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# A SIMULATION MODEL TO EVALUATE SUGARCANE SUPPLY SYSTEMS

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## ABSTRACT

We present, in this paper, a simulation model to evaluate the sugarcane supply system to mills. The model addressed, on the whole, harvest operations (cutting and shipping), transportation and unloading at the mill (also considering the reception system of sugarcane within the mill). The model could adequately assess the relation of the freight, the lead time, the fleet of trucks and discount (opposite of agio), apart from the cost of cutting and shipping, related to the amount to be paid by the sugarcane load furnished to the mill.

## 1 INTRODUCTION

The sugarcane supply system for mills has been of great interest for several researches, due to the increasing world consumption of ethanol. In this context, studies on the analysis of the time when the sugarcane takes from the time of cutting to milling facilities in the mill are noteworthy. More specifically, this time (here called lead time) refers to the period of waiting about the time between the beginning and end of the operations of handling the raw material. That is, the lead time begins to be considered from the moment of cutting sugarcane, through the subsequent operations of shipping, transportation, reception, unloading until the final moment of grinding for processing within the mill. The lead time is important because it has direct bearing on the quality of the juice of the sugarcane and this, in turn, has influence on the quality of sugar and ethanol produced by the mill. The sugarcane has better productivity when the lead time is shorter. It is critical to this system when the lead time is more than forty-eight hours (Arjona, Bueno and Salazar 2001).

Thus, to control the quality of raw material received, the mills perform an inspection of the product when it arrives at their premises. The sugarcane of better quality gets a bonus on its value in weight and that of lower quality is penalized, operation known as agio and discount. For values of lead time more than ninety-six hours, the supplier of sugarcane may be penalized and, as a consequence, his profit will be highly compromised. According to Silva et al. (1994), losses in post-harvest handling can be minimized by reducing the waiting time after burning / cutting up to the processing of sugarcane, what was here called lead time. In this same work, the author reports that "the commercial value of cane per hectare has a decreasing trend over the hours of waiting, due to the loss of sugar per unit area. Thus, the producer receives a total value (revenue) less and less per unit area, although the value of cane per ton has remained constant" (Diaz, Pérez 2000; Santos, Leal and Ferreira 2004).

In turn, in the work by Rangel et al. (2008),it was evaluated, by computational simulation, the inverse correlation parameter between the monetary value of sugarcane and the distance where the crops are located. Of course, the producer located further from the mill has a higher cost of shipping and a lead time tending to be higher also, due to the long transportation time of the product. So, often, sugarcane plantations located in more distant places, with more lead time and consequently higher discount, are highly penalized. Efficient logistics systems are essential to make such integration possible and to be able to operate with adequate time and costs in the supply of raw materials in mills (Gal et al. 2008).

However, to achieve good efficiency of these systems, it is necessary to adjust all operations in an integrated and correct way. If a truck gets stuck for a long time during the operations within the mill, its return to the field will be compromised, therefore, it will slow the supply system as a whole. However, the issue that has hampered the analysis of these systems is that, normally, the simulation models built for evaluation are drawn treating the receiving system of sugarcane within the mill and the system with field operations in different ways. That is, we analyze the agricultural operations separately from industrial operations. For example, in Ianoni and Morabito (2002), the receiving system of cane and the unloading are analyzed in great detail, but field operations are not included in the simulation model. Similarly, the work of Prichamont, Prichamont and Buransri (2005) analyzes the receiving system and the rate of arrival of the sugarcane from field to the mill, but does not consider operations in the field and the return of the trucks to the front of the cane harvest. However, recent studies show that the operations of reception of the sugarcane in the mills affect directly in the field operations. In the study by Rangel et al. (2008), it was shown that there is a direct relationship between the efficiency of the unloading of sugarcane at the mill with its same shipping capacity in the field. Thus, the results suggested that if there is the possibility of increasing the flow of sugarcane from the field to the mill, you will have to scale up not only the fleet of trucks but you need to expand significantly, firstly, the unloading system at the mill. The study showed that there was a bottleneck in the Cut, Shipping and Transport (CST) system associated with the unloading of sugarcane at the mill. This bottleneck was presented as a consequence of the capacity of the truck fleet according to the time of unloading of sugarcane at the mill. The shipping system, linked to the sugarcane loaders (capacity and quantity) had less influence on system operations when compared to the time of unloading of sugarcane at the mill, for the case shown (Marquesini, Sanches and Souza 2006).

However, discrete event simulation models increasingly utilized to analyze systems in which there is integration of logistic operations with dynamic operations of shop floor. Just as in the case of systems related to the supply of sugarcane at mills, such as here related. In these cases, the discrete event simulation is the main mechanism of analysis of the dynamics concerning these systems (Milan, Fernandez and Aragones 2006).

Thus, this paper describes the use of a simulation model that addresses, in an integrated way, the harvest operations (cutting and shipping), transportation and unloading at the mill (also considering the receiving system of sugarcane at the mill). The model, which is in the Appendix A, was used to analyze the variation of the profit of the sugarcane load transported to the mill, considering the variation of freight and discount applied in relation to the lead time.

## 2 DESCRIPTION OF SUGARCANE SUPPLY SYSTEM IN MILLS

The logistics system responsible for the supply of raw materials at mills consists of a set of operations comprising agricultural and industrial activities. They are executed in an integrated way and without any long-term storage that would enable the independence between their field operations and the interior of the mill. The main goal of the system is to always keep the lowest times in operations so as to have, therefore, the less lead time, providing, this way, the maintenance of the best properties in the raw material supplied to the mill.

Thus, the sugarcane supply system at mills can be described as the system formed by the set covering the agricultural operations carried out in the Harvest Front (HF), citing: the cutting and shipping of sugarcane in trucks, and the industrial operations: the reception, the initial weighing, inspection, unloading, final weighing and return of vehicles for the HF. Figure 1 shows schematically the typical system of supply and reception of sugarcane at mills.

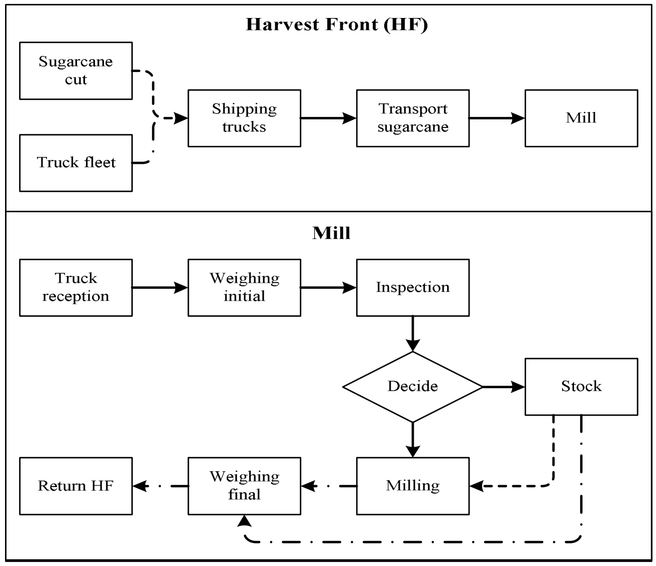


Figure 1: Supply System and Reception of Sugarcane. (Flow sugarcane loaded truck: ——►; flow of sugarcane made by the claw of the temporary stock in the mill courtyard until milling: - - - -►; and flow empty truck: –·–·►).

Cutting sugarcane can be performed in a manual or mechanized form. Often, preceding the manual cutting, burnings are done in the sugarcane fields in order to cause the defoliation of sugarcane and facilitate the cutting operation. When sugarcane suffers the process of burning, this is known as burnt cane. Otherwise, it is known as raw cane.

The shipping, in turn, can also be done in both manual and mechanized form. Thus, there may be the following combinations involving the cutting and shipping in a HF:

(a) Fully manual, with manual cutting and manual shipping;
(b) semi mechanized, with manual cutting and mechanical shipping (using cane loaders); and
(c) fully mechanized, with cutting and shipping being both held by a single machine (using sugarcane harvesters) in a single operation.

Table 1 illustrates the set of existing operations in a HF.

Table 1: Operations in a HF.

| Kind of HF | Operations |
|---|---|
| Manuals | Manual Cutting and Manual Shipping |
| Semi Mechanized | Manual Cutting and Mechanized Shipping (Loader) |
| Mechanized | Mechanized cutting and Mechanized shipping (Harvesters) |

In a manual HF workers cut sugarcane usually burned and then carry it on carts pulled by tractors. The operation is slow and requires a large number of people. A worker cuts between seven and twelve tons of cane a day's work. In a typical HF in the northern region of Rio de Janeiro, there are usually a hundred workers only for cutting cane.

In HF semi mechanized, workers cut sugarcane, usually burned, in the same way as in the manual, and let it cut down. After cut then, the loader collects the sugarcane and carries the truck to do the transport. Transportation is done almost entirely by truck.

After shipping, the sugarcane is transported directly to the mill, not facing any kind of intermediate storage in warehouses or silos. It's also a typical feature of this type of agro-industrial activity and it should be performed in the shortest time possible. However, if this supply system is not working well due to problems such as unavailability of trucks, shipping machines, problems in receiving and unloading at the mill or the weather, the lead time can reach more than 96 hours and seriously compromise the product. (Veiga, Veira and Morgado 2006).

After the arrival of the truck to the mill, the first process to be performed is the reception of raw material, where the identification and weighing of sugarcane are performed. In this process, apart from the weight of the product, it is identified whether the load is owned or from suppliers. After identifying and weighing, the truck goes to the sucrose test sector where a sample of sugarcane is collected to detect the sugar content retained. This is, actually, the test of quality of raw material, being proportional, among other factors, to the time sugarcane took in waiting from the initial moment of cutting to this point.

The selection mechanism of the testing quality of sugarcane is usually in accordance with the following criteria: when the product is from a supplier, the test is always carried out. On the other hand, if it is from the mill itself, the test is done by sampling.

According to the quality of sugarcane and the level of buffer stock in the courtyard of the mill, the operator responsible for unloading, decides whether the cane will be directed to the temporary storage within the mill or taken directly to the mills. From there then the truck goes to one of the two points above (stock or milling) and performs the unloading. After unloading, at the storage or milling, the empty truck moves to the final weighing in order to obtain the value of the load of sugarcane that was delivered.

After the final weighing, the truck returns to HF. Normally the truck returns to the same HF source in order to perform new shipping until the end of the cane already cut. Thus, the model can be considered as a closed system.

It is worth being explained further that the supply of sugarcane in the yard of the mill acts as a kind of lung production in order to maintain a constant flow of raw material for the mills. This is necessary because of the not homogeneity of the flow of sugarcane received by the mill and climate issues that may impede traffic on crops and road. That is, there are times when the mill receives cane in an amount able to keep the mills in constant operation and in others flow decreases. From there then, the transfer of the product, which was in stock, is made to the mill. This operation is performed by the Claw at specific demand in order to balance the flow of sugarcane in the productive process.

Another important aspect is on the lines of trucks that can be formed inside the mill according to the procedures for receiving, weighing, inspection and unloading. These lines cause the delay of vehicles during the unloading of sugarcane, since there are several HFs sending sugarcane to the mill at the same time during the harvest. Thus, the process that could hold the truck for a maximum of 30 minutes at the mill can take hours and delay the return of the vehicle to the country, endangering the functioning of the system as a whole.

## 3 DESCRIPTION OF SIMULATION MODEL

The simulation model of the system proposed here was developed guided by the methodology proposed by Banks et al. (2009), with the following steps: formulation and problem analysis; project planning; formulation of the conceptual model; macro-information and data collection; translation of the model; verification and validation; experimental project; experimentation; interpretation and statistical analysis of the results; comparison and identification of the best solutions; documentation and presentation of results. The model was built considering a period of time pre-set for the start and end of operations, characterizing the model as a terminal system.

The conceptual model of the system was translated into software Arena®12 for carrying out computer simulations (Kelton, Sadowski and Sturrock, 2007). The methodological guidance proposed by Sargent

(2007) was additionally followed during the verification and validation of the model, highlighting the application of tests of continuity with historical field data for typical days of operation on the values concerning the times of CST, reception and unloading, as well as consultations with experts of the mill. The simulations were initiated only after the model has been completely verified and validated and ensured that the assumptions and simplifications adopted from the real system were properly implemented in the computational model.

Appendix A shows the conceptual model of the system with information concerning the operating rules and the times of the processes, obtained from data surveys conducted by the COAGRO Mill (Agro industrial Cooperative of Rio de Janeiro State Ltd.) in the years 2007 and 2008. The elements of the IDEF-SIM (Leal, Almeida and Montevechi 2008) were used for the description of the respective system with a semi mechanized (manual cutting of sugarcane and mechanical shipping on the trucks) HF. Normal functions were used with the respective mean times of operations and with the standard deviation of 10%.

Note that there are not many statistical distributions in the model and, thus, it cannot be called a classic stochastic model, either deterministic. However, the set of rules that interacts composing the functioning of the operations of the system results in a complex dynamic model, with many dependent variables, justifying the use of discrete event simulation for its analysis.

We decided to model the system using a semi mechanized HF due to the fact that these are the HFs, with the largest lead times, as demonstrated in Rangel et al. (2008). Note also that the semi mechanized HFs are the higher prevalence in the country yet. Data in Nunes et al. (2007) show that the HFs fully mechanized are found in few regions of the country. Only a few municipalities in the state of São Paulo and Paraná present level of mechanization close to 50%, highlighting the municipality of Ribeirão Preto - SP which has one of the highest levels of mechanization of sugarcane production in the country. The Brazilian general reality still has a low level of mechanization, as in the north region of Rio de Janeiro state, where it reaches a maximum of 6% of mechanization in farming. In these regions, the reality is still precarious and semi mechanized HFs are predominant.

The input parameters of the model (arrivals) were: sugarcane cut by 100 tons per hour (representing the manual cutting of workers) and a fleet of trucks pre-established. The truck fleet has been changed for the different simulated scenarios, while the total amount of sugarcane cut was kept fixed during the simulations, being established from the total of effective hours of 2 days of cutting cane work.

The fleet of trucks is created in the model of 12 noon on the first day of operation, when the shipping starts. The shipping begins after there is already a quantity of 500 tons of sugarcane cut. Table 2 describes in detail the schedule of operations relating to the processes of cutting and shipping in the model.

Table 2: Cutting and shipping schedule of sugarcane on a semi mechanized HF.

| Time | Activity |
|---|---|
| 7h | Start of cutting (first day of work) |
| 12h | Start of shipping with the arrival of trucks |
| 15h | End of cutting (first day of work – shift of 8h) |
| 7h | Restart of cutting (second day of work) |
| 15h | End of cutting (second day of work – shift of 8h) |

The mechanical shipping of sugarcane in 40 tons truck is performed in the model with cane loaders in a constant time of 100 minutes. Shipping starts at 12 noon on the first day and continues uninterrupted until the end of sugarcane cut. The use of trucks with higher capacity (40 tons) was justified by the fact that we opted for the analysis of HFs located farther from the mill, because these are the ones that provide the greatest lead times in the system. In these HFs, it is predominant the use of trucks with higher capacity to provide better transport efficiency.

The amount paid by the mill for each ton of sugarcane was of $20.00 (twenty US dollars). Then a truck with 40 tons of sugarcane has a load with a total value of $800.00 (eight hundred US dollars).

Table 3 shows the distribution of freight in accordance with the distances of the suppliers in relation to the mill. Note that the value of freight is increasing according to the increase of the distance, but with non linear coefficients of proportionality due to the gain with the distance.

Table 3: Freight cost of the sugarcane per distance on the suppliers of the mill in the 2006/2007 harvest.

| Distance (km) | Value ($)/Ton | Distance (km) | Value ($)/Ton |
|---|---|---|---|
| 01 to 05 | 1.25 | 41 to 45 | 3.75 |
| 06 to 10 | 1.58 | 46 to 50 | 4.02 |
| 11 to 15 | 2.14 | 51 to 55 | 4.22 |
| 16 to 20 | 2.47 | 56 to 60 | 4.57 |
| 21 to 25 | 2.73 | 61 to 65 | 4.93 |
| 26 to 30 | 2.96 | 66 to 70 | 5.20 |
| 31 to 35 | 3.27 | 71 to 75 | 5.39 |
| 36 to 40 | 3.50 | 76 to 80 | 5.58 |

Table 4 describes the cost values of cutting and shipping per ton of sugarcane. Of course these costs are fixed in the same region and are independent of the geographical location of a specific HF. Thus, the total value corresponding to the operations of cutting and shipping a truck with 40 tons is $127.60.

Table 4: Description of sugarcane cutting and shipping costs.

| Description | $/ton | Total (on 40 tons) | |
|---|---|---|---|
| Cutting | 2.28 | $91.20 | |
| Shipping | 0.91 | $36.40 | Total Cutting + shipping |
| | | | **$127.60** |

The factors (variables that can be controlled by the model) were: travel time (on the distance from the HF to the mill), the value of the freight to a truck with 40 tons of sugarcane, the unloading time in the mill and the size of the fleet of trucks with capacity of 40 tons each.

One factor may have different levels in a simulation model. Table 5 describes the relationship of factors and levels that have been assigned in the scenarios simulated with the model. The use of two levels in this work was justified by the simplicity obtained in the experimental project and the possibility to observe the ongoing one-way behavior of variables. A longer time than normal was used to calibrate the value of the unloading operation of vehicles at the mill, as in a real situation there are several HF and not just one, as in the model. Thus, it is explained the level 1 with 30 minutes, being adopted to simulate a situation of normality of the processes of unloading and level 2 with 3 hours to simulate the moments of greatest traffic jam with lines of trucks within the mill.

Table 5: List of factors and levels assigned to the model.

| Factors | Level 1 | Level 2 |
|---|---|---|
| Time travel | 1 hour (on 40 km) | 2 hours (on 80 km) |
| Freight to 40 tons | $140.00 (on 40 km) | $223.00 (on 80 km) |
| Unloading time | 30 min (normal situation) | 3 hours (as congested) |
| Number of trucks | 3 trucks | 6 trucks |

Also noteworthy is that Table 5 does not contain values for the extreme situations of the model. All values assigned to the levels of the factors of the model are related to normal operating conditions and represent only positions close to the minimum and maximum of the operational averages.

Table 6 shows the values of the discount to be applied on the value of sugarcane at the time of delivery to the mill in order to penalize the raw materials of poorer quality. According to Silva (1994), the values of the discount were obtained with reference to the time of sampling on the product with 24 hours of lead time. Thus, the model uses 5% of discount for the sugarcane with average lead time of 48 hours, ranging to more and less than 24 hours; and 10% for an average lead time of 96 hours, ranging to more and less than 24 hours. It was not taken into consideration another interval of more than 120 hours, for after this time period, the degradation of sugarcane is very strong. It may happen cases of lead time of more than 120 hours that the depreciation of the product is such that the mill not even permits the unloading of the load truck.

Table 6: Table of discount

| ***Lead Time*** | **24 hours to 72 hours** | **72 hours to 120 hours** |
|---|---|---|
| **Discount (on 24hours)** | 5% | 10% |

Source: Silva, 1994.

## 4 EXPERIMENTAL PROJECT AND ANALYSIS OF RESULTS

The experimental strategy used in computer simulations was of the $2^k$ Factorial Project. In this strategy, described in detail in Montgomery (2009), one of the two levels of a factor (k) is changed at a time, keeping the others fixed. The idea is to start experiments with a typical configuration (the same used in the validation of the model) for all factors and then the levels of one factor are changed at a time in successive experiments. Table 7 describes the scenarios that were used in computer simulations with 3 factors and two levels each, resulting in a total of eight scenarios (i.e., $2^3$).

The model was prepared to run the time needed to transport the whole cut cane from the HF to the mill, i.e., 1600 tons. Thus, the amount of sugarcane generated by the model in the first two days, as shown in Table 2, was totally delivered to the mill in any of the scenarios simulated.

Table 7: Description of the Simulated Scenarios.

| | **Factors** | | |
|---|---|---|---|
| **Scenarios** | Travel times | Unloading times | Number of trucks |
| 1 | Level 1 | Level 1 | Level 1 |
| 2 | Level 1 | Level 1 | Level 2 |
| 3 | Level 1 | Level 2 | Level 1 |
| 4 | Level 1 | Level 2 | Level 2 |
| 5 | Level 2 | Level 1 | Level 1 |
| 6 | Level 2 | Level 1 | Level 2 |
| 7 | Level 2 | Level 2 | Level 1 |
| 8 | Level 2 | Level 2 | Level 2 |

Table 8 presents the results obtained from computer simulations. The response variables defined for the experiments with the model were: the amount of sugarcane that arrived at the mill with lead time less than 24 hours and the lead time of the last truck transporting the cane from the HF to the mill (second and third columns of Table 8, respectively). It is noteworthy that the lead time of the last truck is the most critical condition for the variable lead time in the system. Partial Profit, shown in the last column of Table 8, was calculated with the expression (1):

$$\text{Profit} = \text{Revenue} - ( (\text{Freight Cost} + \text{Cutting Cost}) / (\text{Shipping} + \text{Discount}) ) \quad (1)$$

Table 8: Results.

| **Scenarios** | Lead time < 24h Cane (ton) | Lead Time (hours) | Revenue ($) | Cost Freight ($) | Cost cutting and shipping | Discount ($) | Profit * |
|---|---|---|---|---|---|---|---|
| 1 | 520 | 51 | 800.00 | 140.00 | 127.60 | 40.00 | 492.40 |
| 2 | 520 | 51 | | 140.00 | | 40.00 | 492.40 |
| 3 | 240 | 112 | | 140.00 | | 80.00 | 452.40 |
| 4 | 240 | 104 | | 140.00 | | 80.00 | 452.40 |
| 5 | 360 | 73 | | 223.00 | | 80.00 | 369.40 |
| 6 | 480 | 52 | | 223.00 | | 40.00 | 409.40 |
| 7 | 200 | 113 | | 223.00 | | 80.00 | 369.40 |
| 8 | 200 | 105 | | 223.00 | | 80.00 | 369.40 |

* *The profit shown in the table represents only the partial profit obtained in the collection, since there are other costs such as administrative, taxes and maintenance of farming (irrigation, pests cleaning, fertilization, etc.) that are not being taken into consideration in this analysis.*

If a truck arrives to the mill with lead time less than 24 hours and with the cost of freight on the Level 1 (Table 5), the partial profit obtained from the sugarcane, in this case, reaches $532.40 (five hundred thirty two dollars and forty cents). This condition is described in expression (2), and represents a situation of normality and desirable for the system:

$$\text{Profit} = 800.00 - (140.00 + 127.60 + 0.00) = 532.40 \quad (2)$$

Note that Table 8 does not have the condition described in expression (2) above for any scenario. This is because this condition is related to a lead time of less than 24 hours and Table 8 presents only the situations with higher lead times. However, it is worth assessing the situation and comparing with the most critical of the system, shown in stage 7 of the same Table 8. Note that, in this case, we reach a percentage change of 44% to the value to be received by the truck load, comparing the two situations mentioned, as in (3):

$$\text{Change of the value of the load} = ( (532.40 - 369.40) / 369.40) * 100\% = 44\% \quad (3)$$

Considering the value of the profit shown in Table 8 does not represent the total net value to be obtained under a load of sugarcane, this negative change may jeopardize the transportation of the product to the mill.

Also note that the size of the fleet of trucks impacts the lead time with increasing travel times. This assessment can be made by comparing scenarios 1 and 2 with the other scenarios. Note that in scenario 1 and 2 there was no change in lead time when it changed the number of trucks, but this has not happened to scenarios 3 to 8. In these scenarios, unlike the first two, a larger number of trucks allowed to reduce the lead time of the system. This analysis shows that the accurate sizing of the fleet of trucks benefits the supply of sugarcane with better properties, thus, improving the revenue with the load.

## 5 CONCLUSIONS

The simulation model proposed in this paper seamlessly addressed operations carried out by the supply system of sugarcane from the operations in the HF to the unloading within the mill. Thus, the model could properly consider the impact of the freight and of the lead time in the value of the load of sugarcane supplied to a mill. The analysis allowed quantifying the waiting times of the raw material from harvesting to unloading within the mill and the resulting penalty imposed by the mill (known as discount) for the sugarcane of worst quality, reminding that the quality of sugarcane is inversely proportional to the lead time.

The model included in its preparation, apart from the estimation of lead time and freight (referring to transportation ), the size of the fleet of trucks and the costs of cutting and shipping.

The simulation results also showed, in line with other references cited, that there is a very precise relationship between the size of the truck fleet and the possibility, thereby, of being able to provide better sugarcane for the mills. The results presented in this study showed the relation of change in the quantity of sugarcane supplied according to the lead time of less than 24 hours and the dependence of this variable according to the fleet of trucks. It also showed the variation of discount for different values of lead time that possibly can occur in the system.

## ACKNOWLEDGMENTS

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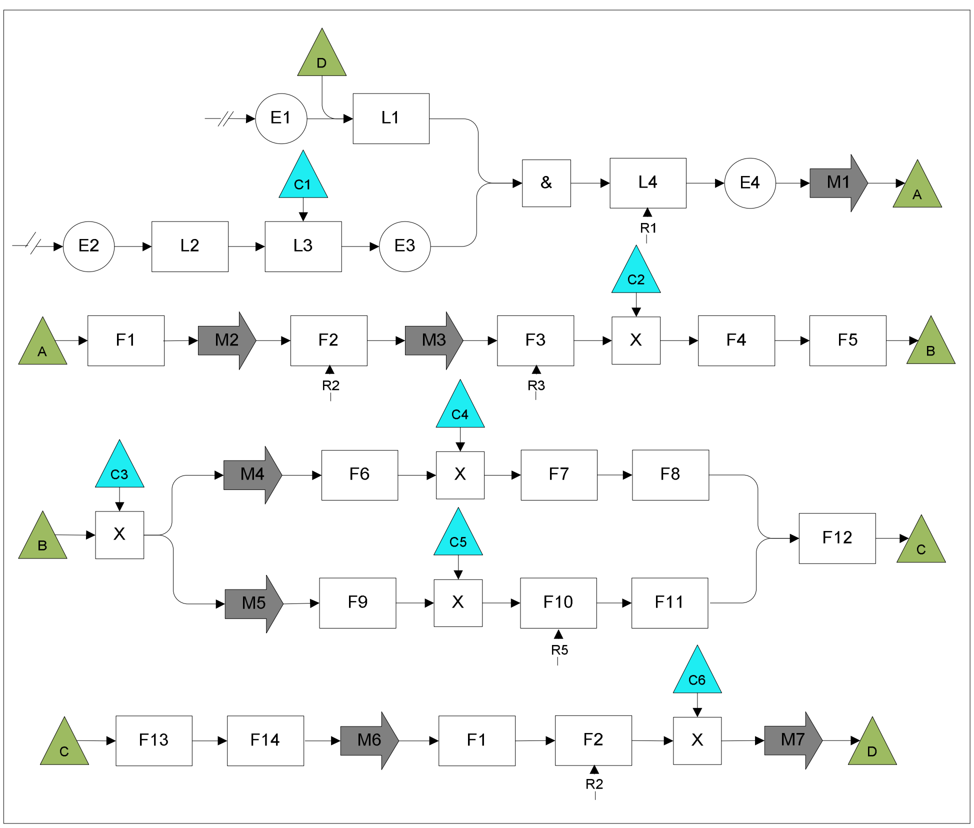
## A APPENDIX

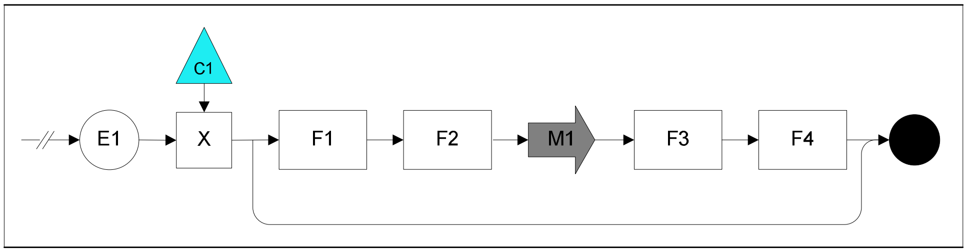
Conceptual model of cutting, shipping, transportation, reception and unloading of sugarcane in mill.



Description of the elements of the conceptual model.

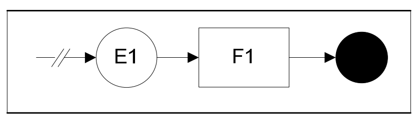
| | Description | Parameter |
|---|---|---|
| $E_1$ | Entity: Truck to HF | Quantity of 3 or 6 trucks at time t = 0 s (depends on scenario) |
| $E_2$ | Entity: 1 ton of cane | 100 Tons of cane cut per hour |
| $E_3$ | Entity: grouped cane | 40 tons of cane grouped for shipping |
| $E_4$ | Entity: Truck loaded | Truck loaded with 40 tons of cane |
| $F_1$ | Location: Input/output of the mill | Not suffer the action (infinite capacity) |
| $F_2$ | Procedure: Weighing the cane | Normal Function with 3 min - standard deviation of 0.3 min |
| $F_3$ | Procedure: sucrose test | Normal Function with 3 min - standard deviation of 0.3 min |
| $F_4$ | Calculation: Lead time HF | Time between cutting and milling of cane or storage HF |
| $F_5$ | Registers: Lead time HF | Transfer data to file |
| $F_6$ | Location: Grinding | Not suffer the action (infinite capacity) |
| $F_7$ | Procedure: Unload grinding | Normal function with 15 min, standard deviation of 1.5 min |
| $F_8$ | Calculation: Amount in Grinding | Quantity: Quantity Grinding + Unloaded bulk |
| $F_9$ | Location: Stocks | Not suffer the action (infinite capacity) |
| $F_{10}$ | Procedure: Unload. Stocks | Normal function with 15 min, standard deviation of 1.5 min |
| $F_{11}$ | Calculation: Quantity in stock | Quantity: Quantity Stocks + Unloaded bulk |
| $F_{12}$ | Registers: Quantity in stock | Transfer data to file |
| $F_{13}$ | Registers: Quantity in Grinding | Transfer data to file |
| $F_{14}$ | Registers: Operating Time | Transfer data to file: time of system operation |
| $L_1$ | Location: HF | Not suffer the action (infinite capacity) |
| $L_2$ | Function: Attribute Time-Cane | Create attribute to start the calculation of Lead Time HF |
| $L_3$ | Function: Control Truck | Looks signal for shipping (truck arrival HF) |
| $L_4$ | Procedure: Loading cane | Normal function with 40 min, standard deviation of 4 min |
| $M_1$ | Drive: HC to mill | Function: constant of 60 min |
| $M_2$ | Handling: Entry for weighing. | Normal Function with 20 s, standard deviation of 1 s |
| $M_3$ | Handling: weighing for sucrose | Normal Function with 40 s, standard deviation of 1 s |
| $M_4$ | Handling: Sucrose for milling. | Normal Function with 50 s, standard deviation of 2 s |
| $M_5$ | Handling: Sucrose for stock. | Normal Function with 45 s, standard deviation of 2 s |
| $M_6$ | Handling: Unload for output. | Normal Function with 90 s, standard deviation of 2 s |
| $M_7$ | Handling: Mill to HF | Function: constant of 30 min |
| $R_1$ | Means: cane loader | 1 loader cane per HF Semi Mechanized |
| $R_2$ | Means: Balance | 1 balance |
| $R_3$ | Means: Probe test / sucrose | 1 probe |
| $R_4$ | Means: Unloader milling | 1 Unloader of cane |
| $R_5$ | Means: Unloader stock | 1 Unloader of cane |
| $C_1$ | Control signal: truck for HF | Controls arrival of trucks for HF Semi Mechanized |
| $C_2$ | Control signal: truck. for HF | Select the truck for FC |
| $C_3$ | Control signal: stock or milling | Select unload: stock or milling |
| $C_4$ | Control sign: unloading Grinding | If the lineF14 $\leq$ F15 turns to F14 |
| $C_5$ | Control signal: unloading stock | If the line F18 $\leq$ F19 turns to F18 |
| $C_6$ | Control signal: truck. for HF | Select the truck for HF |

**CLAW**




| | Description | Parameter |
|---|---|---|
| $E_1$ | Entity: Signal | 1 signal per minute for activation of the claw |
| F1 | Location: Stock | Not suffer the action (infinite capacity) |
| F2 | Calculation: Quantity in stock | Quantity in Stock: Quantity in stock - 5 tons |
| F3 | Location: Grinding | Not suffer the action (infinite capacity) |
| F4 | Calculation: Amount in Grinding | Quantity in grinding: Quantity in grinding + 5tons |
| M1 | Handling: claw | 75 m / min |
| C1 | Control signal: activation claw | Claw is enabled: Mill level $\leq$ 700 ton and stock level $\neq$ 0 |

**MILLING**




| | Description | Parameter |
|---|---|---|
| $E_1$ | Entity: Cane | 4 ton / minutes |
| F1 | Calculation: Amount in Grinding | Quantity in Milling: Grinding in Quantity - 4 tons |

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