

SIMULATION MODELLING OF SUGARCANE HARVESTING AND TRANSPORT DELAYS

AJ BARNES¹, E MEYER², AC HANSEN³, ER DE LA HARPE³
AND PWL LYNE³

¹*Agricultural Research Council, Institute for Agricultural Engineering,
University of Natal, Private Bag X01, Scottsville, 3209*

²*South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300*

³*Department of Agricultural Engineering, University of Natal,
Private Bag X01, Scottsville, 3209,*

Abstract

Reducing the delay between the harvesting and crushing of sugarcane can result in substantial reductions in the loss of recoverable sugar caused by cane deterioration. The investigation of methods of reducing the harvest-to-crush delay requires the use of some form of computer model to evaluate the effects of proposed changes to cane harvesting and transport systems.

Simulation modelling has been identified as a highly effective technique for modelling sugarcane harvesting and transport systems. The use of Arena simulation software to develop a model of the Sezela mill and its supply area is reported and initial results from experiments conducted with the model are presented. The main output examined is overall harvest-to-crush delay, but machinery requirements and utilisation are also discussed.

Introduction

The problem of excessive delays between the harvesting and crushing of sugarcane and the associated deterioration of cane has been recognised and investigated in the sugar industry for many years (Brokensha *et al.*, 1975). The potential for savings to the industry through delivery of better quality cane to the mills, particularly with the proposed introduction of the new cane payment system, has been estimated in the millions of rands per annum. According to Brokensha *et al.* (1975) the loss to the industry due to a one-day delay in cane deliveries was approximately 31 cents per ton of cane. In current terms, and multiplied by the 20 million tons of cane that the industry currently produces per annum, this figure implies possible savings in the region of R58 million per annum if average harvest-to-crush delays can be reduced by 24 hours. The aim of this project, which is being conducted in conjunction with the SASA Experiment Station, is to develop a theoretical, computer based model of the various systems of harvesting, transport and handling of sugarcane that can be used to investigate proposed methods of reducing harvest-to-crush delays.

The initial phase of the project involved an extensive literature review of techniques that have been used in the past for modelling harvesting, transport and materials handling

systems in different industries (Blanchard and Fabrycky, 1981; Hoekstra, 1975; Semenzato, 1995) and it was concluded that simulation modelling was the most appropriate for the situation of sugarcane harvesting and transport and hence the aims of the project (¹unpublished seminar). The Arena simulation system (Pegden *et al.*, 1995) was chosen as the software with which to develop the model. Simulation modelling as it is used in this project involves using time delays to describe various processes and combining them in a manner which represents the way the various processes interact in the real system. Entities (in this case, tons of cane) are passed through the model and in this way the variability and interactions in a system can be analysed (Pegden *et al.*, 1995).

In this paper, the development of an initial model of harvesting and transport systems in the Sezela mill is presented, along with results from a sensitivity analysis conducted on this model.

Model development

The model was developed on the scale of a particular mill and the area supplying it with cane because it is very often the interactions of factors such as the time of day that loads from different farms are delivered to the mill, milling schedules and transport cycles that have the greatest influence on overall harvest-to-crush delays. The Sezela mill was chosen in particular because a simulation study of the millyard operations had already been conducted using the Arena package (²personal communication).

As an initial estimate, the most common methods of harvesting and transport were modelled and the percentage of cane processed or delivered to the mill by each of these methods was weighted according to the corresponding tonnage of cane delivered. Transport was modelled as a non-limiting resource. This assumption simplifies the situation and will cause the delays calculated by the model to be less than real delays.

¹Barnes, A (1997). Systems analysis techniques for sugarcane harvesting and transport. Unpublished Seminar, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, South Africa.

²A Simpson, Cane Supply Manager, Sezela Sugar Mill, KwaZulu-Natal, South Africa (1997).

Hence it is likely to underestimate the sensitivity of the system to parameter changes since no extra delays are incurred by transport not being available. However, it does provide a starting point from which the model can be developed and a framework from which an initial estimate of the sensitivity of the system to various parameters can be made. The model was also split into a harvesting and transport section and a mill yard section to make debugging and verifying easier. This paper discusses the harvesting and transport section of the model.

Information collection

Information about the various systems of harvesting and transport currently in use in the sugar industry was compiled from background reading and discussion with Eddie Meyer of the SASA Experiment Station, as well as from interviews with various people working with Illovo Sugar at the Sezela mill, including Allan Simpson, the cane supply manager, Eric Arde, the miller-cum-planter field manager and Antony Domleo, the small growers field manager. Kevin Cole of Agri-Man, who is also a farmer in the Sezela mill supply area, was also consulted. A number of other farmers in the area are also to be interviewed to collect data on operation times for

various field processes and tonnages of cane on various systems. The times representing the processes are therefore approximations at this stage, but are within reasonable limits.

Model structure

The basic structure of the model is shown in Figure 1. One ton entities of cane are modelled and tracked through the system. These entities are assigned attributes based on user defined percentages which determine by what systems the entities are processed. 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 burning or trash cutting processes according to defined schedules and at such a rate that the target tonnage of cane will be produced each week. The burning schedules are either six, three, two or one burns a week (burn schedules 1 to 4). The burnt cane is cut and thereafter all the cane then goes to the loading process. If the cane is to be delivered to the mill in bundle form or if it is to be delivered to the transloading zones in bundle form before being split up to create spiller loads, it then goes through the stacking process to form bundles. This process produces bundles of three, four, or five tons of cane.

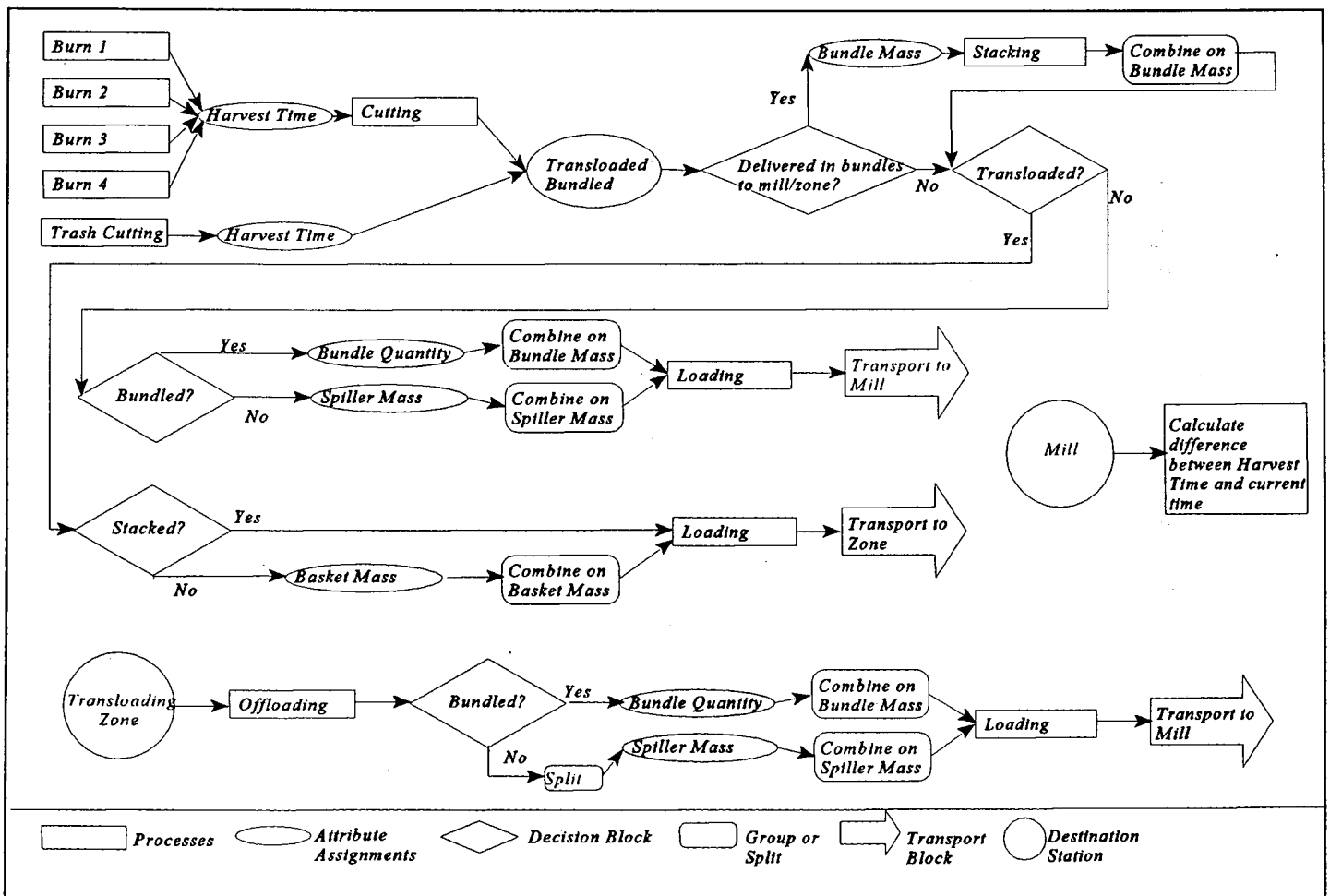


Figure 1. Flow chart of initial harvesting and transport model structure.

If the cane is to be delivered directly to the mill the bundles are combined into loads of six, seven, eight or nine bundles or the one ton entities are combined into spiller loads of mass described by a triangular distribution with minimum 24, mode 28 and maximum 35 tons. Cane delivered to the transloading zones is loaded onto trailers in individual bundles or basket trailers of mass four, five or six tons. The loading process can only start once transport is available. The cane is then routed to the mill or transloading zones with a route time described by a triangular distribution.

Cane arriving at the transloading zones is offloaded and bundles are combined into loads as in the fields or else the loads from the fields are split up into one ton entities and combined into spiller loads as in the fields. Once again the reloading process can only proceed if transport is available. The cane is then routed to the mill with a route time similar to that from field to mill.

Experimental factors and reports

Experimental factors are those variables or inputs to a simulation model that are altered to determine whether an improvement to the system can be obtained. Reports are those statistics or outputs that are used to determine whether one system is better than another. In the case of the initial harvesting and transport model dealt with in this paper, the experimental factors consist of:

- Operation schedules
- Percentage of cane on various burn schedules (Perburn1 to Perburn4)
- Percentage of cane on direct transport (Perdirect)
- Percentage of cane delivered to the mill in bundles (Perbundle)
- Percentage of cane not delivered to mill in bundle form that is stacked in the fields but is split into loose cane on the zones (Persplit).

The experimental reports consist of the time in system (or harvest-to-millgate delays) recorded for each ton of cane passing through the model and levels of various stockpiles in the model.

Sensitivity analysis

A sensitivity analysis was conducted on the initial harvesting and transport model to determine how accurately the input parameters of the model need to be measured and to identify areas of the model that need further development. When considering the results of the sensitivity analysis it should be borne in mind that the interactions and feedbacks between the various processes form a complex system. While usually only one variable at a time is changed in this analysis, in reality, several variables may be changed at one time, which may alter the sensitivity of the model to other variables. A comprehensive statistical analysis would be required to determine the probability of the variation in model output exceeding a specified value for any combination of changes in variable estimation.

Selection of variables for sensitivity analysis

In addition to the experimental factors outlined above, the following parameters which would not be varied in normal experimentation with the simulation model were varied in the sensitivity analysis:

- Cutting, stacking, loading and unloading times all controlled by equations of the form:

$$PT = \frac{TA * Mass}{\% * TMass * rf}$$

Where

- PT = Process time for entity
- TA = Time available in one week for an operation (whole supply area)
- Mass = Mass of entity
- % = Percentage of total weekly supply area crush involved in operation
- Tmass = Mass of total weekly supply area crush
- rf = rate factor used to adjust the process time.

- Mass of spiller loads, adjusted with the mass factor *massf*.

Procedure and method of analysis

Runs of 20 weeks were executed for each case investigated. The first week of results was truncated from the observations to decrease the effect of the initial transient phase in the model in which the various stockpiles, which were empty to begin with, are filling up. The remaining observations were batched to calculate independent means that could be used to determine a confidence interval on the overall mean of the harvest-to-millgate delay using the student-t distribution for each case investigated.

The first parameter that was investigated was different percentages of cane on various burn schedules. The parameter values used are shown in Table 1. Case 2 in Table 1 was used as the standard case with which to compare all other cases.

Table 1. Parameter values for different percentages of cane on various burn schedules.

Variable	Case 1	Case 2	Case 3
Perburn1	20%	10%	40%
Perburn2	10%	20%	20%
Perburn3	10%	40%	20%
Perburn4	0%	10%	0%
Perdirect	5%	5%	5%
Perbundle	10%	10%	10%
Persplit	50%	50%	50%
rf	1,05	1,05	1,05
massf	1,00	1,00	1,00

In other analyses, Perdirect, Perbundle and Persplit were varied between 0 and 100% in different increments, *rf* was varied from 1,00 to 1,10 and *massf* was varied from 0,80 to 1,20. Parameters not varied were kept at the values for the standard case. The rate factor was not varied below one as this would cause cane stocks to build up in the system which would never decrease, contrary to the original assumption that the process rates be set at values sufficient to ensure that the target tonnage of cane is processed each week.

Results and Discussion

Results of the sensitivity analysis are presented in Figure 2. The error bars shown indicate the size of the 0,950 confidence interval half-width within which the estimates of the mean harvest-to-millgate delays fall. These half-widths are small relative to the magnitude of the delays and the results can therefore be taken as sufficiently accurate estimations of the true mean.

Percentages of cane on various burn schedules

Case 1 would represent a mill where only 40% of the cane is burnt before being cut. This is a fairly unusual situation, but shows how total percentage of cane being burnt affects the harvest-to-millgate delay when compared with the second two cases, where total cane burnt is 80%. The greater the percentage of cane that is burnt, the greater the delay. In case 3 the proportion of cane on the various burn schedules is the same as for case 1 and the increase in the estimate of delay for the 100% increase in total percentage of cane burnt is 5,2 h or about 24% of the original estimate of delay.

Case 2 (the standard case) is an estimate of the type of situation that is likely to be found at the Sezela mill, based on discussion with experienced personnel in the industry. The total percentage of cane that is not burnt before cutting is small as most farmers burn as a rule. Unburnt cane is cut only when conditions do not permit burning. The majority of cane is on a schedule that involves burning every second or third day because the management effort involved in burning every day is high. Case 3 represents a situation in which the management of the burning process is very good with at least half of the burnt cane being burnt on a daily basis and the remainder every second or third day when conditions make daily burning impossible. It can be seen that good management of burning produces significant decreases in harvest-to-millgate delays of 8,3 h or about 23% of the larger value. The magnitude of these delays is consistent with figures discussed with experienced personnel which were about 16 to 30 hours for cane where good burning management is practised and 40 to 80 hours where burning management is not as good. These real life estimates are obviously subject to much greater variation due to factors such as weather, breakdowns and the influence of millyard operations, but they do serve to demonstrate that the model is producing delays that are within reason.

Percentage of cane delivered directly to the mill

There is a general trend of delay decreasing with increasing Perdirect. This is to be expected, as cane that is transported directly from the fields to the mill does not have to go through the transloading processes and stockpile waits associated with

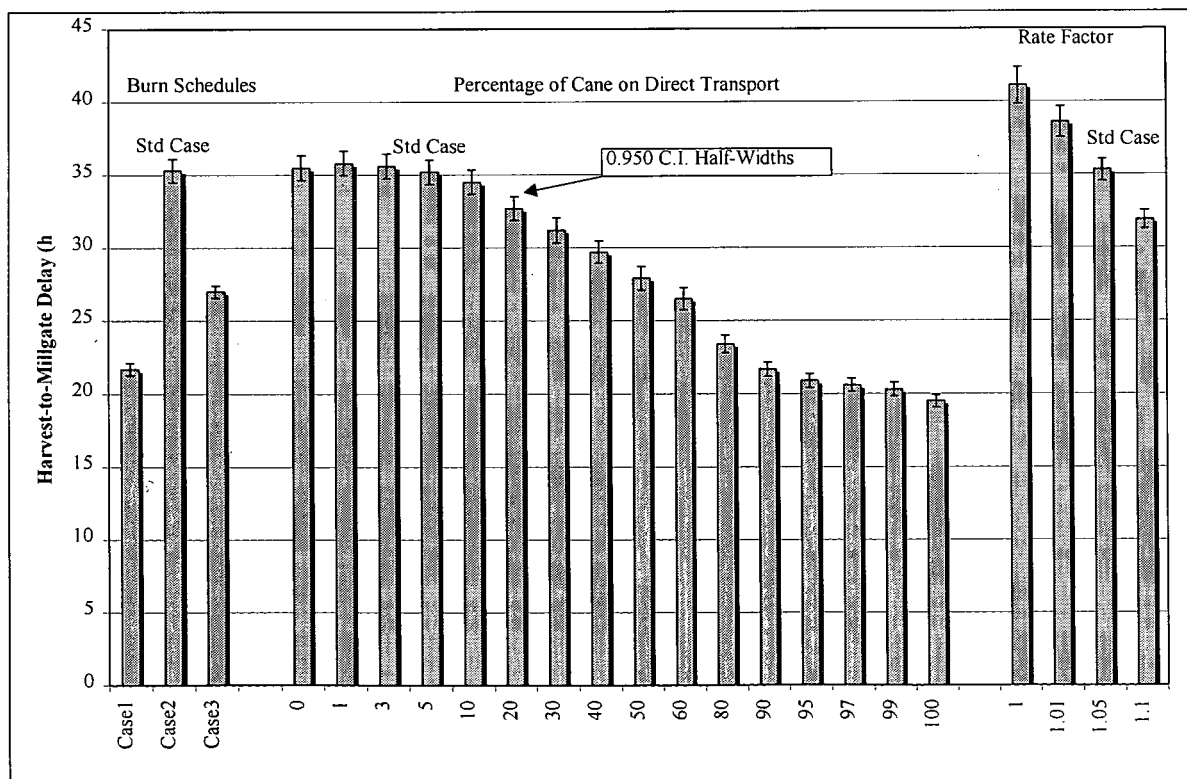


Figure 2. Comparison of harvest-to-millgate delays for various cases.

these processes. Furthermore, as can be seen in Figure 3, the overall decrease in delay caused by a change in Perdirect from 0 to 100% of about 45% of the standard case mean is approximately three times that caused by changing the total percentage of cane that is burnt from 80% (Case 3) to 40% (Case 1), these cases having the same ratios of cane on the various burn schedules. This decrease in delay indicates that the advantages of increasing Perdirect could be significant, especially considering the low levels of cane currently on direct transport to mills such as Sezela (estimated around 5%). Nevertheless, these advantages have to be weighed against the costs and practical considerations of introducing higher levels of direct transport.

Percentage of cane delivered to the mill in bundle form

The analysis showed that harvest-to-millgate delays are insensitive to Perbundle and this can be explained by considering the fact that the only significant time delay difference up to the millgate between cane that is delivered in bundles and cane that is delivered on spiller is the extra stacking process that the bundled cane goes through. Provided the stacking occurs at the correct rate to cope with the amount of cane that has to be processed (which is how it is represented in this model) this additional time delay will be small. Significant differences will occur when, for some reason, stacking is delayed or occurs at a slower rate than that required to process all the cane to be stacked in a week and, as a result, stockpiles of cane waiting to be stacked build up. The maximum tonnage that occurred in this stockpile for any

of the values of Perbundle investigated was 151 tons, with a corresponding average tonnage in the stockpile of 11 tons. This stockpile therefore did not build up to any great extent and there was thus little additional time delay involved in cane being stacked.

Percentage of transloaded, spiller cane delivered to the transloading zones in bundles

This model was also insensitive to Persplit and the reasons are the same as for the insensitivity to Perbundle, since Persplit also only affects the amount of cane that is stacked and, as discussed previously, the stacking process has little effect on overall delays provided there is little stockpiling of cane prior to stacking.

Rate of processes and mass of spiller loads

The general trend here is a decrease in harvest-to-millgate delays with increasing *rf*. This is to be expected, as increased process rates mean that each ton of cane spends less time in processes such as cutting and loading and there is also less stockpiling because the resources necessary for processing become available more quickly. Harvest-to-millgate delays are highly sensitive to process rates with a 5% change in *rf*, from 1,00 to 1,05, producing a change in delay of more than 15%, as shown in Figure 3. The model becomes less sensitive to changes in process rates as the process rates increase, because less queueing of cane waiting to be processed occurs.

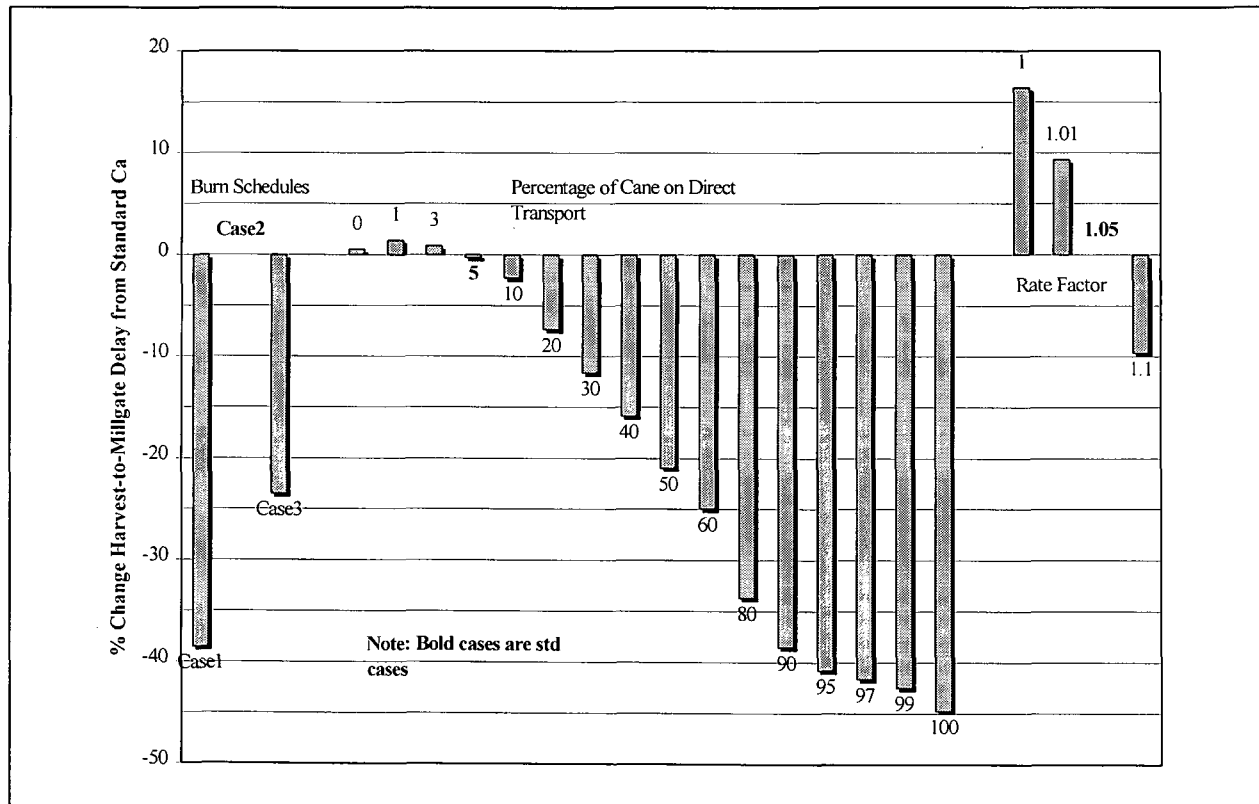


Figure 3. Harvest-to-millgate delays relative to standard cases.

A change in r_f from 1,05 to 1,10 produced only a 10% change in delays. The model proved to be insensitive to mass of spiller loads.

Conclusions

The results of the sensitivity analysis indicate that the most significant decreases in harvest-to-millgate delays can be achieved by addressing burning schedules and the amount of total crush of cane that is delivered directly to the mill. This is a fairly obvious conclusion, but the results serve to substantiate the assumption that these are important areas to investigate. This also indicates that these are areas that will have to be given particular attention in further development of the model.

The results also indicate the high sensitivity of the model to the process rates for operations such as cutting and loading. This means that particular attention will also have to be paid to determining the values for such process rates and the manner in which such processes are represented in future versions of a model of sugarcane harvesting and transport systems.

Finally, it needs to be stressed that the model presented here addresses only half the system. The interaction of harvesting and transport systems with millyard operations is likely to produce further complexities in the model and could have a significant impact on overall harvest-to-crush delay, which is the most important cause of cane deterioration. Furthermore, restrictions on the availability of transport vehicles, which was not modelled in this exercise, will also have an effect on overall harvest-to-crush delays and therefore needs to be examined further.

Acknowledgements

The authors wish to acknowledge the following:

Messrs Eddie Meyer and Erik Schmidt, South African Sugar Association Experiment Station, for their help in directing this project and providing much background information.

Institute for Agricultural Engineering, Agricultural Research Council, for their financial assistance with this project.

Simulation Services cc, for technical help with the simulation modelling.

Kevin Cole, Agri-Man, for advice and the provision of information.

Illovo Sugar, Sezela, particularly Allan Simpson for advice and provision of information.

Foundation for Research Development for financial assistance with this project.

REFERENCES

- Blanchard, BS and Fabrycky, WJ (1981). *Systems Engineering and Analysis*. Prentice-Hall Inc, Englewood Cliffs, New Jersey, USA.
- Brokensha, MA, Buchanan, EJ, Evans, AD, Hoekstra, RG, Hudson, JR., Loudon, TR, Muller, E and Paxton, R (1975). Report on the delays between the harvesting and crushing of sugarcane. Sugar Industry Central Board, Durban, South Africa.
- Hoekstra, RG (1975). How cane delay times are affected by various operational conditions. *Proc S Afr Sug Technol Ass* 49: 29-40.
- Pegden, CD, Shannon, RE and Sadowski, RP (1995). *Introduction to Simulation Using SIMAN*, 2nd ed. McGraw-Hill Inc, New York.
- Semenzato, R (1995). A simulation study of sugar cane harvesting. *Agricultural Systems* 47: 427-435.