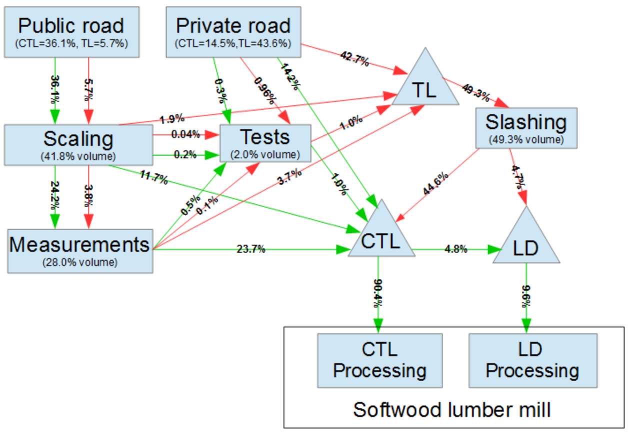

Figure 3: Process Flow Diagram of the Quebec case example

The following conclusions were made after analysing the process flow diagram:

1) CTL processing and CTL stockpiling must be as close to each other as possible (90.4% vol.).
2) TL processing and slashing must be as close to each other as possible (49.3% vol.).
3) TL slashing must be close to CTL stockpiling and/or CTL processing (44.6% vol.).

5 FLOW RELATIONSHIP DIAGRAM

In order to assess flow priorities, it is useful to build a Flow Relationship Diagram. The diagram rates each activity combination, according to frequency of use and rating of importance. The ratings found in the diagram are based on the conclusions of the Flow Process Diagram analysis. Figure 4 shows the Flow Relationship Diagram that was built for the case of study.

For every flow relationship between activities, a rating is given in terms of its importance (a legend is shown in the figure) and, when deemed relevant, a code is given to represent its frequency (from 1 being high to 3 being low).

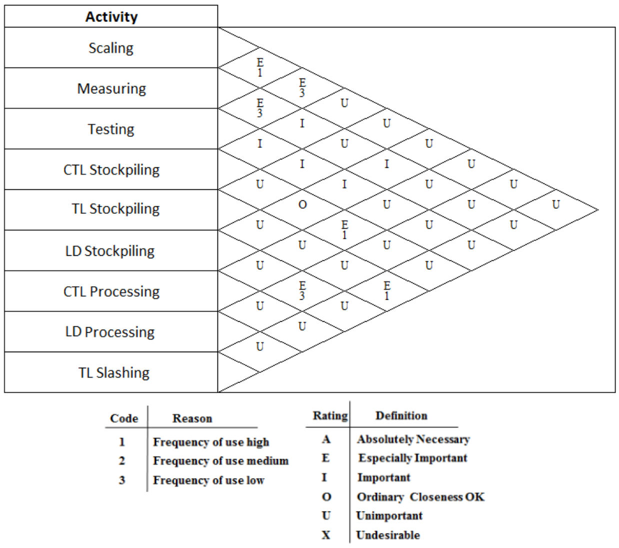

Figure 4: Flow Relationship Diagram

From this diagram, we can see that the most important relationships are the following:

1) Scaling and Measuring must be close: Especially Important and High frequency of use.
2) CTL Stockpiling and CTL Processing must be close: Especially Important and High frequency of use.
3) TL Stockpiling and Slashing must be close: Especially Important and High frequency of use.
4) Testing should be close to both Measuring and Scaling (rated as Especially Important). However, the frequency of use is very low since it only represents 2% of the total volume.
5) LD Stockpiling and LD Processing should be close (Especially Important) but the frequency of use is rather low, standing at around 9% of the total volume.

Conclusions 2 and 3 confirm some assertions made using the flow process diagram. However, in contrast to the flow process diagram, the relationship diagram is used to identify preferred closeness between activities, especially for cases where the volume going through these activities is not particularly high.

6 DETERMINATION OF REQUIRED SPACE FOR EACH ACTIVITY

In order to evaluate the required space for each activity, the volume of raw materials inflowing and outflowing per unit of time must be determined. Some activities have fixed areas, such as the scale and slashing station. Other activities are more flexible and their required space varies over time. For example, specifically for the studied case, TL stockpiling will require a larger volume during its peak arrival rates between January and March of every year, which will then slowly decrease at a relatively constant rate until the end of the summer.

Since the allocation of space for each activity is not only dependent on the area needs, but also strongly relies on the availability of storage area, we can think of this step as balancing needs with capacity. If the total storage capacity for the log yard is known, then it is possible to estimate the required area in function of the total volume.

For example, the studied log yard storage capacity is of approximately 120,000 cubic meters, which was considered to be beyond storage requirements. Thus, since 50.7% of the volume is CTL logs, then 50.7% of the total storage capacity can be safely dedicated to CTL stockpiling. Granted that the storage capacity exceeds requirements, this method allows for flexibility in cases where resource supply increases unpredictably for a certain period. Many other methods for space requirement calculations already exist and can also be used.

Please note that the overall space that is needed for stockpiling greatly depends on the pile heights, which in turn is dependent on the handling machinery decisions. If a front-end loader is chosen to supply the wood to the lumber mill, then pile heights must be lowered (either by using another equipment to divide the piles as they are consumed, or by lowering the standard pile height).

Knowing the required space for each activity individually as well as the flow relationship priorities, it now becomes possible to start constructing preliminary plans.

7 DEVELOPMENT OF PRELIMINARY PLANS

In this phase of the methodology, since a layout is rarely started from the ground up, it is important to consider the different layout constraints that might be present at the time of restructuring the log yard. Indeed, some stations might be impossible to move around or remove due to logistical and/or financial reasons. They then become layout constraints and the methodology user must find a way to work around them.
Generally, the steps to follow in order to develop a preliminary plan are:

- Identify available areas for activities on the plan
- Immediately insert layout constraints on the plan
- Gradually insert blocks corresponding to allocated space for each activity
    - The area of each block is determined by the previous step in the methodology
    - Start by the most important and frequent flow relationships as indicated by the Flow Relationship Diagram

Using this method for the study case, there were many layout constraints to work around.

First, the scale must be located just south of the road, and must be parallel to it. Second, the slashing station must be located north west of the log yard. Finally, there must be a truck waiting area just north of the road. The resulting preliminary plan is shown in Figure 4.

Considering these limiting layout constraints, there seemed to be one logical plan:

- Since front-end loaders appear to be the best equipment for short-distance travels and can only handle CTL logs, CTL stockpiles had to be closer to CTL processing (since 90.4% of the total volume, including the results from TL slashing, is processed there);
- Scaling, measuring and testing were positioned closer to each other (with measuring and testing being centralized into a single activity area);
- TL stockpiles were located further away from the sawmill and slashing station, because the main handling equipment types that could handle TL logs work best for long distance travels with larger volumes;
- Most stockpiles (both TL and CTL) are located relatively close to one another in order to reduce distance traveled for log loaders, which will be used to unload trucks in the designed log piling areas.

Figure 5: Example of preliminary plan

In addition to layout constraints, there are some factors which can make or break a log yard layout that design methodologies can hardly assess, due to the fact that they are difficultly quantifiable. However it is very important to consider them separately in order to have a sustainable log yard. The factors taken into account for the purpose of this study are the adaptability to change, the overall noise, safety, as well as drainage.

The first factor is adaptability to change and is an important factor to consider because supply and demand is variable. The inflow of raw materials can vary greatly from season to season and from year to year, and the log yard must be able to adapt to this phenomenon. Adaptability, in this context, should be measured with pre-treatment storage capacity and peak machinery work capacity.

The second factor is noise and should be taken into account especially if the mill is located very close to residential areas. Since some operations can make a lot of noise, there is a need to make sure that the noise is minimized as much as possible in order to reduce the inconveniencing of citizens living nearby. For this reason, noise-cancelling walls were added to the preliminary plan illustrated in Figure 5.

The third factor is log yard safety. The layout must ensure that operators and supervisors can move around by foot safely. Since log piles may obstruct the line of sight of machinery operators, it is imperative to design the log yard in such a way that hazardous situations be avoided. This can be done, for example, by reducing pile height, or by designing dedicated roads or pathways for pedestrian movement.

The final factor is drainage and is a critical factor to consider in regions where there is a lot of snow or rain. Indeed, if there is no effective drainage system implemented in the log yard, mud spots can form and contaminate the logs, which will become harder to process inside the mill.

During the course of this study, one layout constraint in particular raised our attention. Indeed, by looking at the flow process and flow relationship diagrams, it would have made sense in terms of flow management to have the slashing station be located south east of the log yard (as illustrated in Figure 6), where most of the TL logs are delivered through the dirt road. In the long term, it seemed that it would have been beneficial to move the slashing station there, because it is functioning independently from the lumber mill. Also, the slashing output could directly be stored in nearby CTL stockpiles. Finally, noise-cancelling walls would not be needed anymore, since their primary purpose was to cancel the noise produced by the slashing station.

Figure 6: Preliminary plan - slashing station moved

Once the preliminary plan(s) are constructed, the next step is to evaluate them using simulation modeling software such as SIMIO (by Simio LLC). Note that the amount of preliminary plans can vary greatly depending on the project and layout constraints.

8 EVALUATION OF PLANS USING SIMULATION MODELING

The final step in the proposed methodology is to evaluate the preliminary plan(s) using discrete-event simulation software. Before the simulation model is described, key performance indicators are to be established. Also, since there is only one type of preliminary layout, the different scenarios to be compared are different combinations of handling vehicles and corresponding tasks. The handling vehicles used in the simulation models are: one (1) front-end loader, two (2) log loaders and one (1) truck-mounted log loader. The different scenarios that were compared included varying speeds and volume capacities corresponding to each vehicle.

Moreover, since the flow analysis showed that it would be beneficial to move the slashing station to the south-eastern part of the log yard, a duplicate of each scenario was made, however this time moving the slashing station around to witness the effects on the overall performance of the log yard.

Finally, inter-arrival rates of the delivery trucks were edited to correspond to different seasons of the year (winter for high utilization, and spring for low utilization), assisting in identifying potential redundant capacity for the handling machinery.

8.1 Key Performance Indicators (KPI)

In order to evaluate performance statistics of each plan, these key performance indicators were considered the most relevant:

- Average Time in System (for delivery trucks)
- Scheduled Time Utilization (for each handling vehicle)
- Total Distance Traveled (for each handling vehicle)
- Amount of shortages at sawmill CTL processing entry (Critical KPI, since even one shortage results in substantial costs)

At the log yard's supplier's level, it is important for the average time in the system of their delivery trucks to be minimized. This KPI will help contrast the performance of each scenario in this aspect.

The three main KPIs for layout performance in the log yard layout are the utilization rates of each handling vehicle, as well as their total distance traveled and the amount of shortages at the lumber mill production line.
Measuring utilization rates of each handling vehicle makes sure that they are not over utilized during peak times of the year, and then underutilized when the demand in work capacity is lower. The decision makers might prefer to choose an equipment combination where the system is less effective during peak times but less

underutilized during slower times. This allows for potential operational strategy adjustments.

8.2 Simulation Model

The following section provides a brief summary of how the simulation model was built and executed. The model was built using SIMIO. The simulation model can be simplified into four main parts, which are:

1) Modeling the raw material arrivals (dependent on the time of day and day of the week)
2) Modeling the handling activities (measuring, scaling, etc.)
3) Modeling the activity sequences (e.g. for each supply truck coming in)
4) Modeling the equipment logic (how handling machinery priorities and activities are managed)

Firstly, each type of supply truck (each delivering a different type of wood) has their inter-arrival time modeled independently. These inter-arrival times vary depending on the time of the year (seasonal variability), but also depend on the day of the week and time of day. For example, trucks coming from the private roads originate from Maine, USA. These are dependent on the border control hours, which then mean there are peaks in arrival rates at around 8:00am and early in the afternoon, as shown in Figure 7.

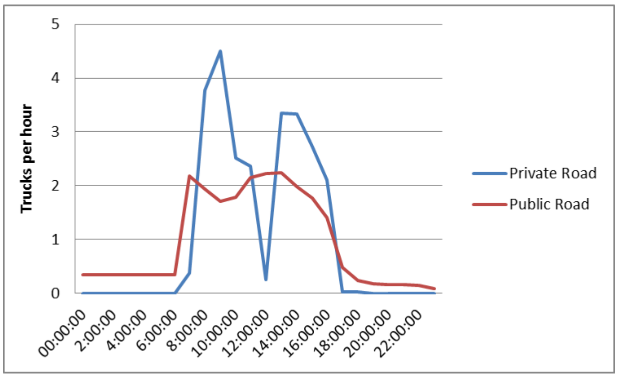

Figure 7: Example of varying inter-arrival rates for a given day

Moreover, delivery trucks arrive mostly during open working days, on Monday through Friday, with the last day of the working week being a little bit less busy than the other weekdays. As shown in Figure 8, overall activity is extremely low during the weekend.

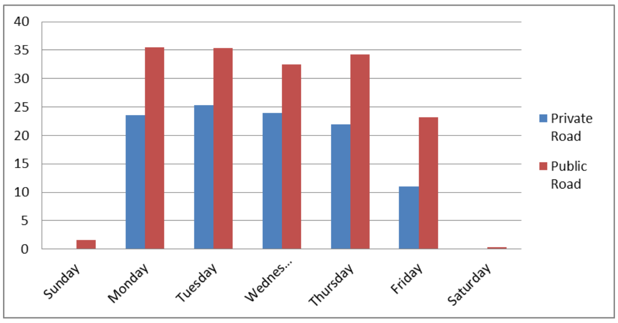

Figure 8: Example of varying number of trucks per day for a given week

Secondly, the handling activities within the log yard were modeled as processes with processing times obtained from databases and time studies. The handling and unloading machinery was modeled to have the properties as shown in Table 1 of the current paper. These properties were modified for the sake of sensitivity analysis, and also to correspond to potential replacement purchases that could be made in order to improve overall log yard performance.

Thirdly, in order to build the sequence of activities each incoming delivery truck must follow, the simulation model was created in a way that flow quantities respect the Process Flow Diagram illustrated in Figure 2. Each time a new delivery truck entity is created, the sequence is determined randomly at the time of its arrival, with probabilities corresponding to the percentage of flow. For example, 100% of the public road trucks delivering CTL logs go to scaling, then approximately 67% of these trucks go to measuring (24.2/36.1), and so forth. Then, once the sequence of activities for each incoming truck is decided, they follow the assigned path and undergo all of the processes that are prescribed by the sequence.

Finally, the equipment logic is as follows:

- Both log loaders unload incoming delivery trucks in a First In First Out (FIFO) single-queue (and only one log loader is needed per truck)
- The truck-mounted log loader is in charge of supplying the slashing station with TL logs and taking its resulting CTL logs to bring them to the CTL processing entry, or to a CTL stockpile.
    - The slashing station entry has a capacity of 100 cubic meters and a re-order point of 20 cubic meters.
    - When this threshold is reached, the truck-mounted loader must increase the entry volume up to 60 cubic meters or more.
- The front-end loader is mainly in charge of supplying the CTL processing entry with CTL logs, but also is in charge of taking the LD logs to the LD stockpiles (LD processing works independently from the lumber mill).

- The CTL processing entry has a capacity of 80 cubic meters and a re-order point of 20 cubic meters.
- When this threshold is reached, the front-end loader must increase the entry volume up to 70 cubic meters or more.
- Both the CTL entry and slashing station exit have maximum volume thresholds for LD logs of 20 cubic meters. When such thresholds are reached, the front-end loader must fetch these logs until their respective volumes are empty.

Once these four main parts of the model are built, a complete simulation model is obtained (as illustrated in Figure 9).

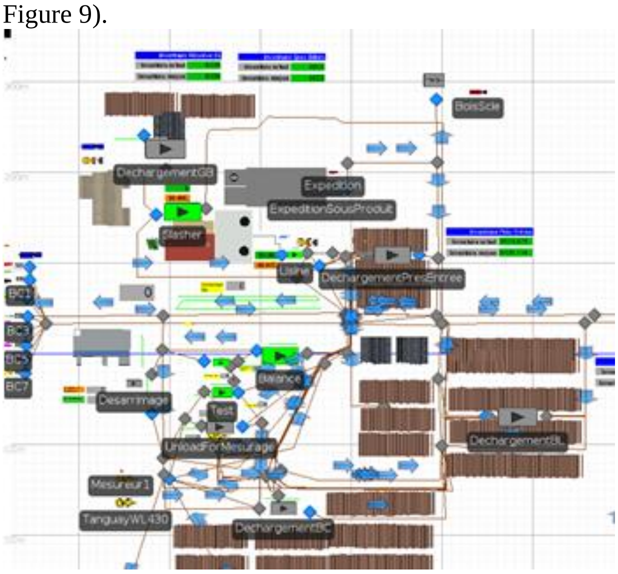

Figure 9: Simulation model screenshot

8.3 Experiment parameters and results summary

Since only one design layout was deemed promising by the company, the simulation experiments were carried out only with varying equipment combinations. Each scenario was evaluated for the winter (high utilization and arrival rates) and spring (low utilization and arrival rates) seasons, with 50 replications per experiment.

The following table (Table 2) shows a sample of results that were observed while running experiments with the simulation model. This table shows results for the Scheduled Time Utilization and Total Distance Traveled key performance indicators.

The scenarios identified with an asterisk correspond to a layout where the slashing station is moved as suggested by the material flow modeling and relationship diagram.

Scenario	Winter	Winter*	Spring	Spring*
Weekly avg. msrmnts	94.42	93.44	93.46	95.4
Weekly avg. tests	5.46	6.04	3.58	3.18
Truck-mounted utilization (%)	105.45	101.7	105.44	101.7
Truck-mounted distance (km)	126.21	29.9	129.21	29.9
Loader 1 utilization (%)	81.42	80.55	56	56.4
Loader 1 distance (km)	32.64	31.78	16.26	16.24
Loader 2 utilization (%)	75.85	75.41	40.73	41.57
Loader 2 distance (km)	32.31	31.21	12.5	12.82

Table 2: Sample of results for one simulation experiment

The first two rows indicate the average weekly amount of measurements and tests that need to be done, while the other rows show the utilization rate (in percentages) and weekly distance traveled (in kilometers) for each equipment used in the experiment.

A noticeable improvement from relocating the slashing station is the reduced total distance traveled by the truck-mounted loader, which is reduced by over 75%. The simulation experiments also show that this equipment is over utilized (with seize requests exceeding capacity by 1.7 to 5.45%), and thus task assignments for the handling machinery should be revised. Moreover, the results show that during spring, utilization rates for the two log loaders are much lower, which means that one of the two machines could potentially be turned off during this season in order to lower costs, and act as a backup in case of emergencies.

After relevant conclusions are drawn from this experiment's results, changes can be made in order to iteratively improve performance, and finally the process can be repeated until a satisfactory layout is obtained.

9 DISCUSSION

In an effort to improve the evaluation of log yard performance, a log yard layout procedure was carried out using discrete-event simulation as primary evaluation tool. This simulation model, which was built exclusively for the purpose of this study, could potentially be used as a more general model for other companies provided their handling activities and raw material profiles are similar. The model was validated by comparing its results with observations on the field (for the initial situation) and also by comparing with pre-existing equipment data. Once validated, the simulation model was used by the company to draw conclusions on equipment alternatives.
In any case, using discrete-event simulation to evaluate log yard performance gave insight on better localizations of log stockpiling areas and equipment utilization. These characteristics could hardly be assessed by previously available methodologies found in the literature.

Still, the proposed enhancement to the evaluation of plans adds credibility to log yard design planning, while also allowing for safe experimentations to be made before implementation.

However, a simulation model can only be as good as the data that is used to build it. Our experiment would benefit from obtaining more complete data over several seasons of operations, for example.

Moreover, further research could be done in order to include all design and operation sub-problems, particularly the operation strategies (random, dedicated, FIFO, etc.) which were not taken into account in this study.

10 CONCLUSION

In conclusion, this study has assisted in ascertaining a problem with currently available log yard design strategies, which is that they barely allow for evaluation to be conducted on their design performance.

In an attempt to solve this problem, a design procedure was used and adapted using simulation software for the evaluation of log yard performance. This updated design methodology was then carried out in partnership with a softwood lumber mill company in order to test its feasibility.

Undeniably, the results obtained through the simulation models guided decision makers with their layout design strategy, as well as with screening between alternatives for new equipment. Upon assessing the methodology, they based their acquisitions on the experiments' results.

By presenting the dynamics and actual movements within the log yard, using discrete-event simulation modeling in design methodologies incorporates the design and operation sub-problems identified in literature. This shows that updating layout strategies by adding such evaluation tools might be a potential solution to the problem, as presented by this study which acts as a proof of concept towards a new formalized methodology.

Nevertheless, additional experimentation within the forest industry needs to be completed in order to validate whether discrete-event simulation is a worthwhile tool for evaluating the performance of log yard designs.

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