MODEL FOR ESTIMATING EFFECTS OF HARVESTING PRACTICES ON FACTORY OUTPUT

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Abstract

Sugar technologists have proposed many models to predict and optimise particular plant and processes used in the production of sugar. This has led to the optimisation of individual activities neglecting the interaction between the activities. This paper is intended to take the process one step further, that is, models for each activity have been combined into a single model to indicate the interaction between the stages. Various models were evaluated and the most appropriate option chosen to model each of the aspects.

Losses associated with burn to crush delays depend on the ambient temperature and the duration of the delay. Initially models for the generation of ethanol were adapted to estimate deterioration losses. A direct correlation model expressing change in purity as a function of temperature and time, that was published more recently, was used in place of the ethanol model.

Factory performance and molasses losses were calculated using a model that could predict response to small deviations from a known operating condition.

The sub-models have been combined to give a single spreadsheet model to predict how changes in operation can change profitability.

Keywords: Cane quality, economics, model

Introduction

There are many parties involved in the chain that ends in sugar crystal and various by-products. For the purpose of modelling, the chain, or probably more accurately, the cycle, will be considered to start with the farming activities. Singels *et al*. (1999) have modelled the production of biomass and sucrose content for given weather and irrigation practices. If it is assumed that the cane crop is ready for harvest in the allotted week, then only the final composition was important for the model that was being constructed.

Once the cane is burnt and/or cut, then deterioration begins. There are many deterioration mechanisms that occur. The sucrose inverts to fructose and glucose. These components can break down further to form ethanol or they can combine to form gums and polysaccharides. Even the sucrose itself can combine to form dextran. Complexities such as these prevent a rigorous model for analysis of all deterioration products from being constructed. Studies such as those conducted by Lionnet (1986), de Robillard *et al*. (1990) and Smith (1992) do, however, give a usable guide for estimating the effect that post-harvest deterioration could have on sucrose content.

When the cane is processed a wide variety of equipment and factory configurations are used. The ideal would have been to model the performance of each piece of equipment depending on its input. This, however, would lead to the need for extensive user input requirements thus reducing the attractiveness of the program. Each sub-model would also introduce new approximations that would probably adversely affect the reliability of the total model. Consequently, it was decided that it would be preferable to focus on the macroscopic quantities such as corrected reduced extraction and boiling house recoveries based on reducing sugar-ash ratios. Since there is no zero based equipment information, the calculations must then be based on known performance figures for the factory adjusted to the conditions that are being modelled. The assumptions in this model, based on the work reported by Wienese (1995), are only approximations, consequently, only small changes in operation can be modelled with certainty.

Cane properties

There are many factors that influence the properties of the cane as it stands in the field. These include the age of the cane, ratoon and time of harvest (Rostron, 1972; Rein, 1988; Lonsdale and Gosnell, 1975) and rainfall (Browne, 1973). The composition of the cane is also a function of the variety of cane (Lonsdale and Gosnell, 1976). The inclusion of this vast quantity of information into a simple model would limit its appeal for general use. It would probably be much more realistic to work on averaged historical data in the region where the mill concerned is situated. Additional information regarding the properties of the tops and trash will be required since the effectiveness of their removal depends on the harvesting method.

Harvesting and cleaning

Unless the fibre is used in a by-product from the factory such as animal feed, paper, board or energy, it is undesirable to transport tops and trash, which have a low purity and high colour, to the factory. Consequently, these are usually removed in the field by burning, hand topping and trashing or topping and trashing devices in mechanical harvesters.

Burning has the advantage that it removes the trash effectively and at low cost. The disadvantage, however, is that the cane starts deteriorating as soon as the cane is burnt. Deterioration, once it begins, is much more rapid than for green harvested cane. Green cane harvesting has the advantage that there is no pollution consideration and that deterioration is much slower.

For the purpose of modelling, cleaning of cane simply removes a low purity component. This increases the purity of the matter delivered to the factory in proportion to the effectiveness of the topping and trashing process.

Deterioration and delays

Once cane is burnt or cut the deterioration process begins. Lionnet (1986) and Lionnet and Pillay (1987) argue that the length of the delay between burning or cutting and processing can be estimated from the ethanol content of the cane. Smith (1992) found that these models were true for burnt cane but could not find consistency in his results for unburnt cane. Lionnet (1986) comments that results obtained for diseased cane did not follow the ethanol production pattern found for healthy cane. This indicated that there were various mechanisms present in the deterioration of cane. Chopper harvesting of cane introduces additional points at which bacteria can enter the stalk changing the deterioration characteristics of the cane (Ivin and Foster, 1977).

As a starting point, it was decided to use the model of Lionnet and Pillay (1987), which took the form:

$$\left(\frac{pol}{brix}\right)_t = \left(\frac{pol}{brix}\right)_0 e^{-kt}$$

t is time in hours

k is a rate value that depends on temperature

The rate of purity drop, k, is given by:

$$ln\ k = -\frac{E_a}{RT} + ln\ A$$
E_a *is activation energy*
R is universal gas constant
T is absolute temperature
A is a factor

From regression analysis on their own data and other published data Lionnet and Pillay (1987) obtained values for the constants of:

$$\frac{E_a}{R} = 9498$$
$$ln\ A = 24.1$$

The data used to generate these values include both burnt and green cane data. There has been a large amount of scatter found in the data accumulated in various tests and by various authors. Consequently, it is quite conceivable that local tests would yield a slightly different value.

The cane loses mass between harvesting and crushing. The main part of this was attributed to dehydration although a small loss might be attributed to volatile deterioration products such as carbon dioxide and alcohols. It is difficult to model evaporation rate since this depends on temperature, humidity, packing density, rainfall, condition of the cane and numerous other factors. Consequently, a simple linear regression at 20 and 17 ºC by Lionnet and Moodley (1993) was used. Their equations may be rearranged by dividing them by the original mass to give the ratio of the current mass to the original mass:

$$\frac{M}{M_0} = 1 - 0.00814 * days \quad (burnt)$$
$$\frac{M}{M_0} = 1 - 0.00291 * days \quad (trashed)$$
where
M = *current mass*
M_0 = *original mass*

Transport

The transport may be represented as a delay in which deterioration occurs. An allowance was made for spillage of cane *en route* to the factory. The tons cane transported determines the cost of transport. Consequently, the cleaning cost needs to be traded off against the value of the fibre (Purchase *et al.,* 1990).

Properties of cane delivered to the factory

Pol
The model for the loss of pol between harvesting and processing has already been discussed. This model was applied based on the time and temperature specified by the user.

Brix
Although some of the carbon may be lost in the form of carbon dioxide and volatile alcohol, it was assumed that the mass of dissolved solids would effectively remain constant through the deterioration process. The per cent brix could then be adjusted for the loss in total mass of the cane.

Fibre
No chemical loss of insoluble components would occur. Consequently, the mass of fibre would remain unchanged. The percent fibre was adjusted for the loss of mass of the stalk.

Water
After account has been taken of the brix and the fibre, the remainder is water.

Reducing sugars
The target purity formula that was developed by Smith (1995) relies on the reducing sugar-ash ratio to calculate the possible purity of the final molasses. The form of this equation shows a reduction in final purity with increasing reducing sugars. On the other hand, an increase in any component implies an increase in the quantity of molasses. Consequently, even though the purity may be lower, more sucrose may be lost in molasses.

Reducing sugars, namely glucose and fructose, occur in the freshly harvested cane or they may be formed by the inversion of sucrose. Once these sugars have formed, they may break down further into alcohols and acids, or they may combine to form gums and other products. In other words, during the deterioration process, reducing sugars are continuously formed and destroyed. This equilibrium level is probably slightly higher than the levels of reducing sugars found in fresh cane. The effect of the deterioration product on target purity difference depends on the product formed. The tendency to form gums, alcohols or organic acids depends on the conditions present in the process. Any depression in the target purity as a result of increasing reducing sugars, is likely to be accompanied by an increase in target purity difference. Consequently, it was decided to leave the mass of reducing sugars unaltered in the deterioration portion of the model.

Ash
Both soluble and insoluble ash will remain unchanged through the deterioration process and the percentages were only adjusted to reflect the change in moisture content of the cane.

Factory results

Extraction plant
The modelling of the individual elements of the extraction plant was not possible. The ultimate performance of the plant depends on the type of equipment used and the settings used. A factory that is operating near maximum capacity will perform differently to one in which there is spare capacity. Consequently, it is not possible to apply a universal performance quantity to a specific factory. A base performance for the factory was required.
Two possible methods for modelling the performance of the extraction plant were found in the literature. The first method was the corrected reduced extraction derived by Rein (1975). The second was the constant ratio method by Wienese (1995).

Corrected reduced extraction (CRE)
The corrected reduced extraction can be found using the equation developed by Rein (1975), which is written as follows:

$$CRE = 100 - 0.1834\frac{(100 - E)(100 - F_c)}{F_c}\left(\frac{P_c}{13}\right)^{0.6}$$

$$\begin{aligned} &where \\ &CRE - corrected\ reduced\ extraction \\ &E - actual\ extraction \\ &F_c - fibre\ in\ cane \\ &P_c pol\ in\ cane \end{aligned}$$

Once the CRE for a factory is known, the extraction for another cane purity and fibre content can be calculated. The relationships used are derived from empirical work done by Rein. From the extraction, a mass balance can then be performed to determine other unknowns. Several other factors such as bagasse moistures would also have to be known to complete the balance.

Constant ratio model
In the model proposed by Wienese (1995), the three ratios of fibre percent mixed juice to fibre percent bagasse, brix percent mixed juice to brix percent bagasse and moisture percent mixed juice to moisture percent bagasse all remain constant in the neighbourhood of a reference condition. Although Wienese did not provide a rigorous proof of the assumption, he used factory data to show that a remarkably close relationship existed between actual factory data and the predictions from the model.

Using this approach, the ratios can be manipulated to yield relationships for mass, fibre percent, brix percent and moisture percent of mixed juice and also for bagasse. In other words, an approximate mass balance can be completed given a base data set and the current cane properties and imbibition percent fibre.

This approach was chosen since it relied on much less user input than the CRE method.

Reducing sugars
Glucose and fructose levels are usually determined using a chromatographic process. These results are not included directly in the routine reports that are compiled. Although the base data for the reports could be extracted and used to create a statistical model, the error in assuming equal extraction between sucrose and soluble non-sucrose would be small and could be neglected. A more rigorous model would have to include inversion losses and these are more factory-dependent than can be expressed in the input data to the model.

Processing results

Target purity
In a study to determine the best possible recovery, Smith (1995) proposed the following equation:

$$Target\ Purity = 43.1 - 17.5\left(1 - exp\left(-0.74 * \frac{Reducing\ sugars}{Ash}\right)\right)$$

This is a model that predicts the best possible result that can be achieved. Under real factory conditions, factors such as viscosity reduce the amount of sucrose that can be extracted. The actual purity of molasses that can be achieved is then higher than the target purity. This difference, known as the Target Purity Difference (TPD) is an indicator of the factory boiling house performance. Viscosity of molasses at standard brix (85) depends on the non-sucrose content of the molasses. The true effect depends on effects such as molecule size of the organic components. Since a general model is not possible, it was assumed all non-pol has the same effect on the TPD.

Assuming that, for a small change in non-pol, the target purity difference varies linearly with non-pol, then the actual target purity difference can be inferred from the relationship:

$$TPD = \left(\frac{TPD_0}{non\ pol_0} \right)_{base\ case} * non\ pol$$

Boiling house recovery and sugar produced

The S-J-M formula of Deer (1913) may be used to complete the mass balance necessary to calculate the boiling house recovery. Allowances for the loss in filter cake and undetermined loss were made in this calculation.

The mass of sucrose in sugar and molasses could be calculated from a pol balance over the crystallisation process. The mass of sugar can then be calculated from the purity that was given. The mass of molasses depends on the purity calculated and the brix specified.

Byproducts

Bagasse, fuel and energy

To estimate the amount of bagasse required to produce the steam for processing, an estimate of the steam on cane was required together with the amount of bagasse required to produce a unit mass of steam. The mass of bagasse required to be burned could then be calculated. If this exceeded the bagasse available, a coal supplement was assumed.

Cost and revenue

Each activity could be assigned a cost. These costs can be estimated from the most recent financial result that is available. It was left to the user to derive these estimates. The value of each product depends on the marketability of that product where the factory is located. A factory that supplies bagasse to a by-product plant, for example, would have a much higher value for bagasse than one where a surplus exists. From these values, an approximate income statement could be constructed.

Example

The input data, shown in Table 1, were entered into the model. A set of scenarios was then created for various transport-time delays.

This example serves to emphasize that the losses that are associated with cane delays are not limited to the reduction of sucrose in cane delivered but also the losses of sucrose in molasses as a result of the reduction in purity.

Even the overall recovery of sucrose is affected by the delays. As the purity drops, so does the overall recovery, as shown in Figure 2.

Table 1. Selected input data.

Factory Data	
Diffusion % cane	100.00%
Milling % cane	0.00%
Imbibition % fibre	300.00%
Undetermined loss % pol MJ	2.00%
Pol in filter cake % pol MJ	0.30%
Brix % molasses	80.00%
Pol % sugar	99.30%
Sugar purity	99.50%
Required steam % MJ	50.00%
Required bagasse % steam	50.00%
Required coal % steam	12.50%
Operating conditions	
Tons cane in field per hour	210 tons/hour
Temperature	25 ºC
Transport time	10 hours

The estimate of raw sugar and molasses were then calculated. These results are shown in Figure 1.

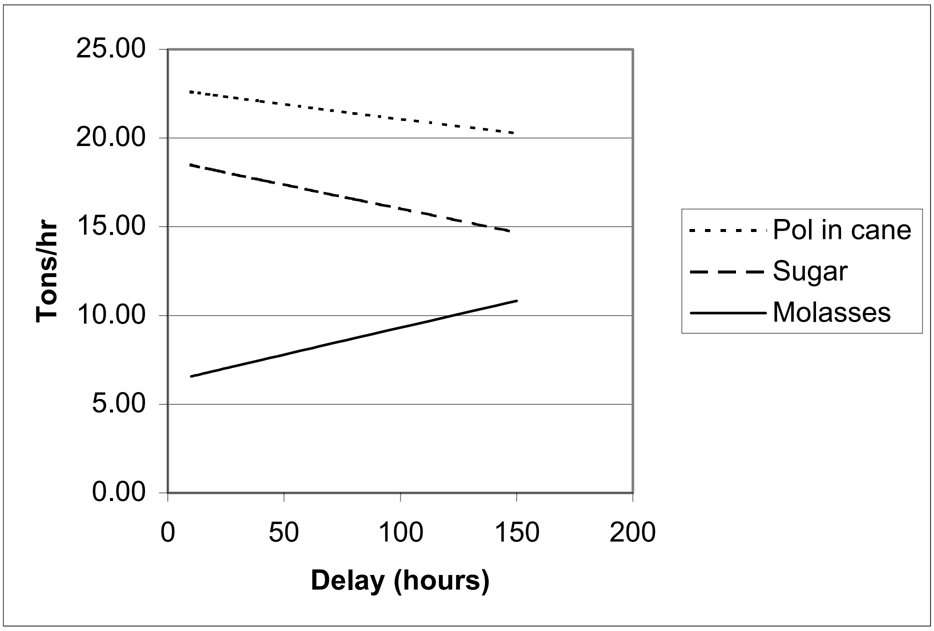

Figure 1. Predicted relationship between delay and sugar production.

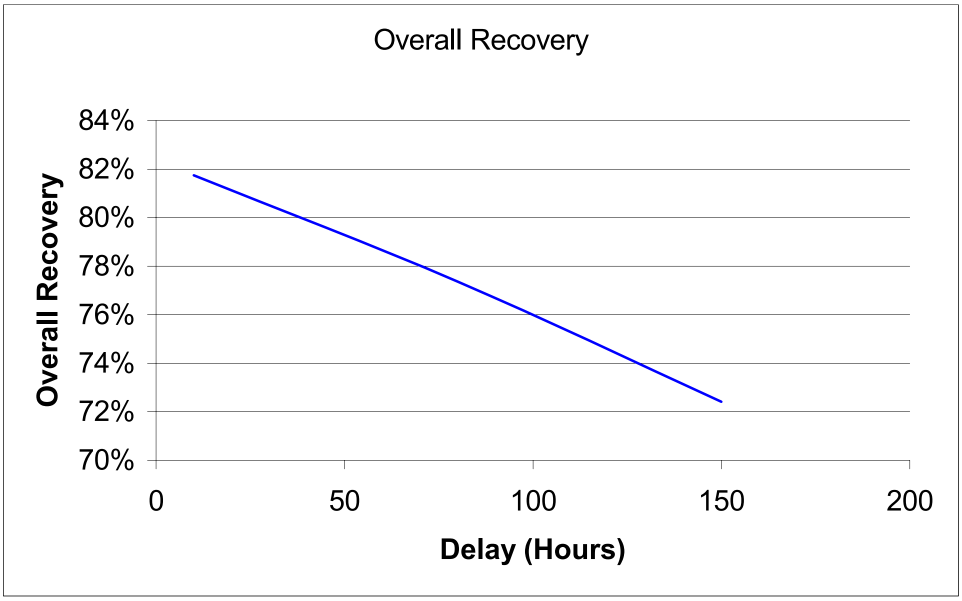

Figure 2. Effect of cane delay on overall recovery.

With suitable realistic cost figures it can be shown that an increase of delay from 10 to 150 hours may result in a loss in net revenue of as much as 35%.

Discussion

In the construction of this model, many smaller models have been used. Many of these models were based on statistical analyses of experimental data derived by several authors. Many of the papers consulted show that there is a wide variation in many of the parameters that were derived. Some authors commented that the data they derived could not support some of the models that were selected for this model. Most of these comments were based on the variability that they had found in their data. In the absence of improved models, it is the author's opinion that the models proposed will nonetheless give a usable indication of the trend that can be expected when changes to the operating conditions are made.

Some of the models used were simply linear or polynomial regressions on the data that was measured by the author concerned. Often no attempt was made to give a theoretical explanation for the trend that was observed. Deviations from the fitted curves were also reported to be as much as ten percent. In other words, the model that is constructed should only be used as an indicator of trends rather than an absolute prediction tool.

Conclusion

A model to estimate trends and effects when parameters such as cut to crush delays are changed was derived. The model was based on data that was reported in the literature. Despite shortcomings in the data, that were pointed out, a useful indication of the impact of various activities and parameters on the possible output of the factory. It must be stressed that, although the data produced by such a model may not be accurate; the trends that may be determined by the model will be useful indicators in comparative studies.

REFERENCES

Browne, EL (1973). Sucrose % cane for the season and other quality factors as related to rain prior to the season. *Proc S Afr Sug Technol Ass* 47: 127-132.

de Robillard, PM, Vawda, A and Lionnet, GRE (1990). The measurement of losses associated with cane deterioration. *Proc S Afr Sug Technol Ass* 64: 5-7.

Deer, N (1913). On available sugar and a system of control in the boiling house. *Hawaiian Sugar Planters' Association Bulletin* 41: 5-19.

Ivin, PC and Foster, DH (1977). Some aspects of cane quality affecting mill processing. *Proc Int Soc Sug Cane Technol* 51: 2701-2710.

Lionnet, GRE (1986). Post-harvest deterioration of whole stalk sugarcane. *Proc S Afr Sug Technol Ass* 60: 52-57.

Lionnet, GRE and Pillay, SV (1987). Ethanol as an indicator of burn to crush delay. *Proc S Afr Sug Technol Ass* 61: 5-7.

Lionnet, GRE and Moodley, M (1993). Preliminary results from a deterioration trial comparing burnt and trashed cane. Sugar Milling Research Institute Technical Report No. 1662. 17 pp.

Lonsdale, JE and Gosnell, JM (1975). Effects of age and harvest season on yield and quality of sugarcane. *Proc S Afr Sug Technol Ass* 49: 177-181.

Lonsdale, JE and Gosnell, JM (1976). Growth and quality of four sugarcane varieties as influenced by age and season. *Proc S Afr Sug Technol Ass* 50: 82-86.

Purchase, BS, Lionnet, GRE, Reid, MJ, Wienese, A and de Beer, AG (1990). Options for and implications of increasing the supply of bagasse by including tops and trash with cane. *Proc SPRI* 1990: 229-243.

Rein, PW (1975). A statistical analysis of the effect of cane quality on extraction performance. *Proc S Afr Sug Technol Ass* 49: 43-48.

Rein, PW (1988). Length of milling season and cane quality. SMRI Colloquium on Cane Quality. November 1988.

Rostron, H (1972). The effects of age and time of harvest on the productivity of irrigated sugarcane. *Proc S Afr Sug Technol Ass* 66: 142-150.

Singels, A, Kennedy, AJ and Bezuidenhout, CN (1999). Weather based decision support through the internet for agronomic management of sugarcane. *Proc S Afr Sug Technol Ass* 73: 30-32.

Smith, IA (1992). Some data on cane deterioration in 1992. *Proc S Afr Sug Technol Ass* 66: 218-221.

Smith, IA (1995). Exhaustability of molasses with very low reducing sugar levels. *Proc S Afr Sug Technol Ass* 69: 163-165.

Wienese, A (1995). The effect of imbibition and cane quality on the front end mass balance. *Proc S Afr Sug Technol Ass* 69: 181-185.