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Approach of flexible log yard design using discrete event simulation

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Abstract

Log yards play an essential role in the proper functioning of the wood supply chain. In Nordic climate, the design and operations of log yards are highly influenced by a seasonality of forest operations. The aim of this paper was to propose an approach to take into account the seasonality of wood supply operations in the log yard design procedure. Our approach integrates flexible design decisions of the log yard into the static design method proposed by Hampton in the 1980s. The process of evaluating the performance of the proposed designs was enhanced with the discrete event simulation. The application of the method in order to evaluate flexible design decisions for seasonal adaptation is demonstrated using a case in an existing log yard in Quebec, Canada. Results indicate that the log yard performance can be improved by the integration of flexible design decisions to seasonal operational conditions. The simulation provided insight into the importance of physical layout and proper use of yard equipment.

Keywords: log yard design; seasonality of wood supply; discrete event simulation

1. Introduction

The log yard is one of the key components of an efficient wood supply chain (Dramm et al., 2004). Since the handling and storage of wood generate significant costs, the operational inefficiencies of a log yard reduce the overall efficiency and profit margin of the sawmill (Rahman et al., 2014a). Logistics costs and operational performance are largely determined at the planning stage of a warehouse design (Rouwenhorst et al., 2000).

Results from a survey of the largest softwood sawmills in Quebec in 2016 showed that one third of managers find their yard inefficient (Trzcianowska et al., 2019a). Further interviews with a dozen of yard managers confirmed that the storage areas are defined on an ad hoc basis and that there is no structured guide for the design and management of log yard available for managers.

Moreover, results from a technical efficiency benchmarking of 38 surveyed yards demonstrated a potential for reductions of 17% in yard area, 20% in equipment utilization, and 14% in labor (Trzcianowska et al., 2019b). Since there are several interactions between design decisions and yard performance, any modification should consider all of the decisions assessed.

1.1. Log yard seasonal adaptation

In Canada, as in other Nordic countries, the forest industry is highly influenced by the seasonality of wood supply. In general, the seasonal nature of the supply can be characterized by the adequacy between the volume of wood delivered to the yard and the consumption by the mill. We can distinguish three seasons: inventory accumulation, inventory run down, and equilibrium (Figure 1).

The accumulation season is the period when log deliveries to the yard are greater than mill consumption. This season runs from late fall through late winter. The frequency of truck arrivals is two to six times higher than the mill's consumption. During this time, the storage areas near the mill deck are used at full capacity and incoming wood is unloaded in remote areas. The accumulation season requires more space to store logs and more handling capacity to unload trucks.

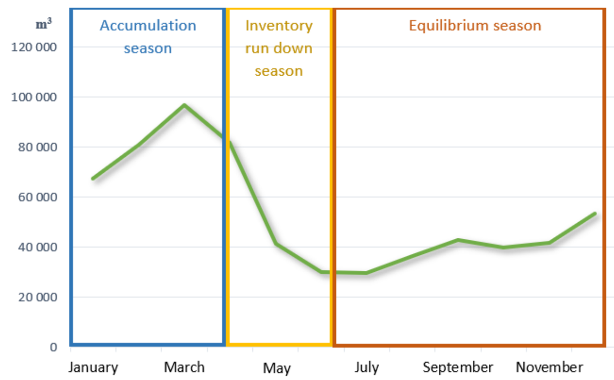


Figure 1. General trend of inventories in log yards in Quebec.

The inventory run down season is when log deliveries to the yard are less than mill consumption. This season corresponds to the spring thaw period during which load restrictions are imposed to heavy transport. Transport operations are often stopped at this time to preserve road infrastructures. The stocks are then used to keep the mill in operation.

Finally, during the equilibrium season, the volumes delivered to the yard correspond approximately to the demand of the sawmill. Transport operations are coordinated with the mill production plan, so that a high proportion of incoming trucks are unloaded directly at the mill deck.

2. State of the art

The design problem encompasses five main decisions: (1) selection of the general structure, (2) sizing of the warehouse and its departments, (3) choice of equipment, (4) determination of a detailed plan of each department and (5) choice of operational strategy (Gu et al., 2007). Design encompasses all of these decisions, their subproblems, and several interactions between them.

Unlike the warehouse design problem, the log yard design was never thoroughly investigated in the literature. Most documents address log yard design sub-problems (Tran, 2009; Beaudoin et al., 2012; Vachon-Robichaud et al., 2014; Rahman et al., 2014b; Pernkopf and Gronalt, 2017). Only two documents present log yard design guides. These guides were published in the early 1980s and describe a design observation rather than structured approaches.

Hampton (1981), presents a general sequential procedure for designing a log yard. His method consists of six steps: (1) collecting data on the yard's resources and the volume flow, (2) analyzing the flow of raw materials, (3) determining the space and equipment required for each activity, (4) proposing the preliminary plan, (5) evaluation of the preliminary plan and (6) evaluation of alternative solutions. Although Hampton's (1981) instructions encompass the design problem, they are too general to perform the whole design procedure.

Sinclair and Wellburn (1984) published a guide for the design, construction and operation of log sort yards. This guide is based on the authors' observations of coastal operations in British Columbia. The guide also presents financial information associated with yard operations. However, this approach is less structured than the method of Hampton (1981) and the design subproblems are addressed separately without an overall performance assessment of alternatives solutions.

Both design guides discussed above rely on annual data to determine a year-round static design. However, a majority of log yards in Quebec and other Nordic regions adapt their resources and operations according to the seasonal supply variations (Trzcianowska et al., 2019a). The feedback from forest industry highlight a need for a log yard design methodology that takes into account the seasonality of the wood supply. Therefore, the aim of this paper is to complete the approach proposed by Hampton (1981), as more structured existing methods, with a method for flexible log yard design.

Section 3 describes the log yard design steps with seasonality consideration. An example of method application is presented in section 4 along with the simulation model developed to evaluate the designs. Discussion and conclusions are presented in section 5.

3. Log yard design method

The proposed steps improve the static method published by Hampton (1981). The revision emphasizes the adaptation of the design over the year under the influence of seasonal supply. This consideration includes determining the triggers for seasonal transition, and proposing design alternatives (additional capacity, additional resources and flexible resources) to use the yard more efficiently throughout the year.

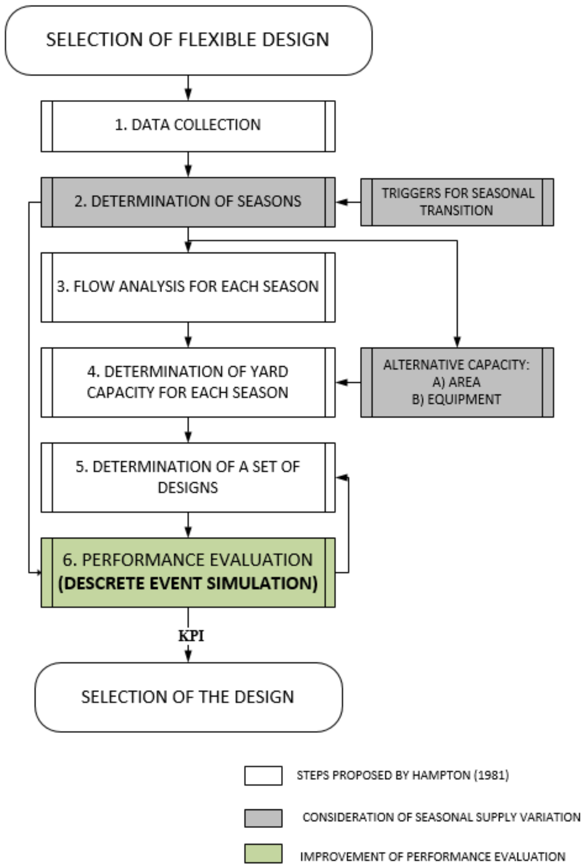


Figure 2. Improvements made to the method of Hampton (1981).

Depending on the objectives of the analysis, the alternative capacity may improve the use of space (allocation of assortments, sizing of zones) and/or equipment (number and type of machinery). The operational year will be divided into periods defined in number of weeks with the same operation's distribution within each period. The design will therefore consist of a series of suitable plans proposed for each season. Figure 2 illustrates modifications made to the method of Hampton (1981). To begin, the step for determining the seasons is presented (step 2). Subsequently, flow analysis, capacity determination and development of alternative designs are performed for each season identified in step 2.

Figure 3 shows in detail steps 5 and 6 of developing and evaluating designs. A design includes both fixed and flexible decisions (e.g. $D_1a_1D_2b_1$ in Figure 3). For a given season, several sets of fixed decisions can be developed (D_1, D_2, ..., D_n) to which several sets of flexible decisions (a_1, a_2, ..., i_n) can be associated. Thus, several solutions can be developed. Then, using a discrete event simulation model, each of the designs is simulated for each of the seasons. Statistics on the performance criteria selected are collected to help decision-making. The decision-making consists of identifying which set of fixed elements will be applied throughout the year (or longer) and which set of flexible elements will be applied in each season.

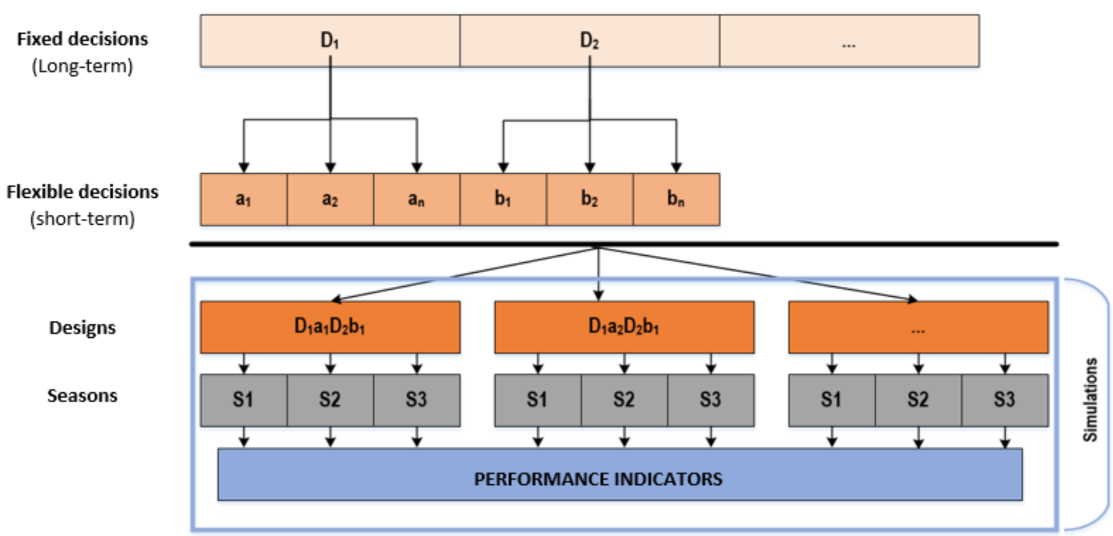


Figure 3. Scope of the decisions in order to develop and evaluate log yard designs

Before starting the design process, the yard manager must define the design scope, which can be the entire site, the log yard, the lumber yard, a specific zone or a process. The method can be applied to a new yard, or used to revise an existing design with all or a subset of the seasonal adjustment decisions.

In this study, we focus on flexible log yard design decisions to illustrate how to take into account the seasonality of wood supply. However, the steps leading to long-term decisions are presented through the design steps. For more details on these elements, please refer to Hampton (1981).

3.1. Data collection

Data collection is necessary for the determination of the seasons, the development of designs to be evaluated, the development of simulation models and the development of various functions (e.g. truck arrival time, volumes per trip, etc.) required for simulations. The range of data to be collected depends on the design scope. Fixed design decisions are based on strategic planning, while adaptive design decisions require more operational data.

3.2. Determination of seasons

In the context of regional supply, we distinguish three seasons based on the adequacy between the reception of wood at the yard and the consumption of the mill: the accumulation season, the season of inventory run down and the equilibrium season. The determination of the transition points and therefore the length of each season is determined from the historical data of weekly wood deliveries and consumption of the mill. The transition points between the seasons are determined as follows:

- Accumulation season (season I): **supply volume > mill consumption volume**,
- Inventory run down season (season II): **supply volume < mill consumption volume**,
- Equilibrium season (season III): **supply volume = mill consumption volume.**

The weekly deliveries at the yard and mill consumption may show variations, which impede delineation of seasons. For example, the data may indicate an alternation of the accumulation season of accumulation and the inventory run down season over a few weeks. In this case, we apply a moving average of a few weeks (depending on supply variations level) on our data, which smooths the curve of the volumes received.

3.3. Flow analysis

The next step is to analyze the activities in the yard, quantify their interactions in terms of handled volume, and prioritize operations to develop preliminary plans. For that step, Hampton's method follows an SLP (Systematic Layout Planning) approach proposed by Muther (1973). The method begins by determining a sequence of activities in the yard using a string diagram. The percentage of flows in terms of volume is used to establish the proximity links of the activities for the design determination step and the volumes of raw materials passing through each activity during the simulations used to evaluate the proposed designs.

The flow prioritization must be performed in order to develop the best scenarios to be evaluated. The method uses a diagram of relationships between activities to position them on the site map. For all pairs of facilities (activities), it determines the proximity category (A - absolutely necessary, E- extremely important, I - important, O - ordinary or U - unimportant) and locates the activities in terms of site following this priority. Since the seasonality can influence incoming assortments and change the sequence of activities in the yard, this exercise should be performed for each season.

3.4. Determination of yard capacity for each season

The determination of the necessary area must take into account the area for the activities of handling and processing of wood (reception and measurement, sorting / slashing and storage) and for complementary activities. The calculated area must ensure the safety of operations and the conformity of the raw material at the mill deck.

The unloading and storage area occupies the major part of the yard. The height of the stockpiles as well as the total storage area are determined by the specifications of the yard equipment and the safety of operations. In order to calculate the total storage area, it is also necessary to take into account the space intended for the circulation aisles. This area is a compromise between facilitating maintenance, snow removal, safety, and loss of storage space. In the case that the yard contains several types of assortments (species, length, and size), calculations should be made for each assortment separately.

The selection of yard equipment is related to the type of tasks to be performed, costs and operational performance. The operational performance of machines depends on a multitude of factors, including the travel distance determined by the shape of the yard and the allocation of assortments, the height of stockpiles and the transported load. The selection of equipment depends on the capacity in terms of space and the physical layout of the yard. A yard with a lot of inventory, which has a small area, will need a log loader to stack the timber as high as possible. This machine is advantageous for transporting logs over long distances (when combined with a trailer). A front-end loader is best suited for yards that store small volume of logs. It is efficient for transporting wood over short distances. The layout of the yard must consider the requirements of the machines concerning the paths (width, steering angles) and the location of the piles.

3.5. Determination of a set of designs

This step consists of assigning the activities to each zone on the yard layout according to the order established in the flow prioritization step, respecting the determined capacities and taking into account the constraints of the yard, such as environmental constraints, the topography of the site or the neighborhood (traffic routes - public roads, railways; residential area - noise level). For each plan established, the type and number of equipment must be determined.

To generate the layout plans, we determine a physical location for each activity starting with the most important flows established in the flow analysis stage (Muther 1973). In the following steps, other activities related to wood handling and complementary activities (tailings area, truck cleaning area, snow location) are assigned on the yard plan.

Then, the capacity in terms of equipment must be analyzed for each layout plan. This relates to the type and number of equipment used to handle logs passing through the yard. In addition, the equipment-activity systems established during this step will be used to compare several operational rules.

3.6. Performance evaluation

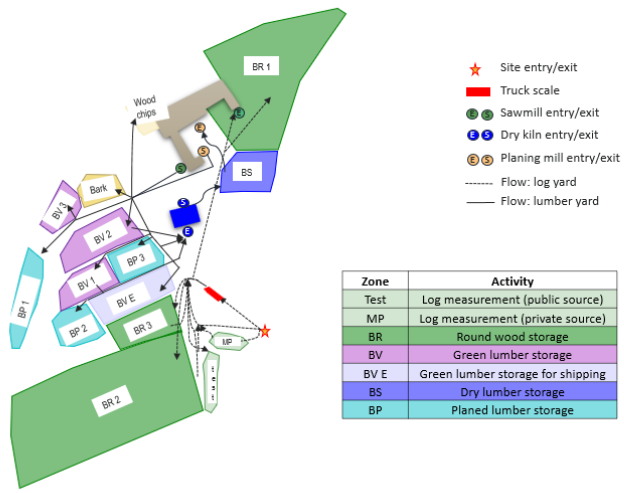
Discrete event simulation is proposed to evaluate the alternative scenarios determined in the previous step (following Vachon-Robichaud et al., 2014). Discrete event simulation has proved advantageous to solve warehouse design and operation problems (Siciliano et al., 2020; Hafner et al., 2019; Gagliardi et al., 2007). A simulation model describes entities (building blocks of a physical system), theirs attributes (main characteristics and interrelationships) and how they interact with each other (Marasini et al., 2001). The model examines the behavior and flexibility of the system during a given period by means of scenarios with different sets of situations. We use the SIMIO software for its graphical interface, which facilitates modeling and allows validating the behavior of the system in real time. Other simulation software could be used.

For each of the designs for each season we simulate the operational performance on a weekly basis. A sufficient number of replications must be ensured in order to compare the means of the results of the scenarios evaluated. The results, the outputs of each indicator chosen for each season, will be compared using the Student's t-test to determine if there is a significant difference between the means of the scenarios evaluated.

Several performance indicators can serve to assess the performance of log yards. A wide list of indicators applicable to warehouse performance evaluation is presented and discussed in (Staudt et al., 2015). The determination of the metrics used in this analysis depends on the scope of the exercise and the business strategy and should be realized for each user. The final selection of the design(s) evaluated will depend on the rating system for each of the indicators which is linked to the company's strategy.

4. Method application

The methodology for taking into account the seasonality of the wood supply was applied to a real case in an existing log yard located in eastern Quebec, Canada. The scope of the design exercise was limited to reassessing flexible seasonal decisions, i.e. the number of pieces of handling equipment and the possibility of sharing storage space between the log yard and the lumber yard. Since the log yard had only one assortment, the issue of product allocation according to the seasons was not addressed. The yard serves a softwood mill with annual consumption of 500,000 m³. The mill site and its various functional areas are presented in Figure 4.



Zone	Activity
Test	Log measurement (public source)
MP	Log measurement (private source)
BR	Round wood storage
BV	Green lumber storage
BV E	Green lumber storage for shipping
BS	Dry lumber storage
BP	Planed lumber storage

Figure 4. Log yard selected for the study

4.1. Data collection

The data was gathered during on-site visits and interviews with log yard managers and employees. The collected data covers one year of operation. For the purposes of properly evaluate design scenarios using discrete event simulation, data on receiving/ shipping and production was collected at the operational level.

The mill receives only an assortment of 9-foot-3-inch logs mixed of two species (typically 80% fir and 20% spruce). The sorting of species is carried out at the mill deck. Inventory in the yard is managed according to a freshness criterion in order to maintain the homogeneity of the humidity of the processed wood. More than half of the wood (59.1%) comes from the public forest against 40.9% from the private forest. This provenance influences the flow of wood in the yard.

The mill consumption is stable throughout the year and amounts to 10,920 m³ per week. The capacity of the mill deck that allows the sawmill to be supplied independently is 15 m³. The reserve area, which is used to replenish the mill deck can store a maximum of 726 m³. This area is replenished from logs stored in one of the two remote round wood storage areas.

The yard has a single point of entry and exit for trucks. The arrivals of trucks at the yard are variable during the week (from 33 to 56 per day) and during the day. The truck-unloading schedule differs depending on the origin of the wood. Trucks arriving directly from the forest road are unloaded 24 hours a day. Trucks arriving by public roads are unloaded from 6 am until 4 pm. The peak in truck arrivals can be usually observed just before the opening and closing the yard.

The log yard disposes an area of 5.60 ha for measuring, handling and storage activities. This area represents 25% of the total area of the industrial site. Given the space constraints of the near storage area, the storage yard is divided into three locations occupying respectively 2.1 ha (BR1); 2.7 ha (BR2) and 0.4 ha (BR3). The three zones provide a storage capacity of 140,000 m^3.

The yard equipment fleet consists of two mobile loaders of the same capacity assigned to the unloading activities of the trucks and feeding the mill. The former is mainly engaged in supplying the mill with timber from the close-up area or directly from the trucks at the mill deck. It unloads the trucks in the storage area near the factory entrance (Zone BR1 - Figure 4). The second machine unloads the trucks in the remote areas (Zone BR2 and BR3) and transport logs from the remote areas to the close area (BR1). Each machine is equipped with trailer of 40 m^3.

Independent on the season, the yard operates three eight-hour shifts. The day shift employs a yard supervisor, a scaler, a mechanic and two loader operators. Only the loader operators work the evening and night shifts.

4.2. Determination of seasons

Transition points between seasons were determined using data from the previous year. Since the data of log deliveries to the yard represented large weekly variations, a three-week moving average of log receptions was used to smooth the curve and facilitate delimitation of seasons. Figure 5 presents the weekly reception volumes, their moving average and consumption level delimited with the transition points described in section 3.2.

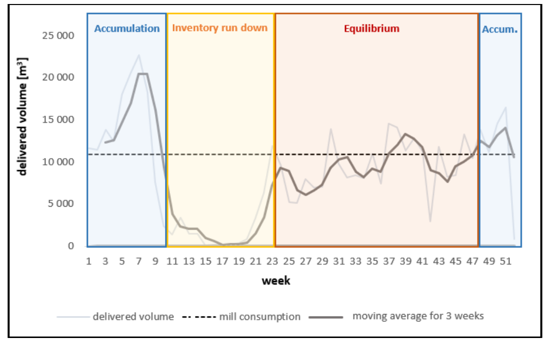


Figure 5. Delimitation of supply seasons.

4.3. Flow analysis

In order to assess the flow priorities, the annual number of movements of mobile equipment connecting one activity to another was calculated (Table 1). This reference is appropriate when the load units transported in the two yards are different. Logs are transported in loads of 40 m^3. Lumber yard mobile equipment can carry 2 to 6 packages at a time depending on the type of product (green lumber, dry lumber, and planed lumber). Movements that do not use yard equipment (e.g. logs moved by truck) have not been quantified.

Table 1 indicates that the most important round wood flow (storage – mill deck) is located below the main timber flows (green and dry), which limits the possibilities of allocating the storage between the two yards.

Table 1. Prioritization of flows based on the number of trips in the industrial site*.

Weight	Category	Proximity criterion
[15+	A	Absolutely necessary
[5,15[	E	Especially important
[0,5[	I	Important
n/a	O	Ordinary closeness
	U	Unimportant

Trips (x 1000)	Origin	Destination	Material	Flow relationship priorities
43.7	Sawmill exit	Green lumber storage	Green lumber	A
16.1	Green lumber storage	Dry kiln entry	Green lumber	A
16.1	Dry kiln exit	Dry lumber storage	Dry lumber	A
11.1	**Round wood storage**	**Sawmill entry**	**Round wood**	**E**
9.4	Planed lumber storage	Shipping	Planed lumber	E
9.4	Planing mill exit	Planed lumber storage	Planed lumber	E
9.4	Dry lumber storage	Planing mill entry	Dry lumber	E
7.3	Green lumber storage	Shipping	Green lumber	E
1.4	Dry lumber storage	Shipping	Dry lumber	I
0.2	**Log**	**Round wood**	**Round**	**O**

measurement (public sector)	**storage/sawmill entry**	**wood**

*for movements using yard equipment.

4.4. Determination of yard capacity for each season

Given the scope of the design exercise, we did not reconsider the sizing of the site. The alternative capacity in terms of space was assessed using flow analysis. The results did not show any advantage in sharing storage space (log and lumber yards) through the seasons of operation. Thus, the distribution of the area of the two yards remains the same. Currently the yard disposes of two log loaders for all seasons of operation. The alternative capacity in terms of the number of rental equipment has been examined for the three seasons.

4.5. Determination of a set of designs

The alternative capacity was assessed in terms of the number of equipment in operation. The hypothesis was to improve the performance of the yard by reducing the number of equipment for the inventory run down season (1 machine) and increasing their number (3 machines) for the accumulation season. In order to examine the proposed solution, we evaluated these three designs across three determined seasons (Table 2). Design 1 is the reference design (current design).

Table 2. Design scenarios for each season.

DESIGN	**SEASON I**	**SEASON II**	**SEASON III**
DESIGN 1 2 machines (Current scenario)	Scenario 1.1	Scenario 1.2	Scenario 1.3
DESIGN 2 3 machines	Scenario 2.1	Scenario 2.2	Scenario 2.3
DESIGN 3 1 machine	Scenario 3.1	Scenario 3.2	Scenario 3.3

4.6. Performance evaluation

The performance of nine scenarios of the yard was assessed using a discrete event simulation model. The model was developed using SIMIO software (version 10 165). Fifty replications were performed for each scenario. The scenarios were compared using three key performance indicators (KPIs): truck cycle time in the yard, distance traveled by loaders, and loader utilization rate. The indicators chosen reflect the internal efficiency of the yard (equipment, layout). The model was verified by comparing the truck arrivals of the model with those from historical data. The model's truck arrivals are similar to those of the historical data for the three seasons of operation (Student's t-test, t_1-value -1.6164; p_1-value = 0.555 for season I, t_2-value 0.1302; p_2-value = 0.448 for season II and t_3 value 1.78621; p_3-value = 0.0832 for season 3). The model was validated with the log yard manager by comparing the KPIs with the on-site observations for the initial scenario.

The model accounts for two main group of activities: truck arrivals and their sequences, and mobile equipment activities. The modeling of truck arrivals (inter-arrival time) was performed separately for each wood origin (different arrival rate). Trucks, the model entities, were generated using a *Source* module with the inter-arrival time randomly assigned from the historical database. The sequences of each truck type were modeled with *Add-on process* using the *Sequence tables*. The sequences of unloading were assigned in order to reduce the distance of intra-yard wood transport from the storage areas. The preferred sequence is therefore: (I) mill deck, (II) reserve area, (III) BR1, (IV) BR3, and (V) BR2. The volumes transported by the trucks, as well as volumes stored in the log yard, and at the mill deck, are represented by *State variables*. The *State variables* representing the stocks in the storage areas are incremented each time a truck is unloaded. Conversely, stocks are reduced when a loader remove wood to supply the sawmill.

The sequence modeled for each type of mobile equipment replicates the behavior of loader operators. The main task for loaders is to ensure that the mill does not run out of logs. Every minute, the model assesses the level of the stocks at the mill deck. If that volume is below the replenishment point (1.50 m^3), one of the two loaders fills the mill deck (capacity 15 m^3) with wood from the reserve area. If the mill deck is full and there is a waiting truck to unload, the loader proceeds to unload. These machines can move in the yard, but unloading priority in the reserve and in zone BR1 is assigned to loader I, whose work schedule follow the mill schedule. The loader I is primarily responsible for feeding the mill deck. Loader II is mainly assigned to remote storage areas (BR2 and BR3) and its schedule follows the arrival of truck with wood from private forests. The trucks are unloaded according to their arrival time (*First-in First-out*). If the mill deck is full and there are no trucks to unload, the loader approaches logs to the reserve area. The log retrieval is performed according to the storage areas (wood freshness management) with the probability: zone BR1 31%, BR2 62%, BR3 7%).

4.7. Performance evaluation results

The summary of the results for three seasons is presented in Table 3. For season I (accumulation of stocks), design 3 (1 machine) cannot be chosen since the average utilization rate of the machine would exceed 100%, in addition to significantly increase the truck cycle time in the yard. For designs 1 and 2, truck cycle time and distance traveled criteria do not show any statistically significant difference. The loader utilization rates for the three designs are statistically different.

For Season II (inventory run down), Design 3 (1 machine) recorded a significantly higher truck cycle time compared to the other two designs. On the other hand, this design stands out advantageously with significant differences for the other indicators: distance and equipment utilization rate. The results of Design 1 (2 machines) and Design 2 (3 machines) are similar for truck cycle time and distance traveled.

For Season III (equilibrium season), all designs are significantly different for truck cycle time and the distance. As in previous seasons, Design 3 (1 machine) results in higher truck cycle time compared to other designs. Design 3 shows advantages in terms of distance traveled and equipment utilization rate.

The method provides results that can quickly indicate which designs to eliminate and those which offer clear advantage for a given season. Otherwise, the manager must weigh the importance of performance criteria in choosing a design for each season.

Table 3. Summary of simulation results (means of indicators).

	SEASON I	SEASON II	SEASON III
DESIGN 1			
Truck cycle time [min]	36	25	39
Distance traveled [km]	178	191	161
Equipment utilization rate [%]	83	64	75
DESIGN 2			
Truck cycle time [min]	34	25	29
Distance traveled [km]	174	192	181
Equipment utilization rate [%]	56	43	45
DESIGN 3			
Truck cycle time [min]	87	45	55
Distance traveled [km]	130	133	131
Equipment utilization rate [%]	107	76	79

5. Discussion and conclusions

The lack of a formal design methodology for yard design led us to upgrade the approach proposed by Hampton (1981). The improved design method allows designing a log yard in an efficient way at two scales: fixed and flexible. To better adapt yard operations to external conditions, the new approach proposes to adjust the yard's capacity at key moment during the year in consideration of the seasonality of supply. The proposed approach may apply to different types of yards, such as log sort yards, transit yards (terminals) or mill's yard. The method can be applied in order to design of a new yard, or to revise an existing design with all or some of the fixed or flexible seasonal adjustment decisions.

The most important step in the design process is the selection of the most suitable design for each season and monitoring over time to apply another design if conditions change (flexible design). The indicators that are used to evaluate the proposed solutions depend on the scope of analysis and on the method of performance evaluation. The importance of performance criterion must be considered according to the mill strategy. For example, the sawmill with a significant variation in truck arrivals may prioritize truck cycle time in the yard. On the other hand, one with a high level of stored volume will mainly aim to minimize distances. The weights determined for each indicator must be determined to make the final decision. In addition, several non-quantifiable criteria have an influence on the design choice. The manager must also consider the financial and technical feasibility, the ability to adapt to changes in proposed solutions, the potential of yard expansion and its costs, the traffic safety and the speed of movement. Thus, the decision to apply the design must take into account feasibility and performance factors based on business objectives and the characteristics of supply and demand. Likewise, the determination of the seasons depends on the company's strategy and can be based on other criteria, such as the processing seasons of particular assortments.

The application of the method takes into account only flexible decisions of the simplest conditions of log supply (a single assortment) and mill consumption. We have not considered other flexible decisions of alternative capacity, necessary in the case of log yards with different operational conditions (e.g. the assortment allocation decision). Thus, future research on the design and performance of log yards should further examine the management of alternative yard's capacities and consider other conditions of the supply and processing of round wood.

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