

Improving Fresh Fruit Bunches Unloading Process at Palm Oil Mills with Discrete-Event Simulation

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Abstract. Palm oil industry is an important agricultural activity in Colombia. Agents of this industry have chosen associative strategies and vertical integrations to increase their efficiency. However, reducing logistics costs to compete with countries such as Thailand and Malaysia, is still a challenge, also due to the scarceness of applied research in the palm oil logistics processes. In this paper, we present a continuous-discrete simulation-based approach to evaluate and optimize the fresh fruit bunches unloading process at the mill. Two simulation models representing the current process and alternative process scenarios were developed and compared. The findings show that important improvements in waiting time and supplier satisfaction can be achieved without major investments.

Keywords: Palm oil mills · Unloading process · Simulation

1 Introduction

Palm oil is one of the main sources of oils and fats in the world. It is used in a wide variety of food and cosmetic products, and can be used as source for biofuel or biodiesel. The palm oil market has grown significantly in the last years, reaching an important quantity of 62.8 million metric tons (mt) in 2015 [1]. Indonesia and Malaysia dominate the global palm oil production, accounting for around 85 to 90 percent of the total production. Colombia, as one of the countries included in the remaining producers, has shown a positive growth in recent years, with a significant production volume distributed in crude oils, refined oils, margarines, and hydrogenated mixtures.

In 2017, Colombian crude palm oil production totaled 1.62 millions of tons, with a positive variation (41.9%) compared to 2016. This data shows evidence of a consolidated growth trend, which can be observed in Fig. 1.

This growth is also visible in the area dedicated to cultivate palm oil. According to the 2017 Statistical Yearbook, the Colombian planted area in 2016 was 512,076 ha, with an increase of 2.6% compared to 2015. Out of this total, 113,029 ha were in development and 339,048 were already in the production phase [1].

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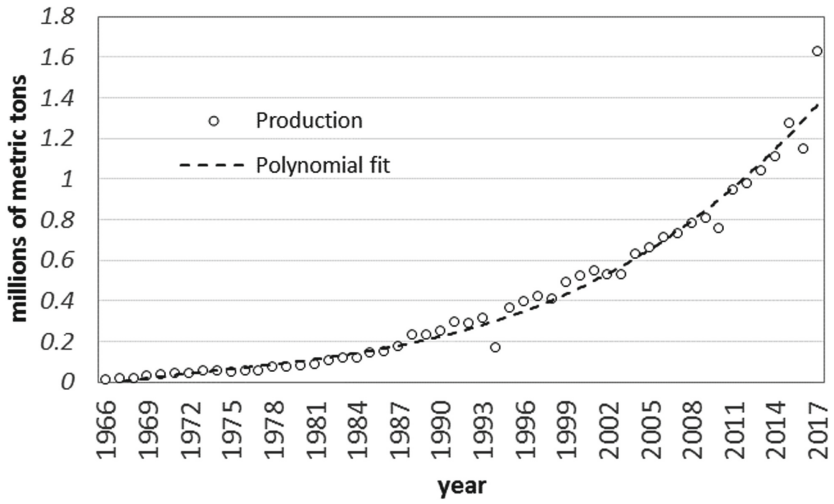


Fig. 1. Colombia palm oil production. Source: Colombian Ministry of Agriculture.

FEDEPALMA (the Colombian National Federation of Palm Oil Cultivators) divides Colombian palm oil planted area in 4 geographical zones, each one with the features described in Table 1.

Table 1. Planted areas with palm oil in Colombia.

Zone	Planted area (hectares)	Municipalities
East	206,559	36
North	124,948	68
Central	161,623	45
South-West	18,946	3

During 2016, all areas presented a remarkable performance in palm oil production, principally the Eastern and Southwestern regions, with a positive annual variation of 3.3% and 5.3%, respectively. Regarding the regional share in domestic production, the Eastern region held the highest contribution with 43.5%, followed by the Central region with 27.8%, the Northern region at 26.6%, and the Southwestern region at 2.2%. In terms of extraction rate, the Eastern and Central regions were more efficient.

Although the gap between Colombian palm oil productivity and the productivity of the leading producers has been narrowing over the years, there are still significant differences. The Colombian palm oil agroindustry faces costs in the processes of cultivation, harvesting, production and marketing that can be higher than those experienced by the international competitors, due to the poor condition of the transportation infrastructure, suboptimal harvesting and transportation processes and underutilization of the installed capacity at the mills [2]. The production costs of crude palm oil

(ACP) is currently experiencing harvesting, transportation of fresh fruit bunches (FBB) and oil extraction with a participation of 16%, 5% and 21%, respectively [3]. Even though 5% may seem insignificant, these transportation costs are relevant to compete in an international market with countries like Indonesia and Malaysia; especially because these countries have proven their superiority in terms of quality and cost efficiency. For this reason, research efforts are required in order to develop strategies for taking advantage of the potential of oil palm crops in Colombia.

This project aims at developing a simulation model approach to evaluate and optimize the unloading process at the mills, by the comparative assessment of the performance of alternative strategies that can be implemented to adjust operations. We describe our methodology by an application case to a mill located in the Northern zone, department of Magdalena. Palm oil industry is one of the economy drivers for that region, and it is considered as a stable source of employment. Currently, there are 17 municipalities with palm oil plantations and eight active palm oil mills located in the four municipalities of Aracataca, Ciénaga, El Retén and Zona Bananera. The presence of many facilities causes a high level of competition between companies since farmers have many options to sell their crops. In term of price, there are certain rules for healthy competition, so the key to retain the suppliers lies on providing them additional benefits. One of the aspects that suppliers value the most is the response time, both the time required for transporting the crop from the farm to the mill, and the unloading time at the mill. In particular, it is evident that weaknesses exist in the unloading process at the mill, where truck can get stuck for a long time inside the facility waiting for been unloaded. This affects the return time to the field, and therefore it will slow the supply chain and increase the transportation cost for suppliers. These undesirable situations lead to supplier dissatisfaction. With our simulation approach, we intend to analyze the waiting time at the mill, both the actual system and for a set of alternative scenarios, seeking to identify cost-effective options for process performance improvement.

The convenience of using the presented simulation approach lies in the fact that it can straightforwardly be replicated to other palm oil mills due to the similarity of the operation mills, with unloading and temporary storage processes taking place to ensure the continuity of extraction oil processes. Additionally, our simulation requires specific data that is available in all these companies, mainly because they are used for billing aspects, and for calculating statistics reported to FEDEPALMA. Thus, collecting the necessary input data to feed simulation models is not a concern. Obviously, some parameters of the simulation will depend on the specific aspects of the supply chain, particularly the unloading rates which must be determined according to the type of vehicles used, rate of palm fruit processing, and the amount of additional resources such as personnel available for manual unloading.

We built our discrete-event simulation models with SIMIO® [4]. A simulation package that facilitates to represent a system from a facility design perspective, and that provides visualization features that makes it easy for decision-makers to understand the model and the proposed improvement alternatives. With SIMIO®, we built a valid model of the processes of interest, and for the considered case study, we evaluate a set of improvement alternative that would allow achieving an estimated reduction of the average time in system by at least 23%. Similarly, the maximum time in system can be reduced at least by 35%.

The paper is organized as follow: first, Sect. 2 briefly describes the literature review on the use of simulation applied to agricultural sectors. In Sect. 3, we describe the palm oil supply process, the performance indicators and the available data. We present details of the simulation model in Sect. 4. In Sect. 5, we detail the result of the evaluation of alternative scenarios and the comparison with the actual configuration. Finally, Sect. 6 offers conclusions and identifies directions for future work.

2 Literature Review

Supply chains performance and logistics processes have been widely studied using different operations research approaches such as mathematical programming models, inventory models, and queuing theory. A comprehensive literature review is presented in [5], and further applications are described in [6–10]. In [11] the authors present a review of the most relevant research works that used mathematical and computational tools for optimizing sugarcane harvesting processes.

Simulation models have been extensively applied for analyzing manufacturing process [12]. For this, a computerized model of a system is created in order to obtain a comprehensive understanding of its behavior for a given set of operational conditions [13]. One clear advantage of simulation over other approaches is that it can predict the performance of a system before actually implementing it, and it allows anticipating the impact of changes before they are applied to the system.

In the context of agro industrial systems, simulation has been used to study mainly manufacturing and logistic processes. A great deal of attention has been paid to sugarcane production. For instance, several simulation studies dealt with the sugarcane production chain, such as [14], which use a detailed simulation model to analyze the receiving system of sugarcane and the unloading processes, without considering field operations. Likewise, [15] study the receiving system and the rate of arrival of the sugarcane from the field to the mill, but do not consider operations in the field and the return of the trucks to the front of the cane harvest. Research conducted by [16] shows how discrete-event simulation allows to identify the impact of different types of transport practices on the overall sugarcane supply system. Later, [17] propose a simulation model to study harvest operations, transportation and unloading at the mill as a whole. The analysis allowed authors to quantify the waiting times of the raw material from harvesting to unloading within the mill and the penalty for poor quality. [18] propose a simulation-based decision support system to analyze the operational performance of Colombian sugarcane supply chain. Recently, [19] use discrete-event simulation to model cutting, loading and transportation processes for a sugarcane plantation located at São Paulo region. Authors use the model to evaluate vehicles allocation and the performance of other logistics operation, considering changes due to climatic variables and vehicle degradation.

With regard to palm oil agroindustry, the literature that proposes using simulation techniques is less abundant, and a review can be found in [20]. A relevant work for the purposes of the study we present in this paper is the one by [12], which uses a discrete-event simulation model to study oil production system in two phases: replicating the actual fresh fruit bunches (FFB) processing system and developing an improved one.

The studies that address the improvement of Colombian palm oil industry have been more commonly using optimization models, sometimes in combination with simulation approaches. For instance, a research presented by [21] evaluated the concept of reverse logistic flows in the palm oil supply chain through the integration of a mathematical model with simulation. The authors demonstrated that integrating practices associated with the implementation of all forward flows and all possible reverse flows can provide significant benefits over the implementation of forward flows only. [22] proposed two mixed-integer programming models aiming to optimize vehicles allocation for transportation of FFB between internal collection centers, external locations and mill. [23] present a description and value of the relationship between echelons of Colombian oil palm supply chain. [24] defined mathematical models to achieve an optimal configuration of a closed-loop palm oil supply chain. Later, [25] developed a MINLP model for planning harvesting and product extraction in the oil palm supply chain at tactical and operational level. Additionally, some authors have used simulation techniques to evaluate palm oil refining process and biodiesel production process from crude palm oil [26–28].

Despite these efforts, little has been done to evaluate logistics operations of palm oil supply chain, such as transportation and unloading process, to the best of our knowledge. Hence, the purpose of this study is to provide a contribution to fill this gap in the existing literature, by proposing a simulation model that captures important aspects of the fresh fruit bunches unloading processes at Colombian palm oil mills, taking as a case study a mill located at the department of Magdalena. Our objective is to study by simulation the current unloading process and to comparatively evaluate possible improvements.

3 Description of Supply Logistics Processes of Palm Oil Mills

Time and quality are two important variables for FFB supply process because they affect the characteristics of crude palm oil extracted. Hence, mills are located near to the plantations, ensuring that once the raw material are harvested, they are processed within a reasonable period of time. Harvesting may occur every day through the year; however, the quantity of FFB harvested tends to be higher during dates close to mid and end of month. This practice makes transportation planning more complex since companies not only have to deal with randomness, but also with the uncertainty in harvesting scheduling.

Supply logistics processes and the type of vehicles used for transportation may vary among companies in the sector. Some companies have their own vehicles, mainly with automatic unloading, for collecting FFB from plantations. This allows a better control of vehicles arrivals to the mill. In other cases, transportation is done by outsourcing, and farmers decide when to send the fruit to the mill. Since different type of vehicles need to be served, companies must hire workers for the manual unloading of non-automatic vehicles.

Despite the above, both basic operations of FFB supply system inside mills and the extraction process are mostly the same for all companies. The manufacturing process of the FFB includes the logistic, crude palm oil, and palm kernel departments. The logistic

department is in charge of planning the resources required for receiving the fruit until the FFB are placed into the wagons for sterilization. The crude palm oil processing at the mill is shown in Fig. 2. Upon reception, the FBB are weighted and unloaded to start the oil extraction phases. First, fruits are separated from the bunches and the spikelet (threshing), then squeezed to release the palm oil in the fruits (digestion), then pressed to extract the oil from the digested mash, and the obtained product clarified and dried to remove solid and liquid impurities. The final products are then stored and finally dispatched to customers

In the following, we shall focus on the first three steps of the process described in Fig. 2.

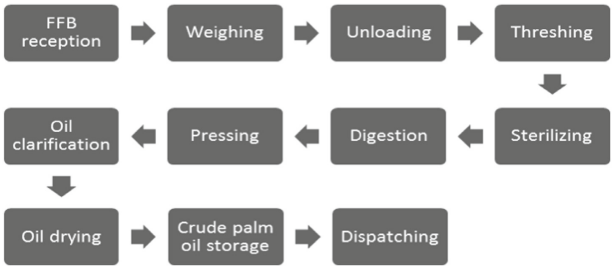


Fig. 2. The crude palm oil process flow.

3.1 Description of the FFB Reception, Weighthing and Unloading Processes

The process begins with the arrival of the vehicle. We identified three different types of vehicles used to transport the fruit: trucks, automatic trucks (trucks with a hydraulic system that eliminates the need to use workers for unloading the cargo) and small wagons towed by tractors. When a vehicle arrives, a ticket number is assigned, and this number is used as an ID to record all information required for the company such as supplier name, place of origin, weight, and type of vehicle, arrival time, and exit time. In order to do that, the drivers must present a document from their respective farm called *reference*. This document includes the code of the place of origin and the number of bunches of fruit. The security guard receives the *reference*, writes down the number of vehicles in the surveillance book and gives the ticket. Once the vehicle enters to the mill, it goes to the weighing area. After the initial weighing, the vehicle goes to the waiting queue to be unloaded. At this point, an employee completes an application form with the arrival time, the number of vehicles, the time of weighing, and the supplier name.

Later, an employee sends a vehicle to the platform for unloading the fruit. When a vehicle goes to the platform, the unloading process begins. First, the vehicle is parked in one of the available places located above the hopper. If the vehicle is an automatic truck, the process takes a little time and no workers are required. Otherwise, the workers will manually remove the fruit using hooks. When the vehicle is empty, it

leaves the platform and goes to the weighing area. This activity is necessary in order to calculate the net weight of the cargo.

Each hour, a specific amount of fruit is removed from the hopper by means of a mechanical system, which allows the fruit to fall into the wagons due to the inclination of the hopper. The wagons are then moved to the thresher and sterilizer, starting the oil extraction process. Figure 3 illustrates the events in the palm oil mill, which were described above.

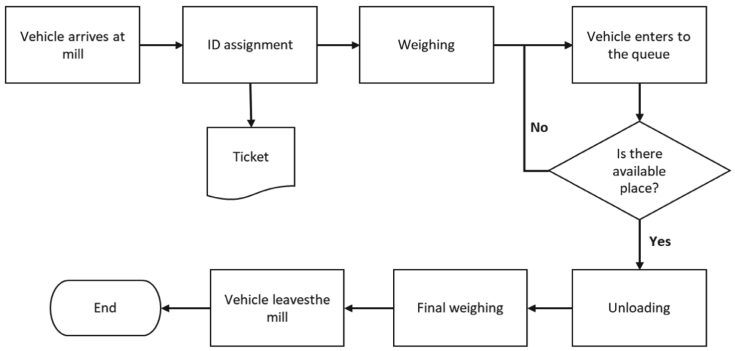


Fig. 3. Flowchart of FFB unloading at mills.

An important aspect of the system lies in the possible truck lines that can be formed in the mill due to the unloading process described above. This situation may occur because of the delay of vehicles during the unloading of FFB, since there are several farmers sending the fruit to the mill. Thus, the process can force a vehicle to be waiting for hours and delay the return of the vehicle to the farm, affecting the functioning of the system as a whole, especially if the vehicle must visit the mill again. This problem may endanger suppliers satisfaction and the relationship between them and companies.

3.2 Data and Performance Indicators

Palm oil companies collect data through the weighing information system using the ID assigned to the vehicles. Since arrival times and net weight transported exhibit a random behavior, this data can be used to estimate the statistical distribution for the interarrival time of vehicles and the load transported for each type of vehicle. It is important to highlight that if a company only uses one type of vehicle, minor changes can be done in the model building to adjust to the actual operations at the mill.

Given that companies want to increase the mill extraction capacity, a stable supply of FFB is required, and it is crucial to maintain a good relationship with suppliers. Because of that, companies are interested in reducing the time that a vehicle remains into the mill. Therefore, we use this variable to analyze the current process and compare it with an alternative strategy based on priority, in order to determinate if it is possible to reduce the time in system of vehicles.

4 Simulation of Palm Oil Supply Logistic Processes at Mills

4.1 Model Building and Assumptions

In this paper, we present a simulation model that combines continuous/discrete modeling in order to increase the results accuracy. Additionally, the methodology proposed by [29] was followed, which includes the next steps: problem formulation; project planning; formulation of the conceptual model; data collection; translation of the model; verification and validation; experimental design; experimentation; setting project interpretation and statistical analysis of the results; comparison and identification of the best solutions; documentation and presentation of results.

The conceptual model of the case study was translated into software SIMIO®, using both Standard and Flow Library. The model was built as general as possible, so it considers the main characteristics of Colombian palm oil companies. The assumptions considered into the modelling step are the followings: a) Mills operate 24 h; however, they establish a time window for FFB reception. b) Three types of vehicles are considered into the model (wagons, automatic trucks, and non-automatic trucks). c) Mill is not interrupted and the rate of FFB consumptions is known and constant during the day. d) There are enough wagons for storaging FFB removed from hoppers and therefore, they would not be considered as a constraint.

The model built in SIMIO® is shown in Fig. 4. As can be seen, the vehicles arrivals are represented by two different sources with interarrival time, one source for trucks and other one for small wagons. The sources create container entities, which content kilograms of FFB. Entities get into a server named *WeighingMach*, and later vehicles are transferred to a station. Entities remain into the station until they can pass to the next stage. We used logic processes to transfer entities from the Weighing area to the station and from to station to the platform (unloading places). In order to properly represent the system, we used an *Emptier object* to model the process that empties the contents of the vehicle (container entity). This object allows us to model the continuous filling of the hopper, while the vehicle is monitored through a Tally statistic that collects the time between the arrival and the unloading ending. After being served, the vehicle goes to the Weighing area for final weighing, and leaves the mill. On the other hand, we used a *Tank object* to model the hopper with specifics weight flow rate for

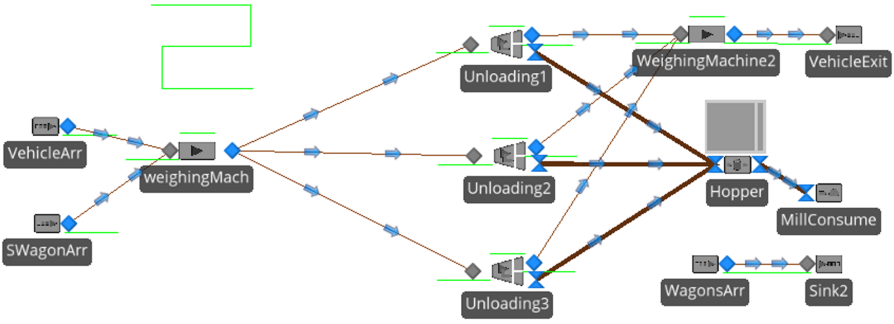


Fig. 4. Simulation model of the current unloading process.

input and output flows. Given that the hopper output flow is not continuous, we implemented a complementary model to enable hourly the regulator flow, so a specific amount of FBB is removed from the hopper.

4.2 Verification and Validation of the Simulation Model

Verification and validation are the most difficult but important step in simulation modeling. While verification is concerned with building the model correctly, validation is concerned with building the correct model [12]. Since the technique of distribution fitting was applied to select the appropriate probability distribution for a series of data of interest such as interarrival time and kilograms of FBB carried by vehicles, we decided to verify the simulation model by comparing the probability distribution of real data with the total number of arrival and the total kilograms of fruit received per day, obtained through 12 replications of the model with a run length of 24 h.

The results indicate that both series of number of arrivals data (real system and simulation model) can be fitted by a normal distribution and the means are not statistically different from each other. A similar outcome was obtained for the variable kilograms of FFB carried by vehicles. These results indicate that the model was appropriately built.

For the validation process, we compared the probability distribution of real time in system with the Tally statistic recorded for all the entities, running the model during 12 days. We established that there are enough similarities between both series of data and hence, we can affirm that the model was correctly built. Once the verification and validation processes were concluded, we analyzed the modification of the current unloading procedure proposed by the company.

The analysis of the results was conducted only after the simulation model was completely verified and validated and assured that the assumptions and simplifications embraced were accurately implemented in the computational model.

4.3 Case Study

We conduct an empirical case study using real data from a Colombian palm oil company. The selected palm oil company is an organization with more than forty years of experience in the market. The company has administrative headquarters in the city of Santa Marta and has a palm oil mill in the municipality of Zona Bananera, which processes the FFB provided by external suppliers and strategic alliances that represent about 63% of the total suppliers. The remaining amount of FFB is supplied by founding partners. The associative structure of inclusive business models known as *Strategic Productive Alliances* integrates small and medium farmers organized in associations, and it has allowed the noteworthy growth of this agroindustrial sector in Colombia, showed in the increase of the number of municipalities with established crops. This type of associative strategy is used by this company and it has enabled it to increase the supply of the fruit, which has a significant effect on the transport and unloading requirements.

The mill has a processing capacity of 34 tons of FFB per hour and has three available places to unload the FFB cargo. It operates 24 h per day; however, FFB load are only received within a time window of 15 h, from 6:00 to 21:00, every day.

To quantify the parameters and the distribution of random variables, the company provided access to the log and the data stored on weighing system. We use information of 12 days of operations in order to estimate. The considered time period corresponds to the arrival of 644 vehicles, including small wagons, trucks and automatic trucks. The vehicles transported a total amount of 3.2 million of kilograms of FFB to be processed at the mill.

Given that different vehicles arrive to the mill, we decided to test if there were statistical differences between trucks and automatic trucks interarrival times. For this, we used a mean comparison test for unpaired data with unequal variances using Welch´ s. The obtained result indicates that the means are not statistically different from each other (See APPENDIX C). Furthermore, the small wagon arrival was modeled apart from the others type of vehicles due to the number of entities per arrival is a random variable. Table 2 summarizes the parameters and random variables values used as input for the simulation model.

Table 2. Input parameters and distributions of random variables.

Parameter/random variable	Value
Interarrival time for trucks and automatic trucks	Random.Exponential (40)
Entities per arrival	1
Interarrival time for small wagons	Random.Exponential (120)
Entities per arrival	Random.Triangular (2, 4, 7)
Weighing server processing time	3 min
Automatic trucks weight	Random.Weibull (5.43286,12047.72)
Trucks weight	Random.Weibull (3.76144,16158.09)
Small wagons weight	Random.Weibull (9.9244, 7721.85)
Unloading flow rate for automatic truck	4500 kg per minute
Unloading flow rate for other vehicles	500 kg per minute
Hopper output flow rate	34000 kg per minute, hourly

5 Results and Discussion

Our objective is to investigate the potential reduction in the time of the system that could be obtained with a simple modification of the currently unloading procedure. The policy conceived by the company consists of enabling another unloading place for those vehicles that have been parked in the station for over 2 h (Scenario 1). For this, the model was slightly changed to incorporate the new policy, as illustrated in Fig. 5. First, we added an object that empties the contents of the vehicle as we did in the initial model; however, the content is stored in wagons until there is available capacity in hopper. This aspect was not modeled since it is possible to place the FFB in the first hours of each day. The output flow rate for automatic trucks is higher due to the

vehicles can unload the box instead of the fruit. Nonetheless, the unloading rate for manual unloading is the same. Second, we modify the logic process used to control the transfer of entities to the emptier objects. The model was prepared to run for 360 h, using an experiment of 10 replications and 95% of confidence level.

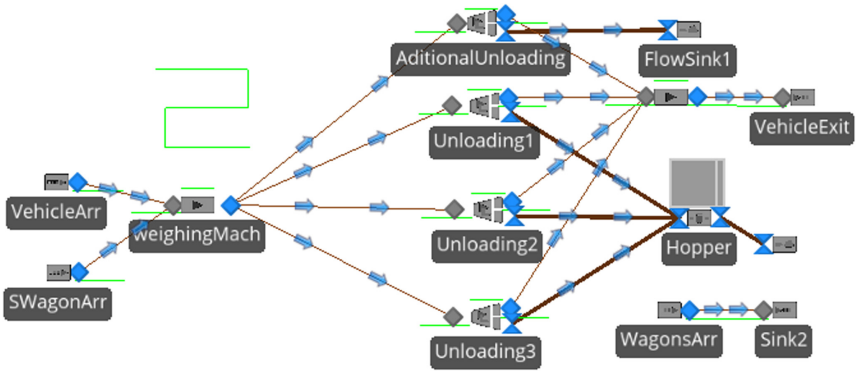


Fig. 5. Simulation model of the scenarios.

As a result of our analysis, we decided to propose a different scenario (Scenario 2) in which the additional emptier could be used as follows: If an automatic truck arrives to the mill and the unloading places are busy, the vehicle could be transferred to the additional unloading. If a small wagon or truck has been parked in the station for over than 2 h, it could be transferred to the additional unloading. An additional scenario is evaluated (Scenario 3), in which the maximum waiting time in station is 1 h. As in the previous scenario, the model was prepared to run for 360 h, using an experiment of 10 replications and 95% of confidence level.

Table 3 provides summary statistics for the variable time in system in each scenario as well as the initial model.

Table 3. Comparision of scenarios.

Model	Measure	Average	Half width
Current procedure	Average time in system	3.0970	0.3496
	Maximum time in system	14.6039	2.3236
Scenario 1	Average time in system	2.3726	0.2154
	Maximum time in system	8.6103	0.9189
Scenario 2	Average time in system	2.2932	0.1873
	Maximum time in system	9.4616	1.0862
Scenario 3	Average time in system	1.7655	0.1333
	Maximum time in system	7.9568	1.1725

It is evident from the previous results that if the company decides to implement any scenario, the average time in system can be reduced at least by 23%. Similarly, the maximum time in the system can be reduced at least by 35%.

This shows that it is possible to decrease the delays in the system and, at the same time, improve the supplier satisfaction. It is expected that readers consider the cost-effectiveness ratio, and for this it is important to clearly explain the following aspects: the unloading process for automatic truck do not require workers, so no additional costs are incurred. The company hires a workers' cooperative for unloading the FFB and it pays it for the total of kilograms moved plus a percentage per number of workers. Since the total of kilograms is the same, the company only needs to assume an additional cost of two workers. There is always a vehicle available for material movements at the mill, and this vehicle can transport the wagons of FFB from the new place to platform for unloading the fruit. In the light of the above, it is far more convenient and less expensive to change the current procedure.

6 Conclusions

This paper describes a simulation model used to analyze the current state and scenarios in the palm oil supply chain. Thus, the verified and validated model had been used to estimate the impact of operative changes in the waiting time for vehicles. In this research, the investigated improvement enhances expanding the number of unloading docks and exploring different priorities in the procedure. Comparison between the simulation of current and alternative systems indicates that the average time in system and the maximum time in system can be reduced at least by 23% and 35%, respectively. The most important finding is that the decrease in waiting time can be reached without a major investment. Due to the similarity between palm oil mills located in the department of Magdalena, this simulation model can be applied to other companies to evaluate improvement alternatives. For future work, a model that includes harvest operations, transportation and unloading at the mill should be carried out. Moreover, the extraction process and its breakdowns should be studied since this causes delays in the system.

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