SIMULATION MODEL TO REDUCE THE IMPACT OF RAIN STOPS AND BREAKDOWNS ON SUGARCANE HARVESTING, TRANSPORT, AND CRUSHING SYSTEM PERFORMANCES

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Abstract

In Morocco, sugarcane is normally harvested between January and June. The rainy season also begins in January and harvesting during this period delays harvesting operations and causes cane quality problems. As a result, growers are penalised for delivering poor quality cane and the harvest is often extended beyond June. Further, the yield in the subsequent stubble crops is reduced for sugarcane fields harvested in July and August. Besides the negative effect of late harvesting on the subsequent crop yields, sugarcane, which has been harvested after June, is more vulnerable to frost damage. Other considerations include mill breakdowns, lack of co-ordination between harvesting, deliveries and crushing, these cause the stockpiling of more cane in the millyard. This leads to cane and juice deterioration and poor quality feedstock for the mills.

A computer model has been developed which could be used to evaluate different methods and to determine the optimal supply chain management which reduces the impact of rain and breakdown stoppages, thus improving overall harvesting and mill efficiency. Simulated results, compared to the ones observed, show that there can be a 68% and a 25% reduction in the average truck waiting time at the mill entrance and before unloading respectively. The average waiting time of one ton of cane before processing is reduced by 31%. The optimal strategy carried by the model, demonstrates that there is scope to not exceed the millyard capacity and not extend the harvest after June.

Keywords: sugarcane, rain delays, breakdowns, supply chain management, simulation model

Introduction

Sugarcane produced in the Gharb region of Morocco, taking into account weather characteristics and cane requirements, is harvested between January and the end of June. The rainy season, which normally begins in January, disrupts harvesting, transport and crushing operations. The sugar mill sets the harvest schedule based on crop yield and sugar content; however, this plan is compromised by the onset of rain that prevents infield access of transport vehicles. In the event that wet conditions do not allow infield access, the harvest schedule is dependent upon the growers' willingness to carry their cane out of the fields for loading into transport units. This operation is very difficult and costly. Furthermore, hand loading reduces the efficiency of the harvest operation, often not producing the tonnage required by the mill. As a result, the harvesting season may extend beyond June, which adversely affects the grower. For sugarcane fields harvested after June, yields of the subsequent ratoon crops are substantially reduced. These ratoon crops harvested late in the year are also more vulnerable to freezing temperatures. Apart from periods of rain, mechanical breakdowns in the mills cause problems due to oversupply of cane causing problems with deterioration of cane supply held over in the millyard. There are also scheduled stops or technical breakdowns that can last from a few minutes to more than 24 hours.

Rain and breakdown stoppages cause harvest interruption and generate long delays between harvesting and delivery, and between delivery and crushing. It follows that the crushing capacity of the sugar mill is reduced and the length of the harvesting season is extended because of cane supply and quality problems. Sugarcane deterioration reduces the quality of extracted juice, as well as the quality and the quantity of the sugar produced. This can lead to considerable financial losses. Consequently, it is necessary to harvest, transport, and crush sugarcane in conditions which maintain its quality and minimise the costs of production.

A simulation model of the harvesting, transporting, reception and crushing system of sugarcane has been developed and could be used to reduce the impact of rain and breakdown stoppages on the performance of the system.

Model formulation

The model was developed using SIMUL8 Visual Interactive Modeling System (Jorio, 2005), and is based on the use of graphic symbols or icons which reduce the need to code the simulation model (Hauge and Paige, 2004). The model is constructed by placing simulation icons on the screen to represent different elements of the model. A particular icon could represent a queue or a work center. Data are entered into the model by clicking on the relevant icon to activate a screen input dialog box. For most business applications, a visual interactive modeling system is the most appropriate although the software package can be expensive (Greasley, 2004). In the present study, the choice of SIMUL8 was made due to the availability of a free version of this software for research purposes at the University of Hawaii. It was also chosen because it appeared to be appropriate to the implementation of the model.

The model was developed for a particular sugar mill and the area supplying it with cane. The harvesting, transporting, reception and crushing system of sugarcane comprises three sub-systems. The first is the supply area with its cutting and loading facilities, located in different Development Agricultural Centrer (CDAs), supplying the mill, its track and road networks and its vehicle parks. The second is the sugar mill reception with its five services connected in series, namely registration, weighing loaded, double sampling, unloading and weighing unloaded. The last sub-system is the processing unit with the millyard. These three sub-systems were modeled and connected to each other the way they interact in the real system. All operations from cutting and loading until the feeding of cane into the mill for crushing were included. Each CDA supplying cane to the mill had to be represented to simulate the effect of cane being delivered from different sources and at different timing. The general structure of the model is shown in Figure 1.

Two main constraints were taken into account in the execution of the model, (i) rain stops and (ii) processing unit scheduled stops and technical breakdowns during the 2002 harvesting season. Several scenarios and system configurations were tested. Thus, different Visual Logics were built using SIMUL8 code and commands to set up these scenarios. SIMUL8 obeyed each of these visual logics, while running the corresponding scenario in the model. The simulation time frame, which is also the length of the harvesting season, was given by the model itself since each simulation run stopped when the total tonnage of sugarcane was harvested and processed. By recording statistics on times and numbers in queues for different scenarios, methods of reducing rain and breakdown stoppages on the performance measures of the system could be evaluated, analyzed and compared to determine the optimal supply chain management.

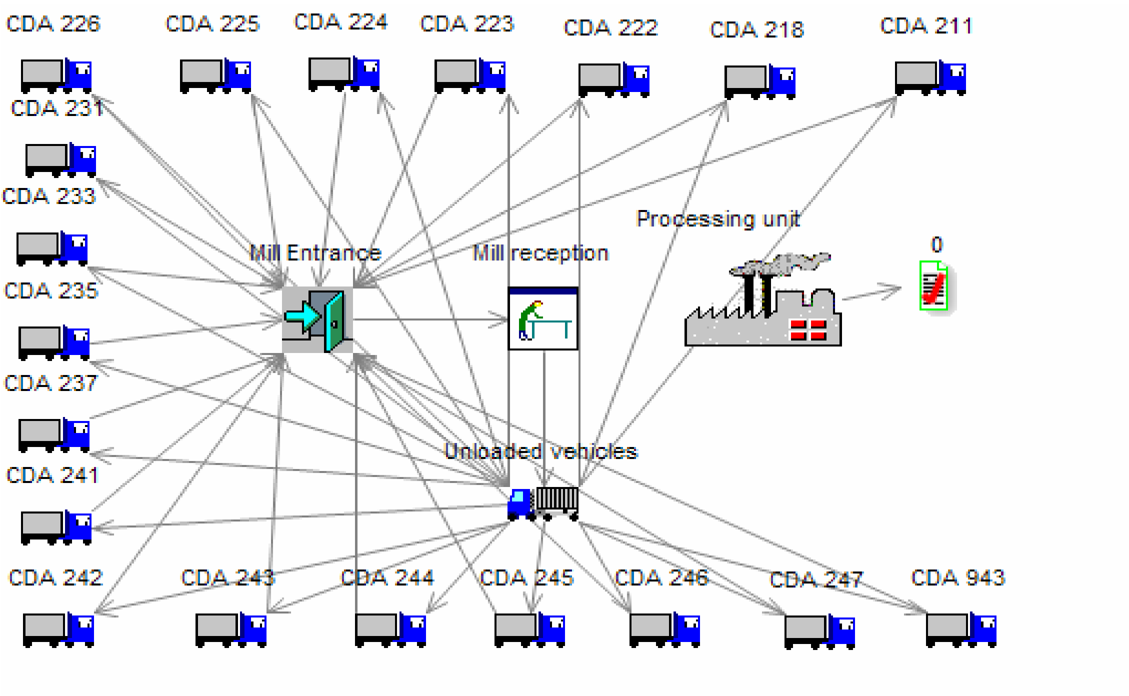

Figure 1. Structure of harvesting, transporting, reception and crushing system of sugarcane in model using SIMUL8.

Model with constraints experimentation

The use of the model as an experimental tool, allows simulations of alternative system configurations, followed by examination and comparison of the results. The objectives of experimenting with the model are numerous. Model without constraints objectives were different of those of the model with constraints. In the first case, harvesting, transporting, reception and processing operations were assumed to be accomplished under ideal conditions, where no stops or breakdowns were considered. The main objectives of the model without constraints experimentation were (Jorio, 2005):

- To determine the optimal fleet size
- To determine vehicle optimal dispatching strategy
- To determine the number of round trips for each vehicle
- To establish daily schedules for trucks
- To determine the performance measures of interest in the best case scenario, where there is no rain and no sugar mill breakdowns.

Two main constraints were taken into account in the model with constraints experimentation, rain stops and processing unit scheduled stops and technical breakdowns. The objective of the model with constraints experimentation was to test several scenarios and system configurations in order to reduce the impact of rain and breakdown stoppages on the performance of the system. As no cost data are available, performance measures or service quality indices that are of interest in this study are waiting time and queue length at different service facilities. They also deal with harvesting season length.

Quality indices of the system

- *At the cane supply level.* It is very important to avoid or at least reduce cut cane waiting time before loading to avoid cane quality problems.
- *At the reception level.* Since the queue capacity is finite for weighing loaded and double sampling servers, vehicles queue length and waiting times at the mill entrance and before unloading are the performance measures of interest that need to be improved.
- *At the processing unit and millyard level.* It is important to keep the stock level of cane before processing at less than 6,000 tons, which is the millyard capacity. It is also essential to avoid long delays between unloading and crushing.
- *For the whole system.* To avoid financial losses, millers need to plan to start and end harvesting at the required dates. On the other hand, to reduce transport costs, it is necessary to optimise vehicle fleet sizes and dispatch strategies.

Basic assumptions or working strategy of the system

All experiments conducted using the model were based on several assumptions:

- Harvest and delivery operations begin simultaneously in all CDAs
- Crushing starts two days after the beginning of the harvest season
- Tonnage to deliver each day from each CDA is cut the day before
- Deliveries are made between 6 am and 12 pm seven days per week
- Processing units work 24 hours per day and seven days per week
- Daily crushing capacity of each processing unit is prescribed by uniform distribution
- The amount of cane to cut and delivered to the mill each varies according to weather conditions and breakdown occurrence (Jorio, 2005)
- Carrying the cane out of the fields manually in wet periods is not permitted.

As the goal of the experiments conducted with the model is to reduce the influence of rain and breakdown stoppages, several scenarios are tested. Each is run 30 times under the same hypotheses, so as to ensure the accuracy of the results. The first scenario takes into account 2002 harvesting season breakdown durations and number of rain days. This scenario requires interrupting cutting and loading where the amount of rain accumulated in 10 days exceeds 20 mm. These two operations can not restart again unless the amount of rain accumulated over 10 days is less than or equal to 20 mm to allow field accessibility. According to 2002 rain data from different meteorological stations in the SURAC sugar mill supply area, cutting and loading were interrupted for three days in February, 22 days in March and 20 days in April. It is also assumed that crushing is interrupted only for the time needed to repair breakdowns. The model uses the processing unit technical and scheduled breakdowns of 2002 harvesting season. The objective of the following scenarios is to reduce the rain and breakdown influence on the quality indices of the system by altering experimental factors to determine whether an improvement to the system can be obtained.

In order not to exceed the millyard capacity, scenario 2 adds to scenario 1 a management strategy that interrupts cutting and loading operations for 24 hours following a breakdown which lasts more than 360 minutes.

To reduce the stock level in the millyard and not extend the harvest after June, scenario 3 consists of delivering only 50% of the tonnage required from each CDA on the day following a breakdown which lasts more than 180 minutes.

The goal of scenario 4 is to keep the stock level below the millyard capacity. Also the harvesting season should not extend beyond the end of June. Instead of cutting and delivering 50% of cane in all CDAs, as was the case in scenario 3, these two operations are stopped altogether on the day following a breakdown which lasts more than 180 minutes, in the CDAs that have the smallest daily amount of cane to deliver to the mill. Eight of the 19 CDAs are affected, while the remaining CDAs deliver 50% of their daily tonnage as in scenario 3.

Scenario results and discussion

Model with rain and breakdown stoppages execution gives the results of the different scenarios proposed and tested. These results are presented and compared to determine the best scenario for optimum supply chain management.

Figure 2 shows that queue performances at the mill entrance are similar in the four scenarios.

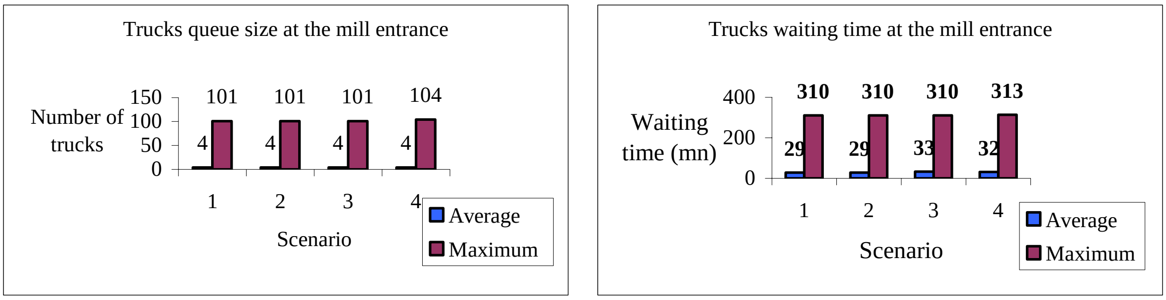

Figure 2. Queue performances at the mill entrance.

Queue performances before unloading are also very close to each other in the four scenarios, as confirmed by Figure 3.

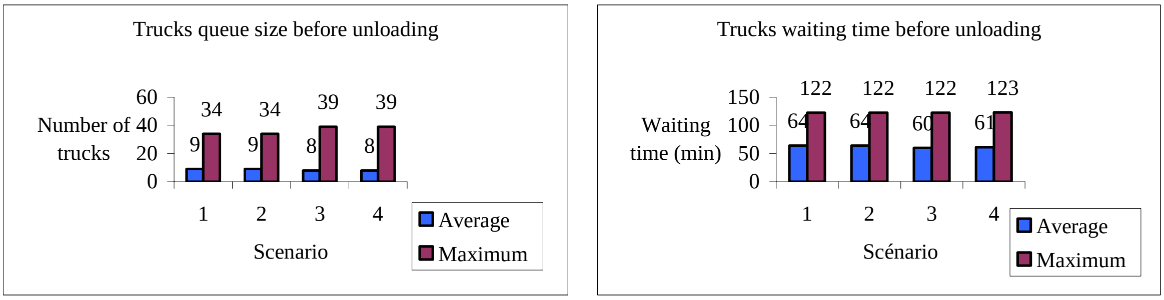

Figure 3. Queue performances before unloading.

Figure 4 shows that, in scenario 1, millyard queue size is very large. In scenarios 2 and 3, it exceeds millyard capacity. So, these three scenarios are inconvenient. In scenario 4, the maximum stock level is less than the millyard capacity, and both queue size and waiting time are reduced. Consequently, scenario 4 gives the best queue performances of tons of cane in the millyard.

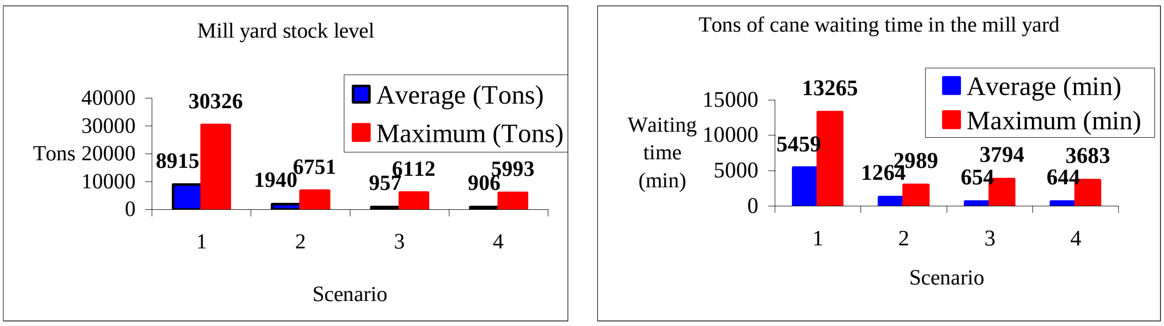

Figure 4. Queue performances in the millyard.

The harvesting season lasts 181 days in scenario 4, as confirmed by Figure 5, which means that the harvest season is not extended after June, since it began on 01 January. Therefore, scenario 4 offers the best solution for optimum supply chain management.

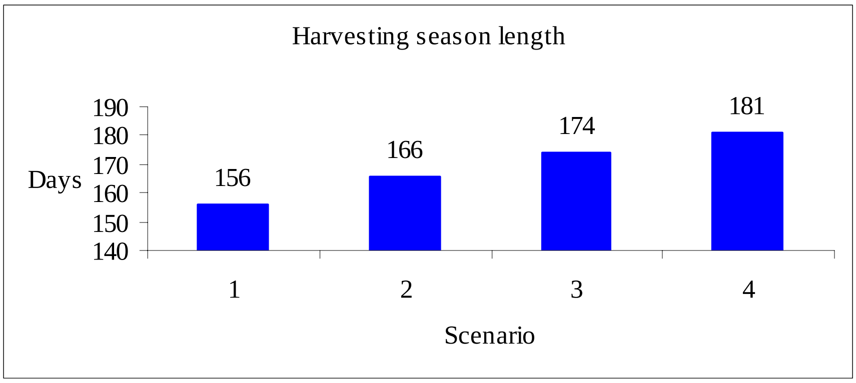

Figure 5. Harvesting season length.

Comparison with actual performances of the system

A comparison of the simulation results with the actual performance measures of the system as it functions at present, shows that there is scope for improving performance. Thus, the performance of scenario 4, compared with that of the real system during the 2002 harvesting season, shows a significant improvement in all quality indices, as shown in Figure 6.

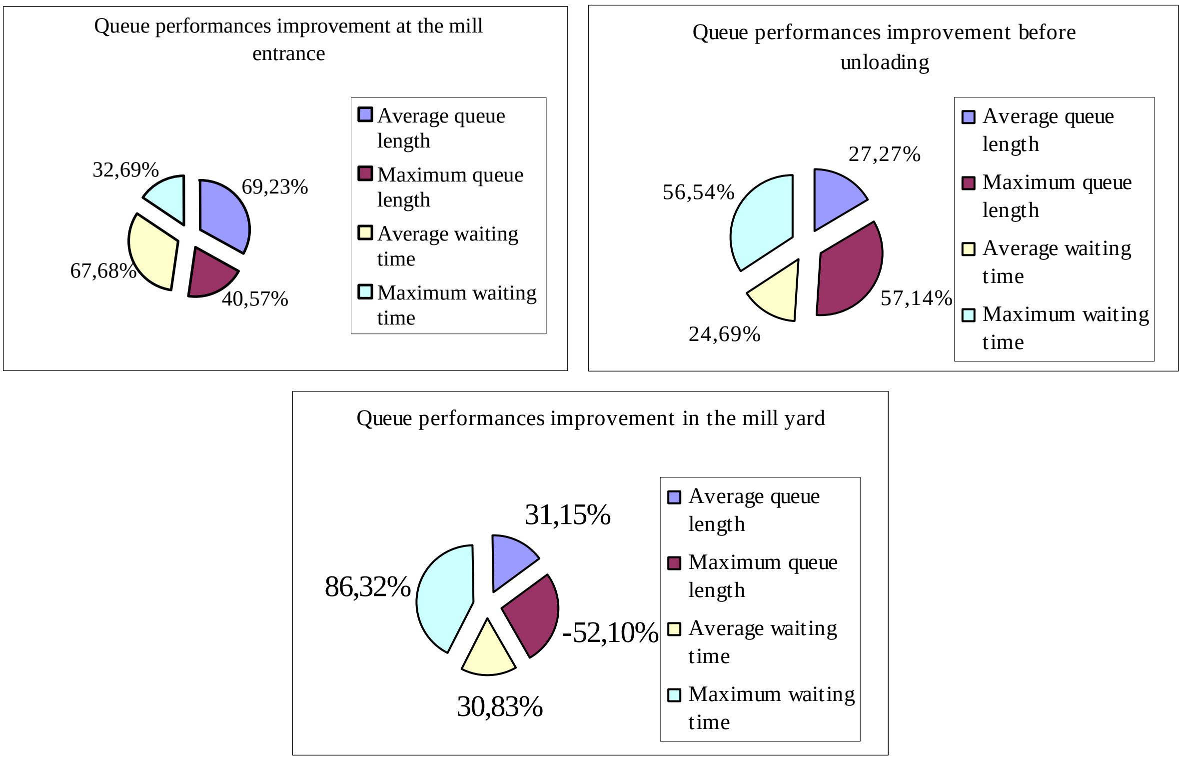

Figure 6. Queue performance improvements.

In the event that the system configuration, the optimal fleet size and the dispatch strategy proposed are adopted, Figure 6 gives the percentage reduction in number of trucks used and maximum queue size, as well as average and maximum waiting times at the mill entrance and the unloading facility. In fact, using a large number of vehicles, as was the case in 1999, 2000, 2001 and 2002 harvest seasons, increases transport costs. More than that, it can lead to a serious deterioration of the cane supply.

Figure 6 also gives the percentage reduction in tons cane average queue size, as well as average and maximum waiting time in the millyard. It shows that there is an increase of sugarcane maximum stock level in the millyard (the minus sign in (-52.10%) means that there is an increase in the maximum amount of cane waiting to be processed). This can be explained by the fact that the simulated system consistently delivers the specified tonnage (3,498 tons) to the sugar mill (unless it rains or in case of breakdown occurrence) causing an increase in millyard stocks, while in the real system the amount of cane delivered daily is very irregular and at times is as low as 400 tons. The low tonnages delivered on some harvesting days in the real system are most likely due to brief (a few hours) interruptions in cutting, loading and delivery due to rain. Also, CDA growers do not like to hand-carry cut cane out to the roadway to load it into vehicles which cannot enter the fields. In fact, carrying sugarcane stalks out of the fields is a difficult task that must be avoided to maintain worker output.

No tonnage below 3,498 tons is delivered to the mill, in the simulated system, unless both cutting and loading operations are interrupted or the amount of cut cane is reduced in case of breakdowns. However, the average queue size in the millyard is smaller in the simulated than in the real system, which can be explained by the fact that in the simulation model, processing time is uniformly distributed while it is irregular in the real system.

Table 1 summarises observed system working and presents the organisation of different operations proposed by the simulation model. It also gives the advantages of the management or working strategy proposed, compared to the actual organisation of the harvesting, transporting, reception and crushing operations.

Conclusion

The use of the simulation model developed to investigate methods for reducing the impact of rain and breakdown stoppages on the sugarcane harvest, transport, reception and crushing system performances, was successful. As no cost data were available, performance measures of the system have been evaluated in terms of waiting times and queue sizes only. Based on the knowledge that time is money, the reduction in time could have a significant financial impact. It will be interesting to estimate the losses generated by the use of a large number of vehicles, as is the case at present. This evaluation needs to include vehicle waiting time costs at different service facilities due to the large number of vehicles used. It is also interesting to evaluate the losses generated by crushing deteriorated cane because of harvest to crush delays. It is also recommended to evaluate the losses generated by sugar mill shut downs and breakdowns, and also by the processing time which is particularly irregular and at times very protracted.

Results of the different scenarios tested show that scope exists to reduce the impact of rain and breakdown stoppages on the performance measures of the system either by interrupting the harvest or by reducing the amount of cane cut. A comparison of the results of the best scenario, which gives the optimal supply chain management, with those of the real system, shows a significant improvement in all system performance measures of interest. Simulation runs give harvesting season length and show that the scope exists to not extend the harvest after June.

Table 1. Performances of simulated and observed systems(2002 harvesting season).

System	Observed (2002 campaign)	Simulated	Advantages of simulated system
Beginning of the season	January 12	January 01	Beginning at the planned date
Beginning of deliveries	January 12	January 02	Cut cane ready to be loaded
Beginning of crush	January 17	January 03	Enough cane to start grinding
Season end	July 08	June 30	Avoid yield losses of the next stubbles
Season duration (days)	179	181	Period and duration of harvesting season respected
Cutting operation	Discontinued in some CDAs	Continued in all CDAs	Reduces shortage of labour problem at the end of the harvesting season
Harvesting plan	Not respected	Established and respected	Harvesting date of each parcel known
Quota per parcel	No clear rule	Based on its area	Same amount to cut and deliver daily from each parcel
Quota per CDA	No clear rule	Based on mathematical formula	Same amount to cut and deliver daily from each CDA
Tonnage delivered	Irregular	Regular	Regular and sufficient supply
Number of trucks available	Irregular and very large	Optimal	Just the number required to ensure regular and sufficient supply
Number of trucks assigned to each CDA	Random	Optimal	Optimal number of rotations for each vehicle
Tonnage processed	Irregular	Regular	Harvesting season not extended after June
Processing time	Irregular and very long	Regular	Reaches the capacity of the processing unit
High amount of rain	Carry cane out of the fields	Harvesting interruption	Reduces the impact of rain stoppage on the system
Breakdowns	Random amount of cut cane delivered	Reduction of the amount of cane cut and delivered	Avoid cane long waiting time in the millyard before processing
Stock reconstitution stops	Exist	Absent	Perfect co-ordination of different operations
Insufficient supply stops	Exist	Absent	Perfect co-ordination of different operations

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