

Discrete event simulation of wood supply chain using the three-phase algorithm approach

Abstract

The wood supply chain is highly important for timely delivery of processing factories' orders and preventing damages caused by natural factors, such as wood beetles, freezing, and rotting of products. These wood cargos must exit rapidly from the jungle by maximum use of resources and amenities available for warehousing or transferring to processing factories. In these cases, decision-making skills and logistics management strategies must be taken based on the contingency advanced scheduling. Therefore, the extant study introduced a contingency planning solution composed of a discrete event simulation model for analysis at the operational level of approaches to deal with challenging occurrences of business decisions, as well as transportation patterns based on the analysis of results of decisions made before actual implementation, which is costly and long term. This tool allows managers to design their contingency plans to cope with natural disasters and possible hazards. The present research assessed the increased use of available trucks and carriages' capacity, as well as reduction of loading time, trucks' queue, and stockyard' capacity in terminal under different conditions. The optimum capacity and number of trucks per train schedule considering limited resources, such as the number of trucks and the terminal depot's warehouse capacity. The terminal station has a gateway and many platforms for unloading so that trucks move in stations based on the FIFO model and probable carriages' loading schedule. Furthermore, computer simulation instruments must be used in this research to focus on the multi-product supply chain with a limited lifetime and probable risks.

Keywords: *Discrete event simulation, Three-phase algorithm, Supply chain management, Wood-based industry*

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Introduction

Wood Supply Chain

Organizations strived to produce high-quality and inexpensive products by standardizing and improving their internal processes over the 1960s and 1970s. In the 1990s, improved production processes and applied to reengineer patterns warned managers of many industries that improvement of internal processes and corporate capacity flexibility are not sufficient factors, but materials suppliers must produce high-quality inexpensive materials while products distributors should have a close connection with producer market's development policies [1]. Therefore, competition in the global markets of new product supply and rising customer expectations made companies invest in and focus on supply chains, so companies required themselves to participate in supply chains to be successful in competitive markets.

Wood is one of the first materials available for humans naturally and abundantly. Hence, wood use goes back to old times. The traditional wood supply chain consists of cutting trees in forests, classifying and transporting them to terminals, timber factories, pulp mills, paper mills, and heating mills, processing them, and manufacturing wood, paper, and pulp for end-users [2].

Computer Simulation

The general meaning of simulation had an old background, and the first computer simulation (using analog computers) was formed from 1948 to 1951. Therefore, rapid computer development (especially digital ones) has had such considerable impact on the development of this science that computer simulation has become one of the most popular and common tools guiding management in the optimization of industrial entities [3, 4, 5]. Simulation is the strongest analysis tool available for designers and complicated processes' users. Simulation allows users to test (real or proposed) systems that are impossible or applicable without it.

Three-phase discrete event simulation

There are two distinct events in three-phase discrete-event simulation: finite and conditional events that are planned as separate procedures. A finite event (or B-event) is an event with predictable occurrences so it can be planned. On the other hand, a conditional event (C-event) is an event whose occurrence depends on specific conditions (e.g., availability of special resources). These two events can be incorporated into activity scanning simulation. According to this approach, completed activities are

events known as finite events at the end of a certain time. An activity onset depends on specific conditions called conditional events [6-7].

Execution steps of the three-phase simulation have been explained herein:

- A phase (time scanning): address future events' list (endpoint of all activities that are in progress, such as finite events). Find the first case and advance the time to the next planned event.
- B phase (B calls): execute all events limited in phase A that is supposed to occur in the present time.
- C phase (C calls): test all conditional events and execute those with observed conditions.

Three-phase discrete event simulation can be facilitated using an activity cycle diagram (ACD). ACD displays are simple (only circles, arcs, and rectangles). Davies and O'Keefe [8] proposed pseudocode, such as organized PASCAL in the design of a simulation program after illustrating ACD. However, ACD display is most suitable for activity-based simulation instead of event-based simulation.

Statement of Problem

Consider a wood supply chain created to load timber products and fast transportation of these products to the train terminal and ship them to the processing factory. Working shifts of this supply chain start at 7:00 am and end at 15:00. When the daily working plan of the supply chain begins, trucks exit from the railway terminal station and move towards the jungle to load their cargos; 25-30 min after entering the jungle, depot place, and loading wood products, trucks load their cargos after 20-25 minutes then move towards railway terminal. Coming back from the jungle usually is 20% longer than the departure time. When trucks arrive terminals can transfer their cargos to the stockyard beside the platform, exit, and return to the jungle if there are empty carriages on the platform, there is an available loading opportunity, there is an empty unloading station, and there is not any train loading in the stockyard. Otherwise, trucks deliver cargo to the stockyard beside the platform, exit from there, and return jungle after transporting cargo to carriages. There are always stations in the terminal's loading platform for simultaneous unloading trucks to train equal to the number of its carriages. Trucks exit from the unloading platform based on their entrance order

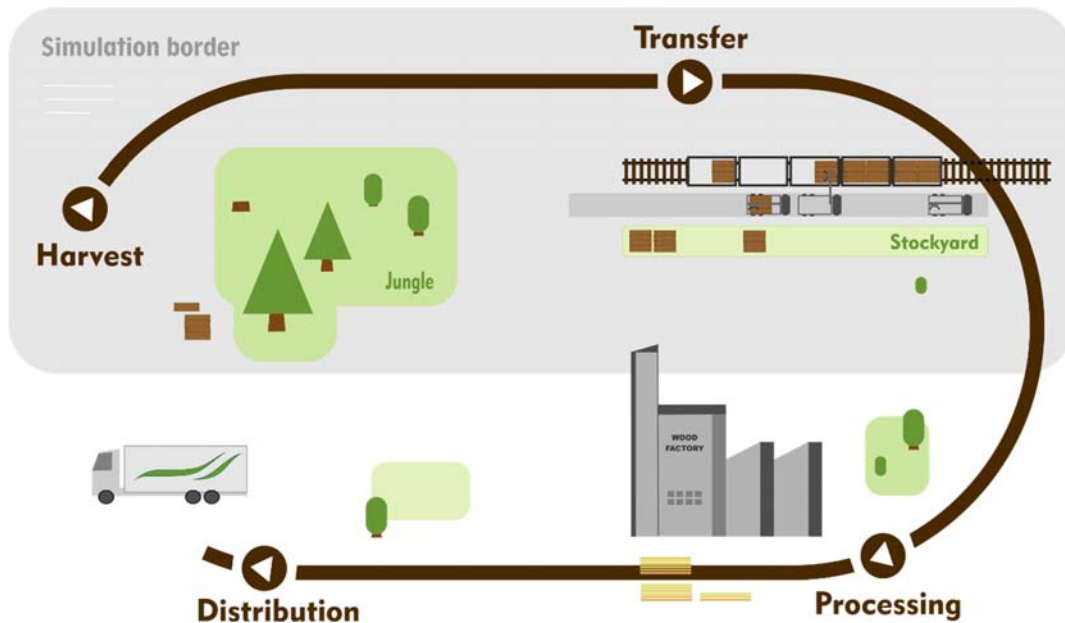
(FIFO) not only based on the cargo delivery time in the station. Cargo unloading takes between 35 and 55 minutes; each truck has a fixed transport capacity called cargo.

Trains and carriages are on the other side of the supply chain and transfer cargo to manufacturing entities. The loading process starts in the early morning after the train enters the loading station and delivers carriages; this process continues until the train starts moving again. If stockyard inventory is positive and no truck is in the unloading station during the loading process, priority is transferring the inventory to carriages; otherwise, cargo is taken from trucks in the queue. About 10-15 minutes is considered for each cargo when carriages are loading in the stockyard. In the case of unloading stockyard, like trucks, when maximum unloading time exceeds the remaining time of train movement then loading process of carriages will stop and stockyard again starts to unload trucks. In this system, trains exit from the terminal within a certain time per working shift, and immediately the next train enters the station, and the last train always moves at the end of the working shift. At the end of

the stop in the terminal station, trains enter the exit by rail and move from the railway station to the destination factories.

Round trips, delivery, and loading times of trucks, as well as loading time of train carriages in the stockyard, depend on traffic, climate, and cargo, which all follow a continuous event with uniform distribution.

According to the points mentioned above, the average waiting time of trucks in queues, the average carriages' full capacity at train exit time, and the inventory at the end of the period were assessed. In the next step, the impact of problem parameters (e.g., number of daily trains, number of carriages in each train, number of transportation trucks, and round trip time between terminals) on the trains waiting time, loaded trains capacity, and inventory amount at the end of the period were examined and sensitivity analysis was performed. Finally, the optimum number of trucks for the initial conditions of the problem was measured (These phases were done through MATLAB software).



Picture 1. wood supply chain, carriages loading station, trucks routes, and stockyard depot place

Basic conditions of problem:

- There are 7 trucks, 2 trains with five carriages, and 5 unloading and loading stations in the terminal.
- The first train is in the station at 7:15 and trucks exit from the railway terminal with a 5-min time difference at 7:05. The time difference between two train entrances to the station equals 15 minutes. It takes five

minutes for the forward movement of each train per extra carriage relative to the station capacity.

- The truck's capacity equals one cargo (24 tons), and the carriages' capacity equals two cargos.
- Jungle has unlimited capacity for wood production and depot without loading delay.
- There is unlimited capacity for the wood depot in the stockyard.
- The simulation period is about one month with a time unit of the minute. Each day includes 8 working hours (480 minutes), and each month equals 26 working days (12480 minutes).

Problem Objectives:

- First objective function: average waiting time of each truck in queues
- Second objective function: average loaded capacity of carriages per train
- Third objective function: inventory amount at the end of each period
- Minimization of the number of trucks based on the basic conditions and minimization of the empty capacity of carriages in each train and minimum inventory at the end of the period

- Minimization of the number of trains based on the basic conditions and minimization of the empty capacity of carriages in each train and minimum inventory at the end of the period
- Minimization of the number of carriages of each train and minimization of the empty capacity of carriages in each train and minimum inventory at the end of the period, and minimum number of trucks in each shift at the end of the period

Equations of problem:

Equation (1) Average truck waiting time: $\Sigma \left(\frac{\sum_{n=1}^N (S2) - (S1)}{(NTruck)} \right) \div (Day)$

S₁: time to reach the queue

S₂: operation onset time

NTruck: number of trucks

Day: number of days in a period

Equation (2) Average empty carriages of trains:

$$1 - \left\{ \Sigma \left(\frac{\sum_{n=1}^N (NTransfer)}{(NTrain) \times (CTrain)} \right) \div (Day) \right\}$$

NTransfer: number of loaded cargos per shift

CTrain: capacity of each train based on the cargo

NTrain: number of daily trains

Problem's details comprise elements, ACD, and its events.

Row	Element name	Type	Number	Explanations
1	Trucks	Entity	7	Each truck transports one cargo (24 tons) and has a crane
2	Trains	Entity	2 Rom (train counting unit) per day	Each train has 7 wagons or carriages that each include two cargos: so each train has 14 cargo
3	Terminal stockyard	Entity	Unlimited capacity	It has an unlimited storage capacity
4	Jungle platform	Entity	One station	Unlimited wood production and depot in the jungle
5	Terminal station	Source	7 stations	Entering to and exiting from the terminal platform is done in a row based on the unloading operation ending time
6	Railway	-		It is not in the system boundary

Table 1. Problem's elements

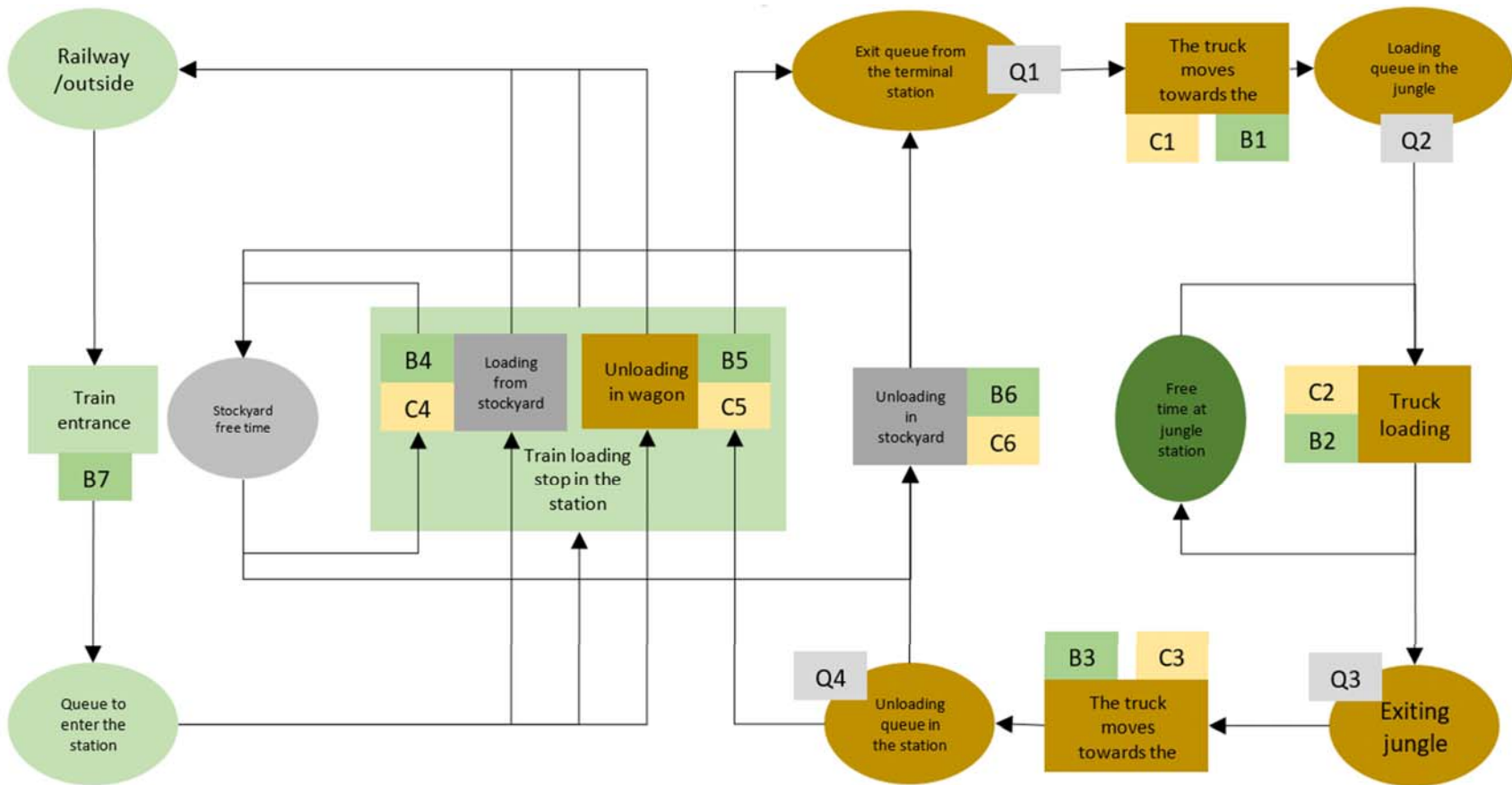


Figure 2. ACD. Qi: queue of trucks when entering or exiting in each phase

Occurrences	Symbol	Changes	
The truck arrives at the destination	B1	End of the truck entrance to the jungle	The onset of the next truck entrance
End of truck loading	B2	End of loading in the jungle	Trucks exist in the jungle
The truck arrives at the destination	B3	End of the truck entrance to the terminal	The onset of the next truck entrance to the terminal
End of loading in stockyard	B4	End of loading from the stockyard to wagons	The onset of loading from trucks
End of the truck unloading	B5	End of truck unloading on train	Trucks exist from the station
End of the truck unloading	B6	End of truck unloading in stockyard	Truck exists from the station
End of train entrance	B7	End of train entrance to the station	The onset of the next train entrance
Occurrences	Symbol	Conditions	Changes
Start to move towards the jungle	C1	Existence of trucks in the terminal exit queue	Trucks exist from the terminal and start moving
The onset of trucks loading in the jungle	C2	Existence of one truck for loading in the entrance queue Existence of an empty station in the jungle	The truck is loaded and made safe
Start returning to the terminal	C3	Existence of truck in exit queue from jungle platform	Trucks exit from the jungle and start moving
The onset of loading wagons in the stockyard	C4	Presence of train in station for loading Unfinished train loading time relative to maximum loading time in stockyard Existence of empty capacity in train Existence of cargo in the stockyard Absence of truck in unloading station	Stockyard transfers its cargos to wagons in a row
Start to unload trucks into wagons	C5	Presence of train in station for loading Unfinished train loading time relative to the maximum loading time of trucks Empty capacity in train Existence of one truck in the unloading queue If inventory capacity is zero, there must be an unloading station for the truck entrance If the inventory amount is not zero, there must be at least one truck in the unloading station	Trucks transfer their cargos to wagons in a row
Unloading trucks in the stockyard	C6	Existence of one truck in the unloading queue Existence of at least one empty unloading station Or the absence of a train in the terminal loading station Or finished time of train loading relative to the maximum loading time of truck Or finished empty capacity in train	Trucks transfer their cargos to the stockyard in a row

Table 2. Problem's occurrences

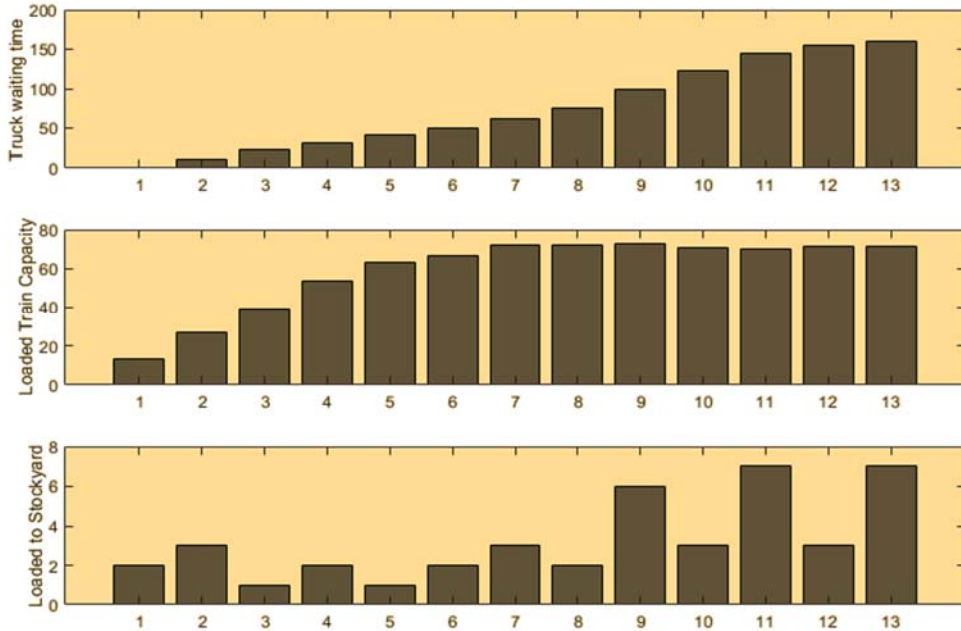
Conclusion

Counting-sort method was used to find the best solution based on the problem's objectives. Accordingly, the problem's objectives are determined first; minimization of average train's empty capacity per exit from the terminal and minimization of

trucks waiting time in queue during the simulation period, for example. Then, the parameter or entity that must be optimized is found to make objectives extremum (number of trucks in this phase). Now, numbers of trucks are added in a row to each problem to calculate solutions, which are the average empty capacity of trains and truck waiting time. The process is

iterated until the difference between two solutions is less than the determined extreme of the problem's logic. In this case, the impact of problem input on solutions (outputs) is examined using sensitivity analysis.

The solution for 13 trucks and 30 days was measured in MATLAB software seen in the figure below:



Picture 2. Output diagrams. Horizontal axes indicate the number of trucks in each simulation phase

Diagram 3.1 depicts the average truck waiting time in queues based on minutes and the certain number of trucks.

Diagram 3.2 shows the average loaded train capacity in each terminal exit (%) per certain number of trucks.

Diagram 3.3 indicates the inventory amount in the stockyard at the end of the period based on cargo per certain number of trucks.

Now, the best (optimum) number of trucks is determined based on the importance of the problem's objectives and priorities. We assume the priority of the average empty capacity of trains. According to diagram 3.2, outputs indicate that 7 and 8 trucks are the minimal changes in the problem objective. Therefore, the number of 7 trucks is chosen as the optimum solution to the problem. After determining the optimal number of trucks based on the maximum load capacity of wagons, it can be possible to estimate the stockyard at the end of the period and the waiting time of the truck in the queue. Loading time in the jungle or terminal unloading must be reduced to minimize waiting time in the queue to achieve the best results.

According to obtained results and multi-objective problems, it is possible to use the optimization method and weight problem objectives simultaneously to achieve the best solution considering all three or two problems. The extant study implemented a wood supply chain to simulate harvest and transfer phases with a three-phase discrete event approach through MATLAB software. The results were examined and the best solution was extracted at the end. This algorithm can

be generalized to the whole wood supply chain or other logistic programs.

Acknowledgment none

Source of Funding none

Conflict of Interest none

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