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SIMULATION AND OPTIMIZATION OF SUGAR CANE TRANSPORTATION IN HARVEST SEASON

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ABSTRACT

Cuba is one of the world's major sugar producers, producing on average more than five millions tons per year. The sugar cane harvest is a huge logistical operation in which between 45 and 50 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. Simulation 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 sugar cane harvest, in which dynamic modeling plays an important role. Simulation modeling with design of experiments, response surfaces and optimization techniques are combined in order to reach the best solution according to some measurements.

1 INTRODUCTION

After tourism, sugar is the second must important generator of revenue for Cuba. The Ministry of Sugar Industry operates a hundred and fifty-six sugar factories, capable of producing 10 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, and it is therefore essential to optimize the transport of sugar cane to the factories.

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.

Each 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 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 three main goals:

1. Identification of logistical bottlenecks in the sugar cane transportation.
2. To provide integrals solutions to these bottlenecks which will support the decision- making process.
3. To develop an effective decision support system for the allocation of resources to each team on a daily basis.

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.

2 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 1.

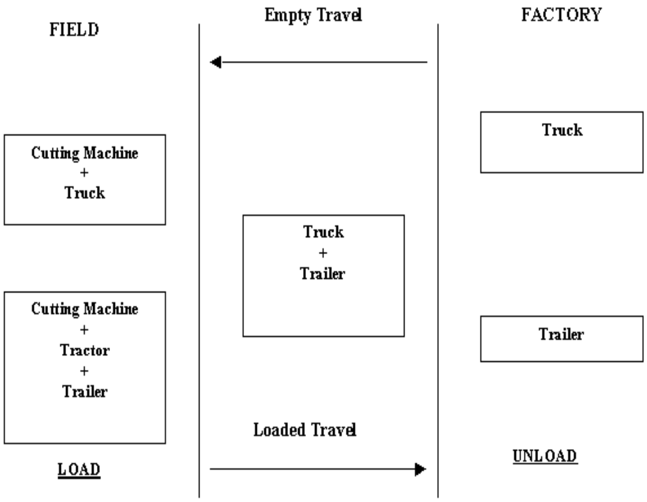

Figure 1: Sugar Cane Transportation System

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 between field and factory.
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.

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 that will make it possible to study the operations involved in the harvest process.

3 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* (Vashi and Bienstock 1995) is illustrated in Figure 2. 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.

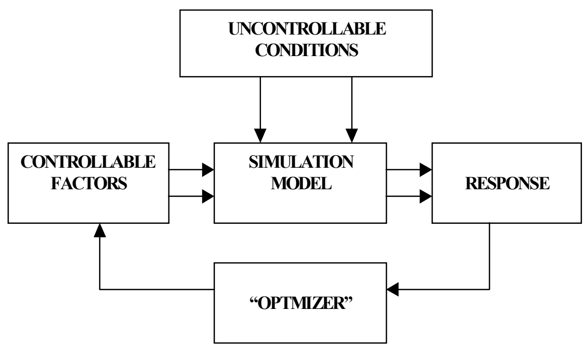

Figure 2: Procedure for Optimizing the Simulated System

The procedure illustrated in Figure 2 involves three phases, as follows.

The first phase is typical of any logistics-modeling problem and involves the identification of the response variables to be optimized 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 (Greenwood, Rees and Siochi 1998). 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 (Montgomery 1995).

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.

4 CONTENTS OF THE SIMULATION MODEL

4.1 Demarcation

The complete sugar cane flow, for a team, from field to factory, as seen in Figure 3, has been modeled into the simulation environment ARENA (Kelton and Sadowsky 1998).

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.

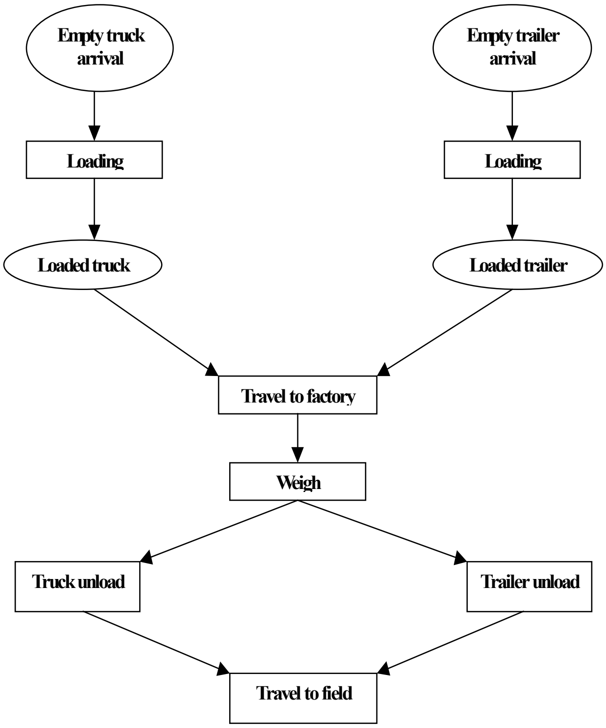

Figure 3: Sugar Cane Transportation Process

4.2 In Practice

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 optimization 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 4 and 5 provide an example of the response surfaces obtained.

5 RESULTS

The *simulation optimization 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.

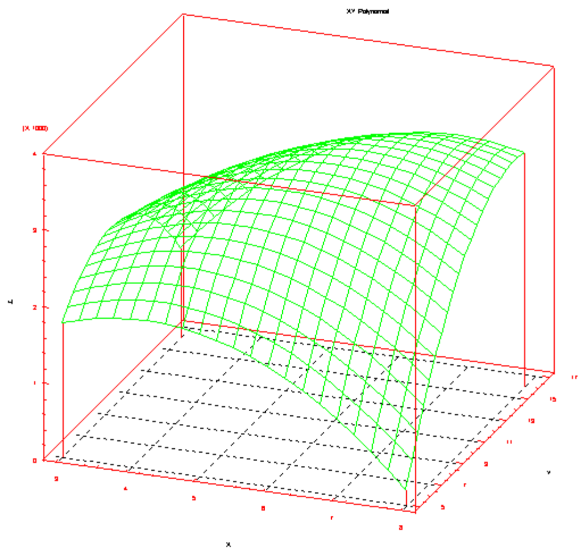

Figure 4: Response Surface Output Variable Sugar Cane Transported as a Function of Number of Trucks and Trailers

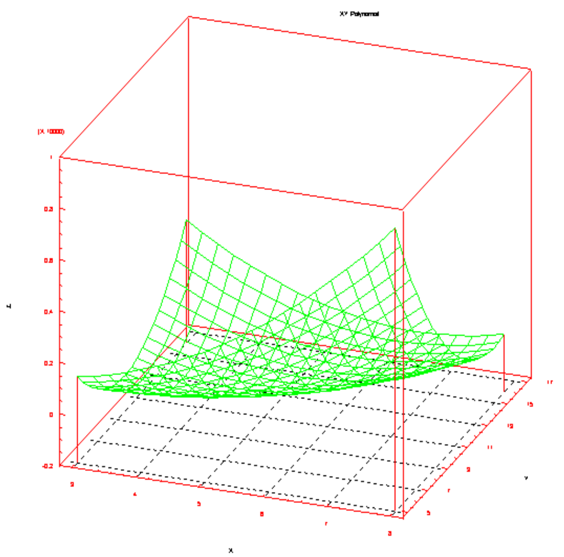

Figure 5: Response Surface Output Variable Average Cycle Travelling Time as a Function of Number of Trucks and Trailers

This quantitative information serves as supporting material to the Ministry of Sugar Industry in making decisions about resource allocation to factories. In addition, a decision support system, based on simulation, was developed 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.

As several departments of the Ministry of Sugar Industry were involved in this study from the beginning, it was 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.

REFERENCES

Greenwood, A. G., L. P. Rees, and F. C. Siochi. 1998. An investigation of the behavior of simulation response surfaces. *European Journal of Operational Research*, 110.

Kelton, W. D., R. P. Sadowsky, and D. A. Sadowsky. 1998. *Simulation with ARENA*. New York: WCB/McGraw- Hill.

Montgomery, D. C. 1995. *Response Surface Methodology.* New York: John Wiley.

Vashi, V. H., and C. C. Bienstock. 1995. The use of response surface methodology to optimize logistics simulation models. *Journal of Business Logistics,* 16.

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