JOURNAL OF ENGINEERING annals OF FACULTY OF ENGINEERING HUNEDOARA
Tome V (year 2007), Fascicole 1, (ISSN 1584 – 2665)

# ABOUT THE USE OF ARENA SIMULATING APPROACH FOR MOROCCAN SUGAR CANE HARVEST TO MILL OPTIMIZATION

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**ABSTRACT**
The sugar cane harvest is a huge logistical operation in which millions tons of sugar cane must be cut and transported every year. This operation involves thousands of workers, dozens of cutting machines, hundreds of tractors and several hundreds of trucks and trailers all over the country. This operation must be carefully planned and coordinated to avoid the waste of valuable resources because long delays between harvesting and processing leads to deterioration in the quality of the raw materials. Simulation modelling was chosen as an appropriate mean of analysing the harvesting and transport. It has been applied here to gain insights into the relations between the various processes, the presence of bottlenecks and their causes and at the same time to optimize the resources allocated to the operation as a whole. This paper describes an application involving the simulation and optimization of a complex man-machine system that is Moroccan sugar cane harvest, in which dynamic modeling plays an important role. Simulation modelling with design of experiments, response surfaces and optimization techniques are combined in order to reach the best solution according to some measurements.

**KEY WORDS:**
sugar cane, Moroccan, optimization, ARENA, harvest

## 1. INTRODUCTION

International sugar industry is undergoing substantial changes as a result of reorganisation of sugar market regulations. As a strategically sector in Morocco, sugar industry profits of a particular attention of the authorities, not only from agricultural but industrial point of view as well. In fact, this sector generates more than 150 millions dollars added value, which represent 6% of that generated by agro-alimentary industries. It represents nearly 5 000 established posts and million working days in industry, and also 5.5 million agricultural working days. The production of sugar knew an evolution during the period 1990 to 2006. Indeed, this one passed from 746.000 tons to 1.058.000 tons [1] There are three categories of sugar products: sugar loaf (figure 1) with an average of 37% of the production, cubes and ingots with a share of 12,5% and the granulated sugar with 50% average.

Figure 1. Sugar loaf

In Morocco, sugar is anchored in the consuming habits of the Morrocans, in particular sugar loaf, which is used specially in the preparation of the mint tea. For a long time, this form of presentation merged with sugar. Currently average sugar consumption is 32 kg per capita with about 6 kg of sugar loaf per person and per year. Sugar industry operates thirteen sugar factories and two refineries, capable of producing 4.5 millions tons of sugar per year. The price of sugar in the world market makes it necessary to keep production costs very low in order to ensure some profit margin. The problem of excessive delays between the harvesting and crunching of the sugar cane and the associated deterioration problems have been recognized and investigated [2]. It is known that higher quality cane and beet has higher sucrose content and enables more sugar to be recovered [3]. It is therefore essential to optimise the transport of sugar cane to the factories. Sugar production can be resumed in three steps [4] as shown in figure 2:

- Preparation of the sugar cane or beet and the juice extraction.
- Clarification and evaporation of the extracted juice to obtain concentrated syrup.
- Crystallization and sugar storage.

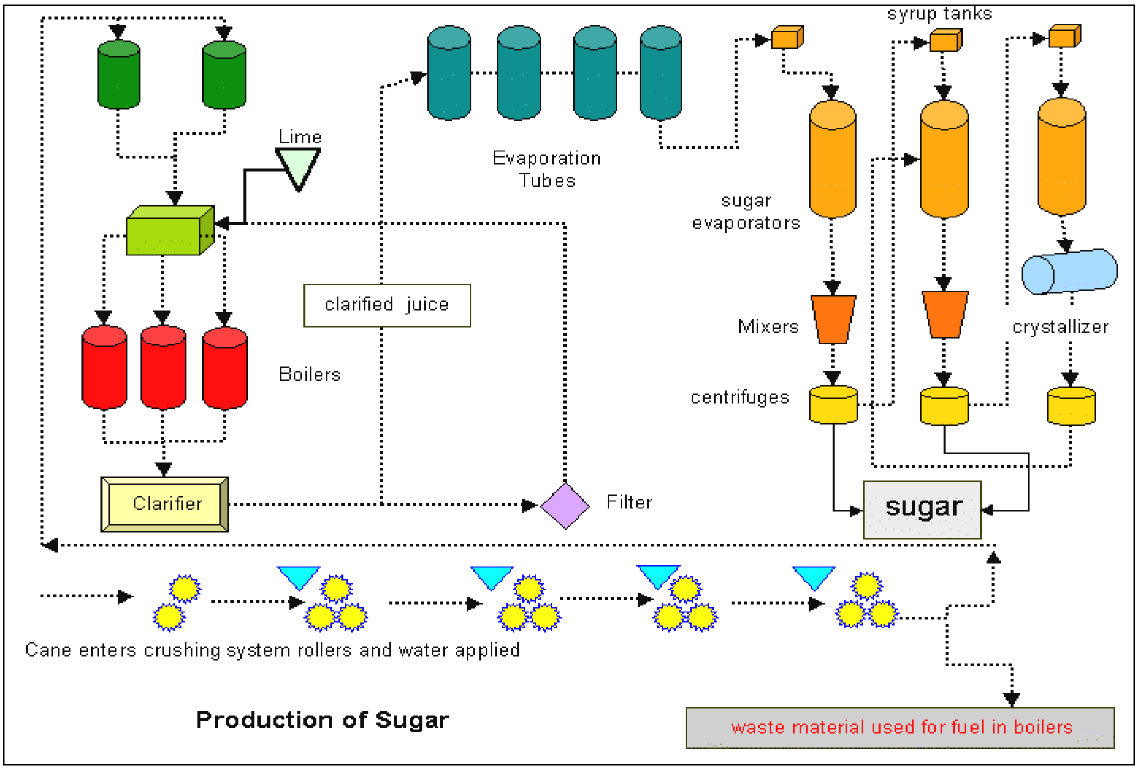


Figure. 2. Sugar production scheme

The sugar beets are harvested by digging them out of the ground, and then transported by trucks or trailers to the factory. Because the beets have come from the ground they are much dirtier than sugar cane and have to be thoroughly washed and separated from any remaining beet leaves, stones and other trash material before processing. The sugar cane harvest is a complex logistical operation that involves the cutting and loading of cane in the fields, the transportation by truck with a trailer to the factories and the unloading of the cane in the factory.3.5 millions tons of sugar beet and 1.5 million ton of sugar cane are harvested from filelds in the most important agricultural regions of Morocco. All sugar cane is irrigated and produced in the Gharb (vicinity of Rabat), Loukkos (vicinity of Larache) and Melouya (vicinity of Oujda) (figure 3).

Figure 3. Irrigated and produced Moroccan sugar cane zones

Each sugar cane sugar factory has a number of teams, which cut cane with several cutting machines in order to meet a daily quota. Then, depending on the quota for a particular day, resources such as trucks, trailers and tractors are assigned. In view of the changes from year to year in the amount of cane and beet available in the fields and in view of changes in conditions in the factories, a reliable method had to be found to ensure that future requirements could be met efficiently. In order to be able to cope with the harvest changes from season to season, there has to be a constant and ongoing analysis of the current organization, the available infrastructure and future needs. This study has mainly two goals: (a) identification of logistical bottlenecks in the sugar cane transportation, (b) to provide integrals solutions to these bottlenecks which will support the decision- making process. This paper combines simulation with an optimization technique. It is proposed that, with a minimum number of runs of a simulation model, the output of the simulation can be the input of an optimizing approach to determine the optimal resource allocation in view of the relevant output variables. Data were obtained from COSUMAR (*Compagnie Sucrière Marocaine et de Raffinage*), which is the Morocco-based sugar producer.

## 3. DESCRIPTION OF THE SYSTEM

Sugar cane flow from the fields to the factory at harvest time is a process that includes cutting, loading, transport and unloading. This cycle is repeated continuously during the day until the team meets its daily quota. In view of the process involved and the quantity of cutting machines, tractors, trucks and trailers allocated to each team, time could be wasted at various stages and holdups of greater or lesser duration could occur, and this has a direct bearing on the efficiency of the team and on the total quantity of sugar cane that can be harvested and transported in a given day. In the system operation trailers have a stabilizing effect on the loading process, because since there are usually more of them than there are trucks, they allow the cutting machines to keep working while the trucks are on their way to or on their way back from the factory. Furthermore, this means that the trucks have to spend less time waiting for loaded and empty trailers in each cycle. An outline of the operation of the system is shown in the figure 4. Many random factors arise, some controllable, some not, and they have an impact, in some way or another, on the whole process. That is why, for the purposes of the simulation model, the random variables entailed in the following operations were taken into consideration:

1. unhitching empty trailer
2. entry into the field
3. loading delay
4. cutting machine turn around
5. cutting machine interruption
6. exit from field
7. unhitching of full trailer
8. hitching of full trailer
9. time taken for loaded truck and trailer to travel
10. time spent waiting for weighing
11. time spent during weighing process
12. transfer of trailer to unloading area
13. transfer of truck to unloading area
14. unloading delay
15. transfer to the empty trailer area
16. hitching of empty trailer
17. time taken to empty truck and trailer to travel between factory and field
18. truck interruption

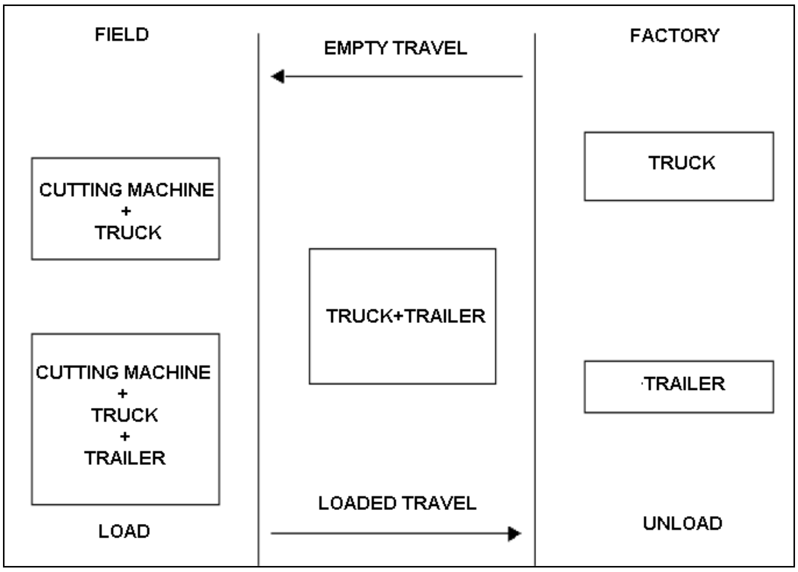

Figure 4. An outline of the operation of the system

As can be appreciated, the magnitudes of some of these variables depend on the organization and technology used, and others on road conditions and technical factors. On this basis a simulation model can be built with the view of studying the operations involved in harvest process.

## 4. SIMULATION OPTIMIZATION APPROACH

There is no single or standard approach to the optimization of a system where the data for the analysis are based on experiments conducted with a simulation model. Some approaches focus on a single simulation run. Others focus on a search process that involves multiple simulation runs. Within this latter approach, which is the most common, there are many philosophies on how the search should be conducted. The process that is followed in the simulation optimization approach [5] is illustrated in figure 5. The operation of the system, as represented by the simulation model, is run for a specified period of time. The performance of the system is based on an output of the simulation model and the response that is to be optimized.

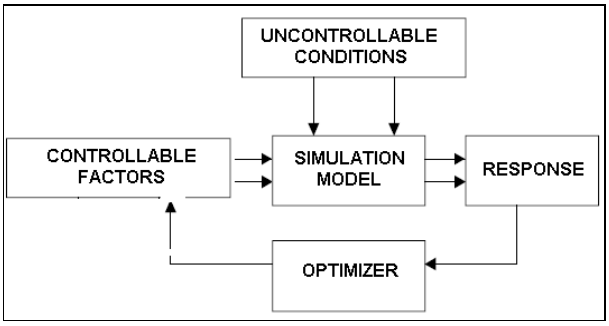


Figure 5. Procedure for optimising the simulated system

The procedure illustrated in figure 4 involves three phases, as follows: the first step is typical of any logistics-modelling problem and involves the identification of the response variables to be optimised and of the independent variables that are expected to affect them. The relationships between these variables were hypothesized prior to the construction of the simulation model. As with any model, identification and selection of the response variable(s), the independent variables, and the relationships between them requires a thorough knowledge of the system under investigation. The essence of the system has to be extracted and unnecessary detail excluded. In the second phase, data on the relevant variables are gathered in a test case. These data are used to further refine the definition of the variable relationships and, consequently, the construction of the simulation model. After construction, a series of runs is conducted to validate the model and test the hypotheses. This is typically where a simulation model procedure stops. It is also where simulation has been faulted in the past. Simulation alone provides no mechanism for finding the optimal solution to the problem; it indicates only the best solution among those examined. The third phase is the point at which the response function is brought into use to find the optimal solution [6]. The preliminary objective of the response surface methodology (RSM) is to approximate the function in a relative small region of the independent variables with some simple function [7]. Response surface analysis in no way limits the number of variables that can be included in the analysis. An analyst may include as many variables as deemed necessary to tackle the problem at hand.

## 5. THE SIMULATION MODEL

### 5.1. Response-Surface methods

It was concluded that simulation modelling is the most appropriate technique for the situation of sugarcane harvesting and transport and hence the aims of the project. Simulation models are well suited to complex systems where there is interaction of different processes which cannot necessarily be described deterministically because they are able to model the individual processes and let them interact in a logical and realistic way. Simulation can also cope with dynamic and transient effects since it models a system as it progresses through time. Discrete event simulation models are particularly well suited to systems, which can be described as combinations of processes and queues. Simulation models are useful in gaining understanding of systems as they force model developers to think about the operation of the system and thus to possibly come up with alternative solutions to problems. They are also useful in communicating the details of systems and problems with systems to system users because simulation models can very often be grasped easily and quickly by non-experts. Most experimental designs, including those mentioned above, are based on an algebraic regression-model assumption about the way the input factors affect the outputs [8]. For instance, if there are two factors ($x_1$ and $x_2$) that are thought to affect an output response $y$, you might approximate this relationship by the regression model expressed by the following expression:

$$y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_1 x_2 + \alpha_4 x_1^2 + \alpha_5 x_2^2 + \delta$$

where the $\alpha_p$ coefficients are unknown and must be estimated somehow, and $\delta$ is a random error term representing whatever inaccuracy such a model might have in approximating the actual simulation-model response $y$. $x_1$ and $x_2$ will represent respectively the numbers of trucks and trailers. Since in this case the above regression model is an approximation to another model (the considered simulation model), the regression is a "model of a model" and so is sometimes called a meta-model. And since a plot of the above situation (with two independent input variables) would be a three-dimensional surface representing the simulation responses, this is also called a *response surface*. The parameters of the model are estimated by making simulation runs at various input values for the $x_i$'s, recording the corresponding responses, and then using standard least-squares regression to estimate the coefficients.

### 5.2. Simulation System

The Arena simulation system, which is based on the SIMAN/Cinema System [9] was chosen as the software for developing the model. Simulation and the Arena environment in particular have been most widely used in the manufacturing environment, but more recently have been applied in the transport environment as well as numerous other fields. The Arena simulation system is a Visual Interactive Modelling System, which implies that the model is developed using a flowcharting methodology to depict the logic of the system, which is then used by the program to generate the underlying model code. The system also allows for animation of the model which is very useful in verification and validation of the model, providing insight about interaction of the systems components and when presenting model results to decision makers. The basic concept of the system is that entities, which may represent people, objects (such as tons of cane) or concept whose movement through the system causes a change in the status of the system, interact over time with resources, which represent constraints such as people, machinery or storage space.

The complete sugar cane flow, for a team, from field to factory, as seen in figure 6, has been modelled into the simulation environment ARENA [10]. Two sub-systems have been distinguished, based on the process involving trucks and the trailers.

*Trailers*: this sub-system starts with an empty trailer in the field, ready to be loaded. The trailer to be loaded is hitched by a tractor. Later the tractor pulls the trailer out of the field, uncouples it, and leaves it until it is hitched to a loaded truck and taken to the factory.

*Trucks*: this sub-system starts with an empty truck in the field, ready to be loaded. When a cutting machine is available, the truck is loaded and then a loaded trailer is hitched to it to go to the factory. Once at the factory, truck and trailer are weighed, and then the truck leaves the trailer to be unloaded, and the truck itself goes to be unloaded. Later an empty trailer is hitched to it and it returns to the field.

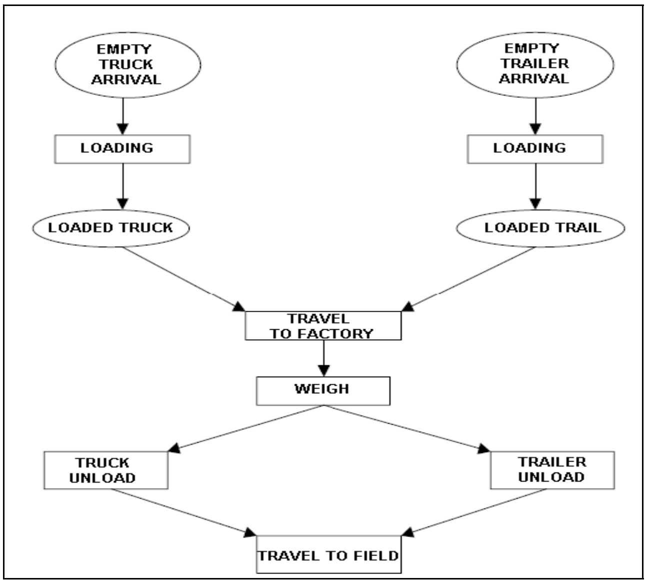


Figure 6. Sugar cane transportation process

Between field and factory the sugar cane undergoes several processes, which are to be carried out with restricted resources. The required throughput times are a result of process times and of potential delays, which might exist if queues arise.

In the model, information is gathered for each team, regarding resource utilization (i.e. cutting machines, tractors, trucks and trailers), waiting times, queue lengths and total quantity of cane transported. Once the simulation model representing the operation of the real system is built, the fields to be harvested are specified, as are their distances to the factory. Then simulation runs are performed with various alternatives of the controllable factors, based on an experiment design that makes it possible to obtaining the response surface required. According to the simulation optimisation approach, the main controllable factors considered were, for every team, the number of allocated resources (cutting machines, tractors, trucks and trailers) and the average truck speed. The total quantity of cane to be transported and the average travelling time, for a complete cycle, were considered as output variables. Figures 7 and 8 provide an example of the response surfaces obtained.

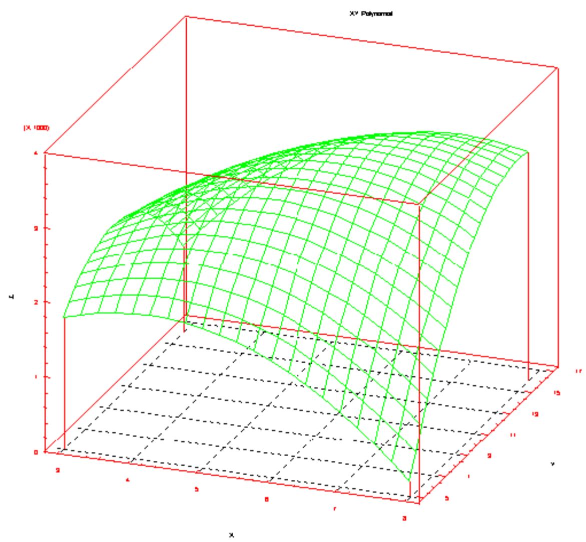

Figure 7. Response surface output variable sugar cane transported as a function of number of trucks and trailers.

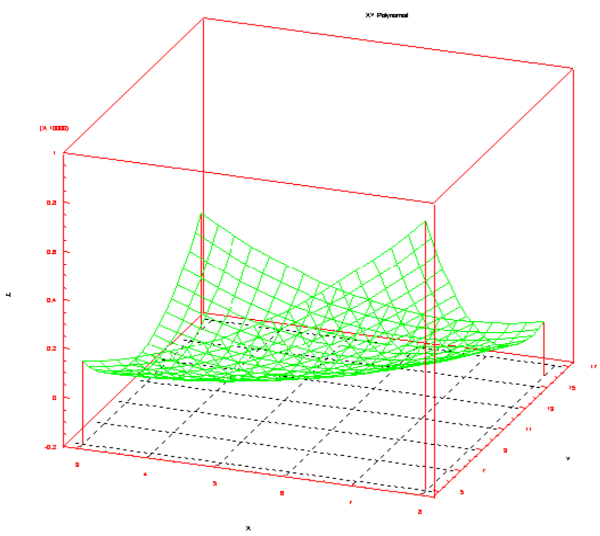

Figure 8. Response surface output variable average cycle travelling time as a function of number of trucks and trailers.

## 6. RESULTS AND CONCLUSIONS

The simulation optimisation approach resulted in huge quantities of output, which were translated into overviews of sugar cane flow, utilization of resources, waiting times and all other performance criteria.

This quantitative information serves as supporting material to the sugar industry in making decisions about resource allocation to factories. In addition, a decision support system, based on simulation, was tested to facilitate resource allocation to teams. The ability to predict bottlenecks and to provide solutions for them can avoid problems and risks in the future. It will be easy to ensure support for the results and to implement them in the sugar factories. The animation accompanying the simulation model greatly facilitated communication with managers and workers in the factories. The data were used to validate the model and then the model can be used to perform experiments to determine which of the proposed methods of reducing harvest-to-mill delays will work best and where bottlenecks occur. The benefits of reduced delays have to be weighed against the costs of implementing the changes to the systems required to effect the reductions. The experimental results show that the simulating method can be significantly transposed to other applied engineering domains.

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