INCORPORATION OF SUGARCANE HARVESTING AND TRANSPORT VARIABLES INTO A SUGARCANE HARVEST AND TRANSPORT SCHEDULING MODEL

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Abstract

Recent changes in the national and international environments of the Moroccan sugar industry pose competitive and efficiency issues. These changes often bring into question the very survival of the Moroccan sugar industry, especially that of the mills. The search for profitability for both sugarcane and sugar beet operations becomes imperative for the long-term survival of the industry. In order to ensure profitability, the industry must focus on novel management tools for harvest and transport operations of both sugarcane and sugar beet. The harvest, transport, reception, and crushing system for both sugar crops are very important components of sugar production that require a systems approach through modelling in order to facilitate the optimal use of the resources involved.

For this study, theory of queues and simulation techniques were used that incorporate sugarcane harvest, transport, reception and crushing into a mathematical programming model to facilitate both scheduling of harvest and transport. The model was developed for the SURAC sugar mill but could be adapted to all other sugarcane and sugar beet mills operating in Morocco. SIMUL8 was identified as the appropriate software for the modelling exercise.

Model validation showed great agreement between observed and simulated results. The model without constraints was used to determine the optimal number of transport units, dispatching strategy, and daily schedules. Simulation results show that the number of transport vehicles could be reduced by 50% and, at the same time, efficiency could be improved by maximising the number of daily round trips per vehicle.

Keywords: harvesting, transport, scheduling, model, simulation

Introduction

Sugar crops and sugarcane in particular have been welcomed by growers since they were reintroduced into Morocco in 1973. However, the Moroccan cane industry still suffers from management problems. These problems are the result of a lack of coordination between harvesting, transporting and crushing schedules due to manual organisation of these operations. Many researchers have focused on modeling sugarcane harvesting, transporting and crushing systems throughout the world. Most of them used, whatever their objectives, queuing theory and simulation techniques to develop their models.

In the United States, Cochran and Whitney (1977), developed a simulation model to estimate the amount of cane delivered to the mill per hour, for a given transport system in Louisiana. In the Philippines, Libunao (1977) developed a model to test alternatives, strategies and decisions in cane transport system management after the harvest. The author determined the arrival rate of transport vehicles to the mill, the average waiting time and the maximum queue length at the mill entrance. In Brazil, Gentil and Ripoli (1977) simulated a theoretical example to determine trucks, harvesters and transport engines number used inside the fields in a specific case. In Thailand, Gajendra and Abeygoonawardana (1982) developed a computer simulation model for sugarcane mechanical harvesting and transport system for a particular sugar mill. The information gathered after simulating the model can help growers to determine the optimal number of trucks required to transport the cane harvested at a certain distance of the sugar mill. Simulation results can also help sugar mill managers to allocate daily quotas to growers depending on the distance between the field and the sugar mill and the number of trucks available to transport the cane. In South Africa, Meyer (1998) developed a computer model to estimate the performances and the cost of harvesters and transport engines which accompany them in the fields. The model, developed in order to evaluate the effect of different field parameters and conditions, and also the number and capacity of infield transport vehicles, showed that factors such as cane yield, infield conditions, and number and capacity of transport vehicles have a significant effect on harvester performances. The model was also very useful to evaluate the viability of introducing mechanical harvesting systems under different agricultural conditions and management rules. In South Africa, Hansen *et al*. (1998), Barnes *et al*. (1998) and Barnes *et al*. (2000) developed a simulation model of the harvesting, transporting and crushing system of sugarcane. The aim of their study was to evaluate methods to reduce sugarcane harvest to crush delays in South Africa. The results of different experiments conducted using the model showed that the longest delays occur when burnt cane waits in the fields to be cut, in transloading zones or in the mill yard. Simulation of different alternatives showed that co-ordination between burning schedule, harvesting, supplying and crushing plans substantially reduced these delays. In Australia, Raicu and Taylor (2000a, 2000b, 2001) developed a simulation model for the cane road transport system of a particular sugar mill. The objective of the model was to minimise the number of trucks used to transport the cane and also to determine their optimal dispatching strategy in order to unsure maximal utilisation of the trucks. The main output variables of the model were average trucks waiting time at the mill, average trucks queue length, total idle time of the mill, average waiting time of loaded bins in the pads.

In Morocco, Belfkih and Madrane (1983) and Aboulal (1993) recognised the complexity of the harvesting, transporting, reception and crushing system of sugarcane; however, no study or research was initiated that focused on its modelling to improve the management of this chain. The main objective of this study was to develop an interactive computer based model that could be used to determine:

- The optimal number of trucks required to meet the daily needs of the mill.
- The optimal dispatching strategy of vehicles between different Development Agricultural Centres (CDAs) to unsure the delivery of the required amount of cane from each CDA.
- Each vehicle daily schedule.
- The performance measures of the system.

The sugarcane harvesting, transport, reception and crushing system consists of many elements requiring service at several service facilities. It seems judicious, prior to model development and simulation, to represent the system as a queuing process.

The queuing and simulation framework of the study

The sugarcane harvesting, transporting, reception and crushing system can be considered as a queuing system or, in fact, as a network of queues. It is a multi source system with one destination, the sugar mill, as illustrated in Figure 1.

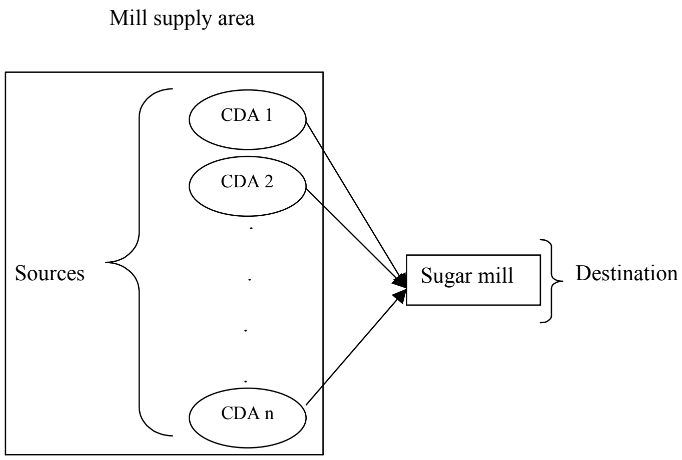


Figure 1. Representation of harvesting, transporting, reception and crushing system of sugarcane as a queuing process.

The sugarcane for the mill originates from different CDAs which constitute the sugar mill supply area (Figure 1). The service facilities located at the point of origin of the sugarcane are the cutting and loading of cut cane in transport units which deliver it to the mill. At the mill reception, service facilities are vehicle registration, weighing in, manual and mechanical sampling, unloading and weighing out. At the production unit and the mill yard level, sugarcane is unloaded for processing immediately or placed in storage for processing later in the day for the production of sugar. Each farmer receives orders from the mill stating the number of tons or trucks to be delivered daily to the mill for processing. However, many factors influence the number of tons to be cut and delivered by each farmer. These factors include yield of recoverable sugar per ton of cane, yield or production in tons cane per hectare, previous harvest date and the variety harvested. All of these factors are normally taken into account to establish the daily harvesting schedule by the mill. This daily harvesting schedule has to be reviewed and adjusted after rain and breakdown stoppages, either to reduce the amount of cane to cut after breakdown occurrence or to interrupt the harvest when it rains. However, because these factors are stochastic and of different duration the scheduled arrivals and production goals are often not met. The analogy with a queuing system can be seen.

Besides being placed in the framework of queuing theory, the study is also a simulation model. In practice, simulation is most widely used and appropriate for applications that involve queuing of people, materials or information (Greasley, 2004). Simulation is also appropriate in the present study because the harvesting, transporting, reception and crushing systems of sugarcane are both stochastic and dynamic. They are stochastic because most of the parameters and service times vary randomly. They are dynamic because their behaviour varies over time. Simulation is also used because of the lack of adequate analytical tools to describe such complex systems and to analyse the resulting queuing system characteristics.

SIMUL8, a Visual Interactive Modelling System, was chosen as the model development platform because this software allows incorporation of both dynamic and stochastic factors in queuing models. The interactive nature of SIMUL8 allows the user to easily modify the model and to perform experiments.

Model development

The model was developed on the scale of the SURAC sugar mill and the area supplying it with cane, because it is very often the interaction of factors, such as harvesting and milling schedules, fleet size and transport cycles that have an influence on the amount of sugarcane delivered daily to the sugar mill.

The sugarcane harvesting, transport, reception and crushing system of SURAC sugar mill includes three sub-systems. The first is the supply area with its cutting and loading facilities located in different CDAs, its tracks and roads networks and its vehicle parks. The second is the sugar mill reception with its five servers connected in series and named, registration, weighing loaded, double sampling, unloading and weighing unloaded. The third sub-system is the processing unit and the mill yard. These three sub-systems are modelled and connected to each other within SIMUL8 according to the way they interact in the real system. Transport, initially modelled as a non-limiting resource, was then optimised by progressively reducing the number of trucks assigned to each CDA, and increasing at the same time the number of daily round trips each vehicle could make to ensure maximum utilisation of vehicles and to reduce transport costs.

Model structure

The basic structure of the model is shown in Figure 2. The progress of tons of cane are modelled and tracked through the system. These entities are assigned attributes or labels based on the CDA from which they originate, and their number in the daily cutting plan of that CDA. Such attributes are also used to keep track of the times at which entities pass through various points in the system. The entities are initially created at the cutting process of each CDA, according to defined schedules and at such a rate that the required amount of cane will be produced daily from each CDA. After cane is cut, it goes to the loading process where the one ton entities are combined into loads of 11 tons. Each load corresponds to average load capacity of the transport units. The loading process can only start when transport and cane are available. Each CDA is supposed to own its park of vehicles as is the case in the real system. The cane is then routed to the mill directly with a route time described by a Normal distribution with a mean given by equation (2) and a standard deviation supposed to be equal to 25% of the mean. Once at the mill, a loaded truck waits at the mill entrance until the registration server becomes idle, then it goes through the mill gate and subsequent reception facilities according to FIFO discipline. After unloading, the truck is weighed empty to determine the amount of cane it carried to the mill. It finally goes through vehicle routing, which is a virtual server that routes it back to the CDA to which it belongs, to be loaded again. The route time back to each CDA is also described by a normal distribution with a mean given by equation (3). The cane unloaded in the millyard is then crushed and processed at the processing unit before leaving the system. The processing time is the time needed to process one ton of cane. Given the lack of data regarding this random variable, its statistical distribution is determined using a heuristic approach. This approach consists of assuming that the processing time is distributed according to a Beta distribution of parameters α_1 and α_2 with $\alpha_1=\alpha_2=1$ (Kelton and Law, 1991). This leads to Uniform distribution. As the average crushing capacity of SURAC sugar mill is 3500 tons per 24 hours or 1440 minutes and, to ensure regular and sufficient supply to the mill, the daily tonnage processed should be between 3000 and 4000 tons. This led to uniform distribution in the interval [1440/4000; 1440/3000].

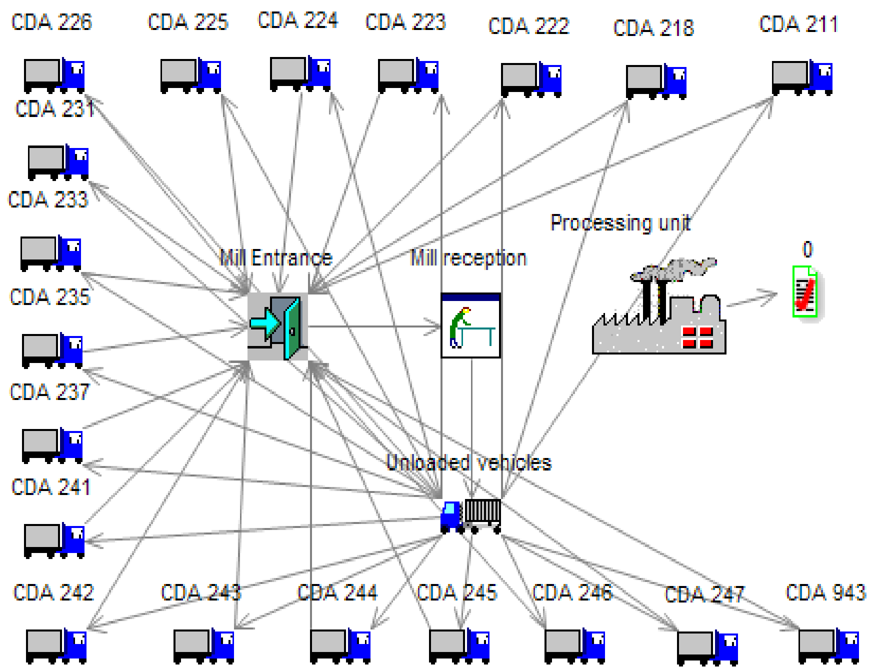


Figure 2. Structure of the harvesting, transporting, reception and crushing system of sugarcane in a model using SIMUL8.

Figure 2 shows the simulation window which gives the main representation of the simulation model within SIMUL8. The most important aspect of this SIMUL8 presentation is that it shows that trucks go round a closed circuit system, while tons of cane move through an open circuit system. In fact, trucks are created at the CDA parks when the harvesting season begins and do not leave the system until the end of the harvesting season. However, as the model is complex, the simulation window does not show all these details.

All CDA sub-window contents are the same. For example, the CDA 211 sub-window or icon content is given in Figure 3.

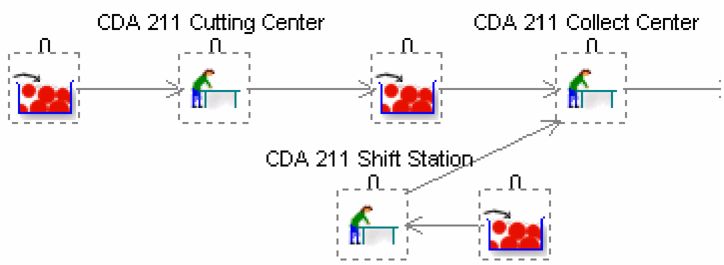


Figure 3. CDA 211 sub-window content.

Cane tonnages are created at the storage bin, which is the process preceding CDA 211 Cutting Centre and it is also the place where sugarcane waits to be cut. CDA 211 Cutting Centre represents the cutting facility which determines cutting time for the amount of cane to be delivered daily from that CDA. CDA 211 Collect Centre collects the amount of cane and the vehicle to be loaded which is supplied by CDA 211 Shift Station. CDA 211 Collect

Centre also sets vehicle loading and travelling times to the mill. The storage bin, which feeds CDA 211 Shift Station, is the CDA vehicle park area, where vehicles are created at the beginning of the harvesting season. CDA 211 Shift Station also has the role of allowing vehicles to run only during daytime.

The mill entrance icon is the sub-window representing the mill gate and its storage bin (Figure 4). Mill Gate is a server with no service time because it only takes one truck from the waiting queue to the registration facility when it is, or when it becomes, idle.

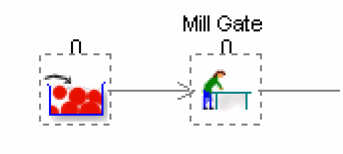


Figure 4. Mill entrance sub-window content.

Figure 5 shows that the reception sub-window contains five servers; each of them is preceded by its storage bin, where trucks wait before being served in case the server is busy. At the Registration server, trucks are registered first, and they are weighed loaded at the Weighing Loaded facility. Their loads are then sampled manually and mechanically at the Double Sampling facility before being unloaded. Although there are six Unloading servers in parallel, usually only four of them are used simultaneously. Unloaded vehicles then go through the Weighing Unloaded facility, where they are weighed again to determine the amount of cane delivered by each of them to the mill. Once weighed, empty trucks go back to the fields, via Vehicles Routing, to be loaded again.

At the supplying area and the mill reception, only the extreme values of service times are available for vehicle loading, registration, weighing loaded, double sampling, unloading, and weighing unloaded. According to service facilities operators at the mill reception, these service times vary between 1 and 3 minutes, except for the unloading facility, where the service time varies between 10 and 15 minutes. At the mill supplying area, vehicle loading time varies between 120 and 180 minutes. The heuristic approach previously mentioned applies here too. All these service times are supposed to be distributed according to a Beta distribution of parameters α_1 and α_2 with $\alpha_1=\alpha_2=1$. This leads to Uniform distribution, between 1 and 3 minutes for registration, weighing loaded, double sampling and weighing unloaded, and between 10 and 15 minutes for unloading service time. Vehicle loading time is also uniform and distributed between 120 and 180 minutes.

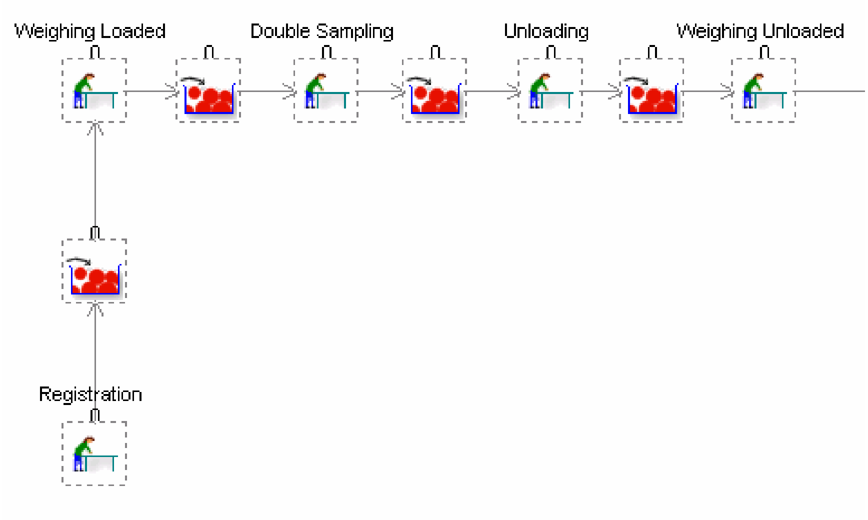


Figure 5. Reception sub-window content.

The Vehicle Routing facility (Figure 6) is a virtual server with no service time. It has been added to the system for modelling purposes. Its role is to route each truck, for another cycle, to its CDA based on a label that specifies the CDA to which it belongs and with a route time described by a Normal distribution.

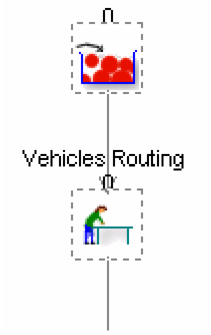


Figure 6. Unloaded vehicles sub-window content.

After vehicles are unloaded, tons of cane, wait in the mill yard represented by the mill processing storage bin, until the Mill Processing server becomes idle (Figure 7).

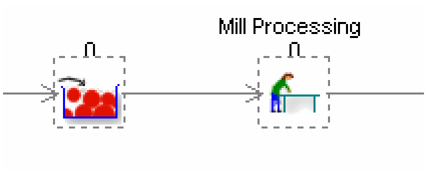


Figure 7. Processing unit sub-window content.

Once processed, tons of cane leave the system at the work exit point (Figure 8).

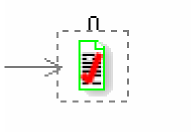


Figure 8. Work exit point.

General equations of the model

Two equations specific to the study are necessary to model execution. The first one concerns the amount of cane cut daily in each CDA, while the second gives the mean of the statistical distribution that describes vehicles travel time between each CDA and the mill.

Daily tonnage to cut in each CDA

To ensure regular and sufficient supply of the mill, the tonnage to cut and deliver daily normally depends on the crushing capacity of the mill. Several sugarcane producing countries determine the daily tonnage to cut in each plantation as a function of the estimated tonnage of the plantation, the estimated tonnage of the whole season and the mill crushing capacity. The daily tonnage to cut and deliver from each CDA is determined using equation (1):

$$T_{tocut,CDA} = \frac{T_{CDA} \times C_{crushing}}{T_{total}} \quad (1)$$

Where:

$T_{tocut,CDA}$ is the daily tonnage to cut and deliver every day from each CDA in tons.

T_{total} is the estimated tonnage of the supplying area for the season in tons.
T_{CDA} is the estimated tonnage of each CDA for the season in tons.
$C_{crushing}$ is the mill processing capacity in tons per 24 hours.

Equation (1) application assumes that the mill processing capacity is 3500 tons, which is SURAC sugar mill crushing capacity per 24 hours. The amount of cane that has to be cut and delivered to the mill every day is supposed to reach this value. If all this tonnage is not delivered because of the lack of co-ordination between harvesting, delivery and crushing schedules, sugarcane remaining in the supply area will deteriorate. Cane which has been delivered but has not been processed because of mill problems will deteriorate even further. Harvesting interruptions because of rain and or frequent processing unit breakdowns create a dynamic in the model. Breakdowns and weather events are stochastic. Thus, although the above equation gives a deterministic value for the cane to cut under ideal conditions, the amount of cane to cut daily varies with time and random events.

Parcels to mill average travel times

According to Raluca and Taylor (2001), Statistical analysis of the data available at a particular sugar mill in Australia, showed that in most of the cases truck travel times were described by Normal or Erlang distributions. In this case study and, given the lack of data and the fact that travel times are the function of numerous events with their own distributions, travel times between the mill and different CDAs were supposed to be described by Normal distributions. The means of such distributions were determined using data available at SURAC sugar mill, and equations (2) and (3) were deverloped. Vehicle average speeds used in these two equations have been estimated by vehicle park managers and confirmed by truck drivers. The average speeds used were:

- Road average speed of loaded trucks is 50 km/h
- Track average speed of loaded trucks is 10 km/h
- Road average speed of unloaded trucks is 70 km/h
- Track average speed of unloaded trucks is 30 km/h.

Trucks travel faster on road than on track (infield road). They also travel faster unloaded than loaded. Thus, travel times depend on track and road distances between the CDAs and the sugar mill and also on vehicle road and track average speeds, loaded and unloaded, as follows:

$$T_{time,loaded} = 60 \times \left[\frac{D_{track}}{S_{track,loaded}} \right] + 60 \times \left[\frac{D_{road}}{S_{road,loaded}} \right] \qquad (2)$$

Where:

$T_{time,loaded}$ is loaded vehicle average travel time in minutes
D_{track} is average track distance between each CDA and the mill in km
D_{road} is average road distance between each CDA and the mill in km
$S_{track, loaded}$ is loaded vehicle average track speed in km/hour
$S_{road, loaded}$ is loaded vehicle average road speed in km/hour.

And,

$$T_{time,unloaded} = 60 \times \left[\frac{D_{track}}{S_{track,unloaded}} \right] + 60 \times \left[\frac{D_{road}}{S_{road,unloaded}} \right] \quad (3)$$

Where:

$T_{time,unloaded}$ is unloaded vehicle average travel time in minutes
$S_{track, unloaded}$ is unloaded vehicle average track speed in km/hour
$S_{road, unloaded}$ is unloaded vehicle average road speed in km/hour.

Using truck average speeds mentioned above, track and road distances between each CDA and the mill, available in SURAC data base, trucks average travel times between each CDA and the mill could be determined using equations (2) and (3).

Table 1 gives truck travel times distributions and parameters.

Table 1. Truck travel times statistical distribution and parameters.

CDA	Loaded trucks travel time (min)		Unloaded trucks travel time (min)		Distribution
	Mean	Standard deviation	Mean	Standard deviation	
211	64	16	39	9.75	Normal
218	44	11	26	6.5	Normal
222	39	9.75	26	6.5	Normal
223	44	11	26	6.5	Normal
224	40	10	25	6.25	Normal
225	88	22	55	13.75	Normal
226	44	11	29	7.25	Normal
231	69	17.25	42	10.5	Normal
233	62	15.5	39	9.75	Normal
235	52	13	35	8.75	Normal
237	107	26.75	67	16.75	Normal
241	19	4.75	9	2.25	Normal
242	15	3.75	9	2.25	Normal
243	42	10.5	25	6.25	Normal
244	33	8.25	21	5.25	Normal
245	41	10.25	26	6.5	Normal
246	33	6.25	19	4.75	Normal
247	22	5.5	14	3.5	Normal
943	42	10.5	25	6.25	Normal

Model validation

Validation is necessary to enhance confidence in the model. It is concerned with determining whether the conceptual simulation model is a sufficiently accurate representation of the system under study (Kelton and Law, 1991). The approach used to validate the model in this case study consists of comparing its output data with historical performance data of the modelled system by constructing the 95% confidence interval of the differences between the simulated results and the observed data. If these differences are not statistically significant, the model of the existing system is considered valid.

To validate the model, data from the 2002 harvesting season were used. The inputs of the model comprise the service times which are supposed uniform, the travel times which are supposed normal, the total tonnage of each CDA and the total tonnage of the 2002 harvesting season. The actual processing time of the 2002 harvesting season, which was irregular and varied every day, was used for model validation. To take into account sugar mill breakdowns and rain, daily duration of these stoppages was also incorporated into the model.

Using these data, model validation showed a great agreement between observed and simulated amount of cane delivered daily to the mill (Figure 9). In fact, the 95% confidence interval of the differences [-3.54, 4.98] contains zero, which means that these differences are not significant. The average value of these differences does not even reach 1 ton of cane.

There is also a great agreement between observed and simulated amount of cane processed every day (Figure 9). The 95% confidence interval of the differences [-0.37, 3.61] contains zero, which means that differences between simulated and observed tonnage processed are not significant. Figure 9 shows also that processing started five days after the beginning of the harvesting season. This means that sugarcane delivered on the first day had been waiting five days before being processed.

The daily stock level simulated in the millyard compares also favorably with the observed level, as shown in Figure 9. The 95% confidence interval of differences [118,41; 141,43] does not contain zero. This shows that the difference between observed and simulated stock level is between 118 and 141 tons of cane, which is a good estimate.

Figure 9 also shows that the model underestimates the round trips number made daily by the trucks. The 95% confidence interval of the differences is [18, 22]. The difference between the observed and simulated number of rotations is between 18 and 22 rotations. This is due to the fact that truck loading capacity is supposed to be 11 tons on average in the model. In fact, the observed number of rotations that trucks make daily is greater than that simulated, because the model does not allow a truck to be loaded until the amount of cut cane to deliver reaches at least 11 tons. This is not the case in the real system because every grower wants his cane to be delivered individually even if its amount does not reach the truck capacity.

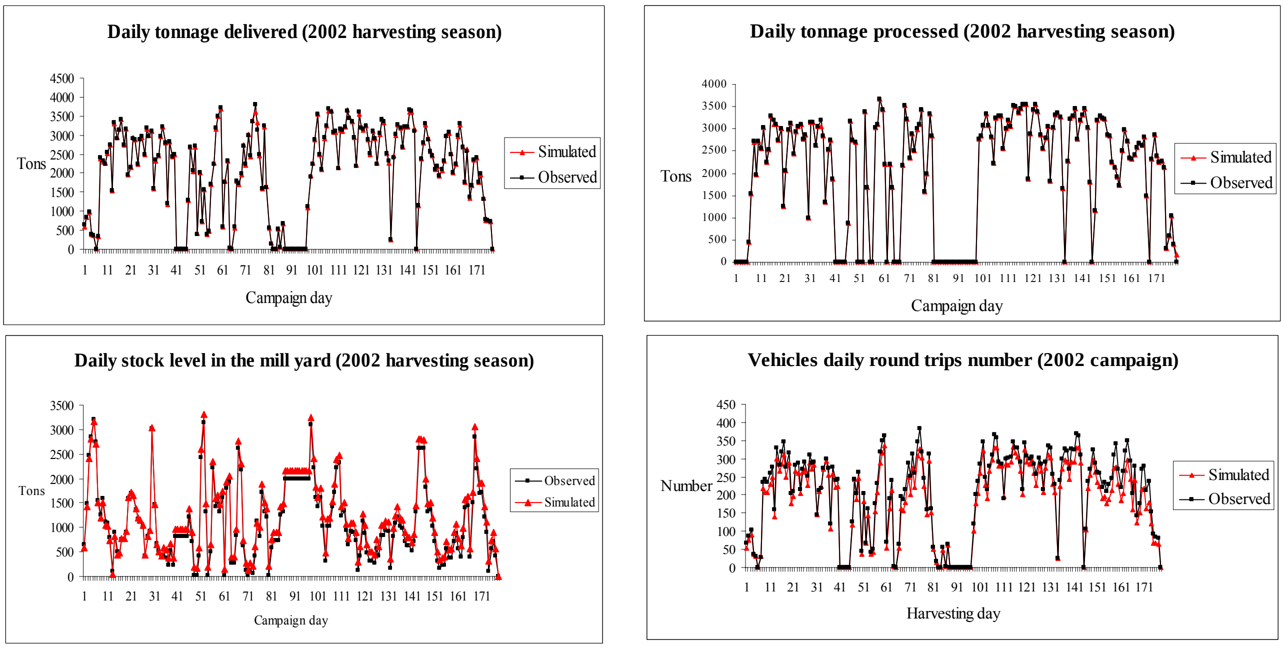


Figure 9. Comparison of simulated results to observed data.

No data regarding the fleet size, the performance measures of different queues in the real system were recorded by the sugar mill for the 2002 harvesting season nor for any previous season. No comparison could therefore be made with simulated performance measures of these queues. Nevertheless, even where no quantitative data were available, mill managers agreed and confirmed that truck waiting times were usually very long at the mill entrance, as well as at the unloading facility, and this was confirmed by simulation results.

Performance measures of the simulated system

Table 2 results show that maximal waiting time of one ton of cane in the mill yard is 26914 minutes = 19 days. This result confirms sugar mill stoppage for 19 days between 2-20 April during the 2002 harvesting season because of rain. It shows also that truck maximum queue length at the mill entrance was 175, which means that more than 175 vehicles were used to transport the cane during the 2002 harvesting season.

Table 2. Queue lengths and waiting times at the sugar mill reception.

Service facility		Mill entrance (trucks)	Unloading (trucks)	Mill processing (tons of cane)
Queue length	Average	13	11	1316
	Maximum	175	91	3941
Waiting time (minutes)	Average	99	81	931
	Maximum	465	283	26914

Table 3 shows good agreement between simulated and observed sugar mill efficiency.

Table 3. Sugar mill efficiency (simulated and observed).

		Simulated	Observed
Sugar mill efficiency	Working (%)	58	59
	Stopped (%)	42	41

Model without constraints experimentation

In order to ensure the delivery of the daily tonnage required to the sugar mill, the number of vehicles necessary has to be determined independently of sugar mill stops and breakdowns. As SURAC processing capacity averages approximately 3498 tons per 24 hours, this tonnage needs to be cut every day. On the other hand, the fleet size has to be determined based on the delivery of this amount of cane to the mill every day in order to co-ordinate between harvesting, transporting and crushing capacities.

Before the beginning of the harvesting season, it is essential to determine the optimal fleet size and dispatching strategy. The optimal fleet size is that which ensures the delivery of the daily amount of sugarcane required to the sugar mill and minimises the number of vehicles used. The optimal dispatching strategy is that which ensures the maximum utilisation of trucks and also the delivery to the sugar mill of the daily amount of sugarcane cut from each CDA.

Several experiments were performed with the model without constraints. These trials were conducted by progressively increasing the number of round trips each vehicle can perform per day which leads to a reduction in the number of trucks needed at each CDA.

Trial 1 assumed that each truck can only make one round trip or rotation per day. In this case, the number of trucks assigned to each CDA equaled the number of loads to deliver daily from this CDA. The tonnage delivered in this case was 3498 tons. Trial 2 assumed that each truck can make two rotations, trial 3, three rotations and trial 4, four rotations. Trial 5 was based on at least three rotations from CDAs which were close to the mill and, at most, three from those CDAs which were far from the mill.

Results and Discussion

Optimal fleet size and dispatching strategy

The number of trucks assigned and the total tonnage delivered in trials 1 to 5 are given in Table 4.

Table 4. Fleet size and tonnage delivered in trials 1 to 5.

Trial	1	2	3	4	5
Number of vehicles	318	159	110	84	105
Cane delivered (tons)	3498	3498	3498	3424	3498

Simulation results show that the optimal number of trucks that ensures the delivery of 3498 tons of cane daily to the mill is 105. Table 5 gives the optimal dispatching strategy of these 105 vehicles between different CDAs.

Table 5. Optimum fleet size and dispatching strategy.

CDA	211	218	222	223	224	225	226	231	233	235
Trucks #	1	1	7	21	3	1	1	2	5	1
CDA	237	241	242	243	244	245	246	247	943	Total
Trucks #	1	7	9	7	8	8	6	10	6	105
Total cane delivered (tons)										3498

Truck round trip numbers and schedules

In the event that the optimal fleet size and dispatching strategy are used, simulation results also give the number of round trips each truck makes between its CDA and the mill (Table 6).

The schedule of trucks for each CDA is also given. For example, trucks schedules of CDA 242 are given in Table 7.

Table 6. Number of round trips of each vehicle assigned to each CDA.

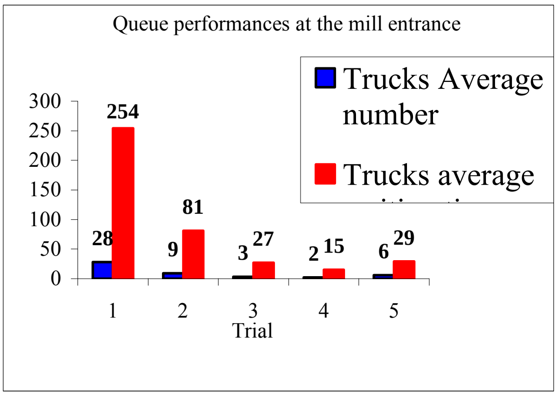
Vehicle number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total
CDA	Round trips																					
211	3																					3
218	3																					3
222	3	2	3	3	3	3	3															20
223	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	63
224	3	2	3																			8
225	3																					3
226	3																					3
231	3	2																				5
233	3	3	3	2	2																	13
235	3																					3
237	3																					3
241	4	4	3	4	3	3	3															24
242	4	4	3	4	3	3	4	3	4													32
243	3	2	3	3	3	3	3															20
244	3	3	3	3	3	2	3	3														23
245	3	3	3	3	3	3	2	3														23
246	3	3	3	3	3	3																18
247	4	3	3	3	3	3	3	4	3	3												32
943	4	3	3	3	3	3																19
Total																						318

Table 7. CDA 242 vehicles schedule.

Vehicle number	1	2	3	4	5	6	7	8	9
Number of round trips	4	4	3	4	3	3	4	3	4
Load number	1 10 19 28	2 13 22 31	3 17 26	4 14 23 29	5 16 25	6 15 24	7 11 20 32	8 18 27	9 12 21 30

Model without constraints performance measures

Trials 1 to 5, previously described, showed how the performance measures of the system, particularly truck queue lengths and waiting times at the mill entrance and before unloading, could be improved when the fleet size was reduced from 318 trucks in Trial 1 to 105 vehicles in Trial 5. Each trial consisted of 30 independent runs and gave all the performance measures of interest with their 95% confidence intervals. Figure 10 gives for each trial, truck queue length and waiting time at the mill entrance and at the unloading facility.



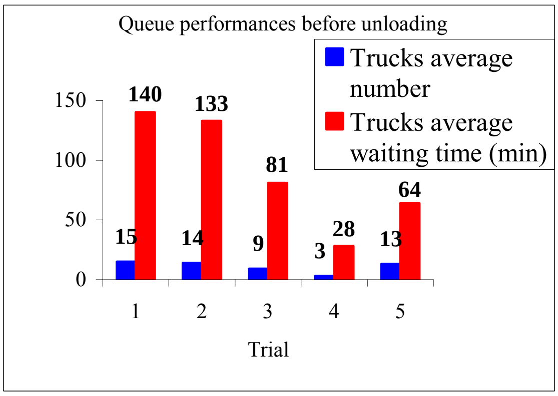


Figure 10. Performance measures of the queuing system.

Using the optimal number of trucks and dispatching strategy (Table 4) and, running the simulation model for the whole harvesting season, gave the harvesting and crushing season lengths which are the periods needed to harvest and process the total amount of sugarcane (366,382 tons). That is, the simulation time frame is determined by the model itself, since it stops when the total tonnage of sugarcane is harvested and processed. The duration of the crushing season was 109 days; however, the duration of the harvest season was 111 days because it was assumed that the harvest season began two days prior to the beginning of the crushing season. This means that 111 days would have been enough to harvest and process the total tonnage for the 2002 harvesting season, assuming no rain and no factory breakdowns.

Performance measures of the system (Figure 10, Trial 5) showed that vehicles queue size was large at both the mill entrance and unloading facility. The average queue length was longer before unloading. Thus, a truck waited twice as long at the unloading facility than at the mill entrance. The average tonnage waiting in the mill yard was 3,933, which exceeded the daily crushing capacity of the mill. This could be explained by the fact that cutting and deliveries started two days before the beginning of the crushing season. The maximal tonnage waiting in the mill yard was 6,106 tons. This means that the mill yard is correctly sized since its capacity averages approximately 6,000 tons. To keep the maximum stock level below 6,000 tons, it seems to be necessary to interrupt or at least to reduce the amount of cane harvested in case of rain stops or breakdowns. Experimentation using the model with constraints, and taking into account rain and breakdown stoppages, will provide a recommended breakdown duration to keep stock level bellow the millyard capacity.

Conclusions

The use of queuing theory and simulation techniques to investigate methods for determining the optimal fleet size, dispatching strategy of vehicles, the number of round trips per truck and schedules was successful. The combination of these two techniques made it possible to model this very complex system, which could not have been represented using analytical techniques such as linear programming or only the theory of queues. Another advantage of using simulation is the integration of the main components of the system, in order to take into account the interests of both growers and millers.

Model validation using the 2002 harvesting season data showed a good agreement between simulated and observed results.

Experimentation results of the model without constraints gave the optimal fleet size and dispatching strategy, reducing the number of vehicles by 50% of that currently used. Simulation runs also gave the number of round trips per vehicle and schedules that insured maximum utilisation of trucks. The execution of the model determined the performance measures of interest, of the queuing system and harvesting season length. It also showed that using a large number of trucks led to the deterioration of all quality indices of the system.

The simulation model developed is not SURAC specific. It can be used for planning purposes at any of the sugarcane mills that use a road transport system exclusively. Being designed as an interactive model, it allows changes to the resource characteristics. The model developed can, for example, easily be applied at SUNACAS sugar mill, also located in the Gharb region of Morocco. This mill has similar problems. It can also be applied to SUCRAL, located in the Loukkos region of Morocco, which uses a completely mechanised harvesting system.

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