A REVIEW OF THE FACTORS THAT DETERMINE THE LENGTH OF THE SUGAR MILLING SEASON IN SOUTH AFRICA

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ABSTRACT

The sugarcane Length of Milling Season (LOMS) refers to the length and timing of harvesting and crushing operations in a sugar producing area.

The LOMS varies widely by country and region. It is a controversial topic and is widely debated. Whenever it is discussed it is likely to raise conflicting views since the different stakeholders in a sugar supply chain often approach the milling season decision from different perspectives. However, it is an essential part of the supply chain to ensure the continued profitability and competitiveness of supply chain participants in a sugar producing region.

The factors that affect the LOMS are, among others, climatic factors, agronomic practices, economic considerations, industry rules, policy, legislation set by governments and the internal politics between growers and millers. Often historical norms play a large role in determining the LOMS. Seasonal variations in weather conditions, especially rainfall and temperature, dominate the timing and length of an acceptable season. The factors that influence the harvest season are different for any sugar producing region.

This project will aim to review how the sugar harvest season is modelled, so that a wider range of variables, risks and uncertainties can be included. A stochastic modelling approach will enable a wide range of factors to be considered and provide deeper insight into the LOMS in South Africa.

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1. INTRODUCTION

The length and timing of sugarcane harvesting seasons vary widely by country and region (Hildebrand, 1998; Moor and Wynne, 2001). For example, the milling season in Louisiana (United States) is relatively short and comprises 14 weeks. In contrast, there is no milling season in Columbia and cane is crushed the whole year round (Hildebrand, 1998). Grunow *et al.* (2007) describe a mill and refinery in Venezuela with a milling season from October to May. Imported raw sugar is then processed during the off-season. Higgins and Muchow (2003) state that in Australia the harvest season is from early winter to late spring and is carried out over several months because of limits to the capacity of mills and transportation. In South Africa the harvesting season is relatively lengthy at between 30 to 38 weeks, running from April until December (Moor and Wynne, 2001; Bezuidenhout and Singels, 2007).

The sugarcane Length of Milling Season (LOMS) is a widely debated topic in many sugar producing areas (Hildebrand, 1998). The nature of the South African sugar supply chain implies that often growers and millers approach the LOMS from different perspectives. On the one hand growers would prefer to harvest the majority of their sugarcane when the crop is fully mature with a high sucrose content and when fields are dry and accessible (Hildebrand, 1998; Stray *et al.,* 2012). On the other hand, the miller, who has considerable fixed costs in the mill, aims to spread the milling operation out over a longer period of time (Hildebrand, 1998; Stray *et al.,* 2012). A longer season reduces the capacity required to cope with the annual crop and reduces the time during which the mill stands idle in the off-season.

The length of the milling season must be such that it balances the needs of the grower and the miller, while concurrently ensuring the continued international competitiveness of the sugar industry (Hildebrand, 1998). Rising input costs, especially fuel and fertilizer, and increased global sugar supply have reduced the international competitiveness of many sugar producing regions (Higgins *et al.,* 2004). The South African sugar industry is no exception. For this reason, the sugar supply chain should be evaluated as a single entity to ensure continued competitiveness and profitability when determining the LOMS (Hildebrand, 1998; Lejars *et al.,* 2008; Gaucher *et al.,* 2004).

This review covers the scientific literature on the sugarcane milling season and identifies the factors that drive its length and timing. The LOMS, as it is referred to in South Africa, may be referred to as the “length of the campaign” or the “length of crushing season” in other sugar producing regions around the world.

Chapter 2 of this review deals mainly with studies that explicitly cover the LOMS. Chapter 3 then presents brief reviews of the general factors that can drive the LOMS decision. The identification and review of the LOMS driving factors will point to the necessary data and relationships needed for stochastic modelling of the length of milling season in a particular mill area.

The objectives of this review are to:

a) Explain the importance and context of the LOMS,
b) Review previous studies that explicitly focussed on the LOMS,
c) Identify the factors that drive the LOMS, and
d) Provide a brief discussion of each of these factors.

In terms of scope, the literature review will not focus in detail on in-field agronomics. The focus is rather on how the operating environment, sugarcane quality, harvesting, transport and milling of the crop interact and impact the LOMS.

2. A REVIEW OF STUDIES THAT PERTAIN TO THE LENGTH OF THE SUGARCANE MILLING SEASON

This section of the review is concerned with studies that deal with optimising the timing and length of the harvest season. However, there is not a of published material that deals explicitly with the LOMS.

The length of milling season is a controversial topic and is widely debated (van der Pol, 1987; Hildebrand, 1998). Whenever it is discussed it is likely to raise conflicting arguments, but it is a discussion which must be accommodated to ensure the continued profitability and competitiveness of any sugar producing region (van der Pol, 1987; Muchow *et al*., 1998a; Wayne and Groom, 2003).

During the 1990's, while the South African sugar industry was undergoing deregulation, the South African Canegrowers Association developed an economic model to facilitate the determination of an optimal harvest season for a mill area. Hildebrand (1998) and later Moor and Wynne (2001) provide a description of the model and the reasoning behind it. The LOMS Model was run for all but three of South Africa's 15 mills. Optimal LOMS for the individual mills ranged between 34 and 38 weeks (Moor and Wynne, 2001). Results from the LOMS Model provided an objective starting point for growers and millers to negotiate a milling season length for many of the mills in South Africa (Wynne and Groom, 2003).

Hildebrand (1998) defines the optimal milling season as maximising profit from sugar as if the grower and miller were a single business entity. This allows the international competitiveness of the mill to be judged, but is not often put into practice (Hildebrand, 1998). In many places the growing and milling segments of the supply chain are separately owned and leads to conflicting perspectives of what the optimal milling season should be.

The LOMS Model of Hildebrand (1998) was based on linear programming principles. Hildebrand (1998) stated that the approach was to maximise profits from sugar by optimising the season length for a specific mill area while taking into account the proceeds sharing arrangements. This would seem to contradict the approach of viewing growers and millers as a single business entity.

The length of the season can be determined by dividing the total sugarcane that must be crushed by the throughput of the sugar mill. Hildebrand (1998) optimised the LOMS by taking into account historical crop performance, mill utilisation, agronomic and harvesting factors as well as the relevant costs and incomes. The optimal season length, in weeks, is reached when marginal losses from declining cane quality are greater than the benefits of increased capacity utilisation (Wynne and Groom, 2003).

A longer harvest season results in higher utilisation of the mill capacity, which reduces the fixed cost component of milling, but reduces the season average cane quality because a larger fraction of the crop is crushed when cane quality is relatively poor (Moor and Wynne, 2001). In South Africa the division of proceeds from sugar production is governed by the partnership between growers and millers based on historical costs of production and capital employed. If either side of the partnership pursues a LOMS to benefit themselves to the detriment of the others, it is likely that the mill area as a whole will suffer. This could systematically lead to the reduction in international competitiveness of the South African sugar industry (Hildebrand, 1998).

From an agronomic perspective Donaldson (1998) investigated the production of summer harvested sugarcane in South Africa and found that a crop harvested annually in January was more beneficial than in March. The productivity of summer harvesting and hence a shortened milling season depended on (a) labour availability and the discomfort of working in summer heat, (b) rainfall causing problems with extraction and increased ash percentage, (c) damage to wet fields, (d) higher temperatures influencing canopy development and (e) the resulting weeding costs as well as a tendency towards lodging and diseases. These factors have significant impacts on the feasibility of extending the milling season further into summer. Donaldson (1998) did not assess the impacts on other parts of the supply chain, such as disruptions to the annual mill maintenance plan and possible severe cane deterioration.

Muchow *et al.* (1998a) state that the optimisation of harvest dates can improve productivity and profitability. Extensive research in Australia has been carried out on the optimisation of harvest dates to take into account seasonal and geographical variation in the sucrose content and quality of sugarcane to increase profitability (Higgins *et al.*, 1998; Muchow *et al.*, 1998a; Higgins and Muchow, 2003; Le Gal *et al.*, 2004; Zhaorong, 2005).

Higgins and Muchow (2003) found that significant gains in profitability may be achieved through the optimisation of the harvest date without any further investment in harvesting or milling equipment. However, these gains can vary widely across geographic locations and seasons. Accurate weather forecasts improve optimisation efforts, because these aid in planning for possible disruptions in cane supply due to bad weather.

Muchow *et al.* (1998b) argue that field experimentation and crop growth simulation are useful to assess the production risk with different harvest dates and crop ages, but these approaches alone cannot account for other constraints, like transport and milling capacities and milling season length, to determine the best cane supply arrangement. Mathematical optimisation and schedule modelling is needed to consider these varied constraints. The input needed to arrive at an optimum decision must include crop yield and quality variation, climatic data, transport and milling capacity information, financial data for growing, milling and transport and finally sugar storage capacity before sale and marketing. A good relationship between all supply chain stake holders is essential if any measure of success is to be achieved.

Another project in Australia that investigated the optimisation of season length was met with resistance from the growing sector and no significant adjustment to the milling season was made (Di Bella *et al.*, 2008). Growers would only consider an extension to the milling season if this meant an increase in financial returns. The project aimed to optimise the length of the milling season by examining the regional variation in sucrose content, soil moisture and in-field mobility to increase profitability by increasing total sugar production.

3. AN OVERVIEW OF FACTORS THAT AFFECT THE LENGTH OF MILLING SEASON

The local circumstances which affect the LOMS are weather conditions, agronomic practices, economic factors, industry structures, policy and legislation set by government and the politics between growers and millers. Often historical norms play a large role in determining the LOMS (Hildebrand, 1998; Moor and Wynne, 2001). The length of the milling season depends on the amount of sugarcane that needs to be processed for a particular area and the capacity of the sugar mill (Hildebrand, 1998).

The start and length of the harvest season impacts on seasonal cane quality, recoverable value and the growth and yield of the following ratoons (Muchow *et al.,* 1998b). Milling profitability depends on these factors as they determine the use of capital assets, maintenance schedules, labour planning, rate of crushing, recovery of sugar and financial planning. When and how much sugar will be produced also impacts on marketing strategies and the maximisation of earnings from sugar exports (Muchow *et al.*, 1998b).

The following chapter comprises short literature overviews of the factors that affect the length of milling season. Although a high degree of connectivity exists, factors are broadly separated into (a) the operating environment, (b) seasonal effects on the crop, (c) harvesting issues, (d) transport issues, and (e) mill throughput and production.

3.1 The Operating Environment

The operating environment can be defined as the conditions, entities, events and factors surrounding an organisation that influence its activities, choices, risks and opportunities (Business Dictionary, 2013). Some of the operating environment factors that influence the length of the milling season are (a) mill and farm ownership regimes, (b) industry rules and configuration and (c) payment and incentive systems.

3.1.1 Ownership and politics

Greater complexity is added to determining acceptable milling season lengths when the milling and growing segments of the industry are owned separately (Hildebrand, 1998). For example, in South America the mill and farms are often under the same ownership (Grunow *et al.,* 2007) and this offers different options for decision making regarding harvesting compared to South Africa where the milling and growing segments are often separately owned. Implementing changes to the milling season's timing and length are more difficult when the number of stakeholders is increased. Historical norms and the political strength of either growers or millers may be the reason why such vastly different milling season lengths can be observed around the world (Hildebrand, 1998). Milling season adjustments can often only be made after negotiations between the growers and millers have taken place (Hildebrand, 1998; Todd *et al.,* 2004). A mutually beneficial length of milling season must be negotiated between growers and millers. The arrangement must enable the survival of both parties, but also ensure the competitiveness of the mill area as a whole (Hildebrand, 1998).

3.1.2 Cane payment systems and the LOMS

Cane payment systems can change stakeholder's perceptions about an acceptable milling season length. There are also links between cane payment systems and incentives to improve cane quality or to expand production (Todd *et al.*, 2004).

Cane payment systems can be divided into either fixed cane price, fixed revenue sharing or variable revenue sharing systems (Todd *et al.,* 2004). A fixed price system is where growers are paid for the tons of sugarcane delivered to the mill. Fixed revenue sharing means that proceeds are shared between growers and millers at a fixed percentage. A fixed revenue system is used in South Africa (Hildebrand, 1998). A more sophisticated system is variable revenue sharing. Under this system any proceeds from cane quality, above a benchmark, benefit the grower. Alternatively, any improvement in sucrose recovery, above a benchmark, benefits the miller. The complexity of variable payment systems makes them harder to administer, but offer incentives to improve cane quality and factory efficiency (Todd *et al.,* 2004).

To encourage an improvement in sugarcane quality delivered to sugar mills the recoverable value (RV) payment system was adopted in the South African sugar industry in 2000 (Wynne, 2001). The RV formula is used to link the farmer's payment to cane quality including the sucrose, non-sucrose and fibre levels. This payment system averages out the seasonal change of sugar content (See Section 3.2.1) so that there is no direct incentive to deliver cane when sucrose content is at its peak (Wynne *et al.,* 2009; Stray *et al.,* 2012). This is referred to as relative cane payment.

A disadvantage to relative cane payment systems is that they have the potential to disguise the effects of a sharp drop off in cane quality at the start and end of the milling season. This can lead to an unacceptable drop in season average sugar content (Wynne *et al.,* 2009).

3.1.3 The role of the Mill Group Boards

At South African sugar mills the committees responsible for administering cane supply are known as Mill Group Boards (MGBs). This committee comprises grower and miller representatives and chairmanship alternates annually between these two parties. MGBs are legislated and must set the starting date and length of the milling season based on estimates of the size of the crop to be crushed and the rate at which the mill can operate (Hildebrand, 1998; Gaucher *et al.,* 2004; Schorn *et al.,* 2005). MGBs are responsible for season planning and ensuring a reliable supply of cane to the mill. The aim is to utilise the mill's crushing capacity while maximising the recoverable value throughout the season (Le Gal *et al.,* 2008).

MGBs are required to make an informed decision about the size of the sugarcane crop to be processed by using field estimates provided by growers, scouting of fields by mill employees and forecasts from crop models (de Lange and Singels, 2003). MGBs across the sugar industry apply different methods to predict the size of the crop. Bezuidenhout and Singels (2007) indicate that some of the methods used by MGBs tend to be more subjective, while others are more scientific.

The MGB allocates daily or weekly rateable deliveries to each grower, based on the grower's crop estimate. This system is meant to aid the grower in making deliveries but can lead to supply issues as many growers are unable to meet their targets (Wynne, 2001). After comparing several seasons' worth of data from the Sezela mill, Le Gal *et al.* (2004) noted that failure to meet daily rateable deliveries (DRDs) occurred more frequently at the start and end of the milling season. It took roughly three weeks for growers to reach their DRDs at the start of the season. After DRDs are reached the supply remains fairly constant until it begins to taper off over the last couple of weeks of the season.

3.2 The Crop as Affected By the Season

The most important crop issues that play a role in the milling season are cane quantity and cane quality. The impacts that seasonal weather conditions have on sugarcane production are well documented. In South Africa, sugarcane is grown under widely varied climatic conditions (Bezuidenhout and Gers, 2002; Bezuidenhout and Singels 2007). The South African sugar milling areas are also at the mercy of weather events, such as tropical cyclones and frequent droughts (Bezuidenhout and Singels, 2007).

3.2.1 Sugarcane quality

The quality of cane delivered to a sugar mill is of utmost importance as it influences sugar production and profitability (Le Gal *et al.,* 2008). If determining the length of milling season was a simple matter of maximising the quality of sugarcane processed, i.e. maximum sugar yield and low fibre content, the season would have to fit into two weeks (Grunow *et al.* 2007). However, cane quality must be balanced against many other factors to maximise supply chain profitability.

The impact of harvest season length on cane quality has been thoroughly covered in the literature (Higgins and Muchow, 2003; Wynne and Groom, 2003; Wynne *et al.,* 2009). Seasonal weather patterns have a large influence on sucrose content and accumulation in sugarcane (Inman-Bamber, 1994; Singels *et al.,* 2012).

The sucrose content, non-sucrose content and fibre content of sugarcane delivered to the mill, and hence RV, follow seasonal patterns (Wynne *et al.,* 2009). In South Africa RV is low at the beginning of the harvest season and gradually rises to a peak. When this peak occurs depends on the geographical location, weather conditions, the variety of the cane and its age (Inman-Bamber, 1994; Higgins *et al.,* 1998; Le Gal *et al.,* 2004). After the peak, RV remains fairly constant until spring, when rainfall causes a sharp drop in cane quality (Grunow *et al.,* 2007). Le Gal *et al.* (2004) and Stray *et al.* (2012) argue that the recoverable value of sugarcane follows a bell-shaped curve.

Season average sucrose content tends to decrease as season length is increased. This is because more of the milling takes place when sucrose levels are low at the beginning and end of the season (Moor and Wynne, 2001; Todd *et al.*, 2004). Figure 3.1 illustrates the theoretical difference in season average sucrose content for different season lengths for a typical sucrose percent curve.

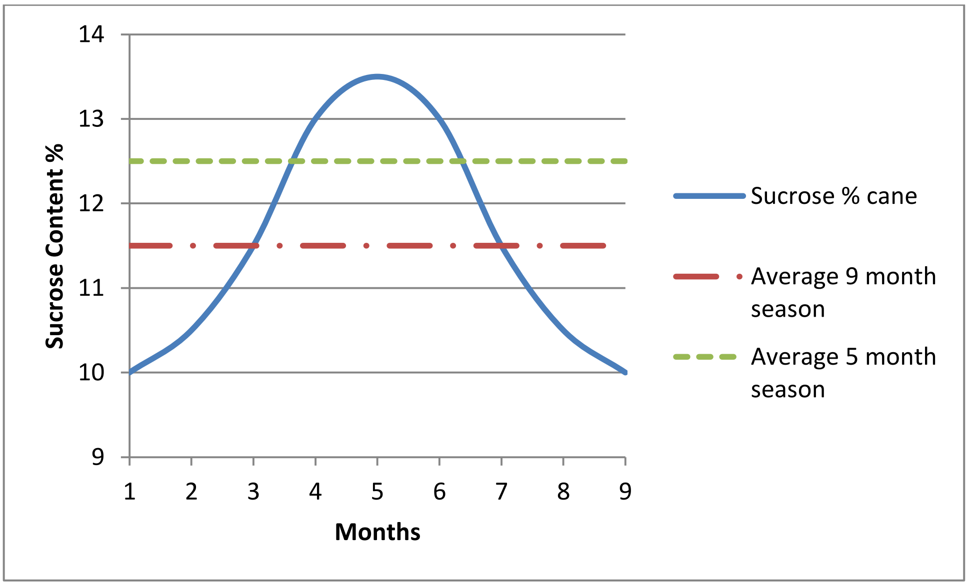

Figure 3.1 A stylized version of a sucrose curve and seasonal average sucrose contents for different milling season lengths (after Todd *et al.*, 2004).

Todd *et al.* (2004) note that even if a relative cane payment system is used, the length of the milling season is still a contentious issue. This is because the average sucrose content is taken into account when distributing revenue between growers and millers.

Mill area recoverable value curves are slightly different each year depending on weather conditions. For each mill area it is possible to produce a representative sucrose curve for all the weeks of the year using historical data (Moor and Wynne, 2001). Le Gal *et al.* (2004) noted general trends in cane quality over several seasons for a particular mill area, but greater inter-annual variability in RV at the start and end of the season. Figure 3.2 shows typical seasonal and regional variations in RV for a mill area.

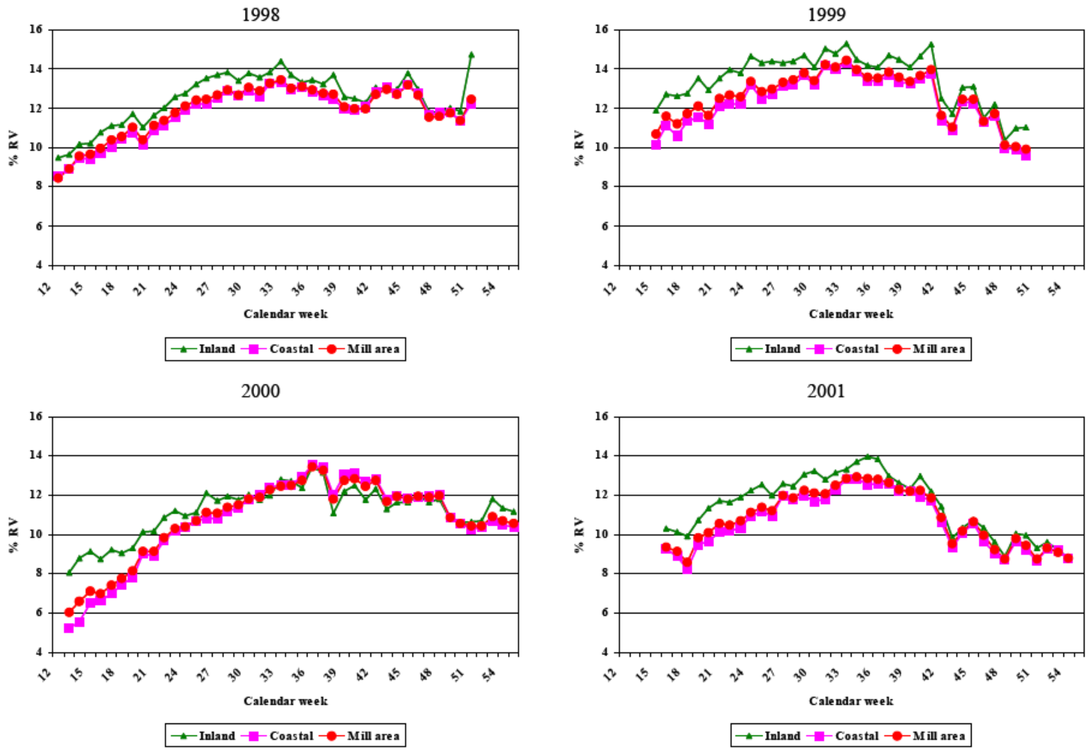

Figure 3.2 Recoverable Value curves for the Sezela mill area, 1998-2001 (Le Gal *et al.*, 2004).

Rainfall has a significant impact on the optimal harvesting season for sugarcane. Sufficient, well distributed rainfall is needed during the summer months to allow the proper growth of the sugarcane crop. As the sugarcane reaches maturity lower availability of water is desirable to allow the cane to ripen (Singels *et al.*, 2000). High amounts of rainfall during the harvest season promote growth and reduce sugar recovery (Higgins and Muchow, 2003).

3.2.2 Reduction of optimal growing periods

The further the milling season stretches into the summer months the less growing time is available for sugarcane to grow with a full canopy under optimal conditions. This has an influence on yields of the subsequent ratoons (Hildebrand, 1998; Moor and Wynne, 2001; Donaldson *et al.*, 2008; Donaldson *et al.*, 2011).

Crops harvested in December have a lower biomass yield than crops harvested in autumn and winter. The main reason for this is lower radiation use efficiency in December crops, most likely due to premature ripening during winter and a slow recovery from this effect (Donaldson et al., 2008; Donaldson *et al.*, 2011).

3.2.3 Crop estimate

An accurate estimate of crop size allows for the efficient milling of the crop and is used to determine the start and end dates of the milling season (de Lange and Singels, 2003; Weekes, 2004). Crop size is primarily a function of the area under sugarcane and the climatic conditions experienced over a season. The nature of crop estimation is that uncontrollable factors such as climatic variability lead to inaccuracies in predictions. It is important to be able to predict the level of error or be able to calculate the risk associated with a particular estimate (Bezuidenhout and Singels, 2007).

Crop forecasting is most often approached by using statistical and sampling techniques (Stephens and Middleton, 2002; cited in Bezuidenhout and Singels, 2007). However, Lumsden *et al.* (1998) and Bezuidenhout and Singels (2007) demonstrate the effectiveness of using a sugarcane yield model and climatic forecasts to provide an estimate of crop size at a mill area scale. Accurate prediction of climatic factors, among others, is needed for this approach to be effective.

Crop estimates can be divided into vertical and horizontal components. Vertical refers to the yield per area and horizontal refers to area under cultivation. Vertical performance is dependent on climatic variability and this cannot be controlled by growers, but horizontal performance can be (Wynne, 2001).

3.3 Harvesting

Wiense and Reid (1997) state that the harvesting practices in South Africa have evolved to an optimum point over many years. Harvesting is either manual or mechanised. Fields are often burnt before cutting to defoliate the cane which makes harvesting easier. Harvesting can be fully manual, where cutting and loading is by hand, semi-mechanised, where cutting is manual and loading is mechanical, or fully mechanised, where cutting and loading is combined in a single operation by using sugarcane harvesters (Rangel *et al.*, 2010).

Milan *et al.* (2006) suggest that of great importance when considering sugarcane harvesting is determining the optimal combination of transport means. The aim must be to minimise costs while meeting daily supply obligations with high levels of quality. Decisions growers make about harvest capacity affect mill efficiency (Gaucher *et al.*, 2004). The harvesting factors that will be discussed in the following subsections are (a) delays caused by rainfall, (b) difficulties caused by wind, (c) disruptions due to frost, (d) labour issues, and (e) cane deterioration.

3.3.1 Rainfall and harvest delays

Weather conditions determine how many days are available for harvesting (Higgins and Davies, 2005; Rangel *et al.*, 2010; Kadwa, 2012). Besides reducing the recoverable value, spring and summer rainfall cause disruptions in the supply of sugarcane to mills in South Africa (Boote *et al.*, 2011). Rainfall leads to harvesting difficulties, increased burn to crush delays and damage to fields (Hildebrand, 1998; Kadwa, 2012). Rainfall can also make burning cane fields for harvesting difficult or impossible (Weekes, 2004).

Boote (2011) and Kadwa (2012) assumed a relationship between the depth of rainfall and the duration of harvest delays for the Umfolozi and Eston mills respectively. The thresholds used by Boote (2011) and Kadwa (2012) for modelling the mill areas are presented in Table 3.1. It is likely that the relationship between rainfall depth and harvesting delays will be different for each mill area, depending on local conditions.

Table 3.1 Rainfall depth and harvest delay assumed for the Eston mill area (after Boote, 2011; Kadwa, 2012).

	Number of harvesting days inhibited	
Rainfall depth (per day)	Umfolozi (Boote, 2011)	Eston (Kadwa 2012)
> 5 mm	1 day	2 days
> 10 mm	2 days	3 days
> 30 mm	3 or more days	4 days
> 50 mm		5 days

There is a compound effect of extending the milling season into the rainy season. Higher chances of rainfall can interrupt harvesting and milling operations, thus prolonging the milling season even further (Boote, 2011; Kadwa, 2012).

3.3.2 Wind and harvest difficulties

Windy conditions can have an effect on the degree of lodging of sugarcane. Lodged sugarcane experiences reduced growth rates (Stray *et al.*, 2012) and it is difficult to harvest (James, 2004).

Windy conditions can also delay cane burning before harvesting as there is increased risk of uncontrollable or runaway fires (Weekes, 2004). Avoiding wind is one of the reasons why burning is usually performed early in the morning. These delays can potentially extend the milling season by disrupting harvesting.

3.3.3 Frost and harvest disruptions

In Louisiana the milling season is kept to approximately 3 months because of the risk of winter frosts (Eggleston *et al.*, 2004). In South Africa frost can affect inland, higher altitude cane growing areas in the KwaZulu-Natal midlands. Between one-fourth and one-third of the sugarcane grown in the midlands can be affected by frost every season (De Haas, 1981). The lower the temperature experienced the greater the damage to sugarcane. Temperature and damage relationships vary with cane variety and crop cover (Irvine, 2004).

The biggest impact that frost has on cane quality is the formation of dextran in damaged internodes (Mann, 1991; Eggleston *et al.*, 2004; Irvine, 2004). Cane that has been completely frozen may be unsuitable for sucrose crystallization three weeks after the frost occurred. In less severe cases there may only be a reduction in sucrose yield several months after the cane was frosted. Economic losses can be minimised by harvesting severely frosted cane soon after the freeze occurs (Irvine, 2004). Mann (1991) suggests that the drop in cane quality observed at some sugar mills after widespread frosting may be due to cutting immature cane which has not been properly topped, instead of the deterioration of sucrose.

Widespread frosting will disrupt a uniform cane supply because large areas of damaged cane may need to be harvested as quickly as possible. This means that some farmers must deliver above their DRDs, while others may need to hold back.

3.3.4 Labour and harvesting

Shortages of cane cutters are becoming more common in South Africa throughout the sugar industry (Murray, 2008). In South Africa the majority of sugarcane is cut manually and it is therefore important to consider labour issues when determining suitable milling season lengths. The majority of labour that is employed during the milling season is directly involved with the harvest operation.

Manual harvesting is hard physical work, usually performed under hot unpleasant conditions (Christie *et al.*, 2008). It is not regarded as an ideal job and there is often low social status associated with cane cutting. Shortages of cutters occur as national levels of industrialisation increase and easier or better paid jobs become available (James, 2004; Kadwa, 2012).

Cutter productivity varies with trash percentage, stalk length and thickness, degree of lodging, presence or absence of weeds, crop yield per hectare, suitability of the tools used, physique and age of the cutters, and the payment systems and financial aspirations of the cutters (James, 2004). Meyer and Fenwick (2003) found that cane cutter performances were widely different between cutters, farms and regions and that the type of cutting system used has the biggest impact on cutter output.

The availability and reliability of cane cutters is an important factor to consider. Kadwa (2012) found that absenteeism of cane cutters, especially after pay weekends, lengthened the milling season due to reduced harvesting rates. Absenteeism after pay weekends was often greater than 50 per cent. After Christmas there is generally a low availability of cutters (Le Gal *et al.*, 2004) making extending the milling season beyond this date problematic.

Climatic conditions not only affect the ease of extracting cut sugarcane from the field but can also affect the productivity of labour. On rainy days there is often a high level of staff absenteeism. Temperature extremes make physical labour unpleasant. Most cane cutters begin work early in the morning to avoid cutting during the midday heat (Christie *et al.,* 2008).

There is the risk of it becoming harder to find labour for cane cutting, due to factors such as debilitating diseases, e.g. HIV/AIDS, or the hard nature of the job (Meyer and Fenwick, 2003). A shortage of cane cutters meant that growers in Mpumalanga were unable to meet their DRDs at the start of the 2006/2007 season (Murray, 2008).

A shortened milling season would result in higher DRDs, meaning that growers would require more cutters over a shorter period to meet their deliveries. Employing more people for a shorter time would probably result in individual cutters earning less money per season (Le Gal *et al.,* 2008).

Strikes and industrial action are factors which can potentially have a devastating effect on the length of sugar milling season and hence profitability. Profitability of a sugar milling area will be severely affected if strikes occur when the recoverable value of the sugarcane is at its highest.

3.3.5 Cane deterioration

Sugarcane, like most other agricultural crops, starts to deteriorate immediately after burning and/or harvesting (Milan *et al.,* 2006). Enzymes that are naturally present in the cane stalks begin the deterioration process. Deterioration is worsened by other organisms that enter the sucrose bearing tissues at a later stage. These organisms invert the sucrose, consume the glucose and form other products including alcohols, acids and gums (Lionnet, 1996). Loading and transport should be arranged as soon after cutting as possible to minimise deterioration (Weekes, 2004). Road transport or tractor transport allows the shortest time between harvesting and crushing (Milan *et al.,* 2006).

Of the number of postharvest deterioration products formed in sugarcane, Dextran polysaccharide has often been used as an indicator of the level of deterioration because it is the cause of many of the problems experienced in a sugar factory due to deteriorated sugarcane (Eggleston, 2002). There are other deterioration products that affect mill operation and these are often lumped under the term dextrans (Ravno and Purchase, 2005).

Dextrans in deteriorated cane reduce the quantity and quality of sugar produced (Morel du Boil and Wienese, 2002). High levels of dextrans cause an increase in viscosity, slow boiling rates, crystal deformation and increase the inversion of sucrose. This leads to a reduction in milling capacity and sugar recovery. This can increase the length of the harvest season and influences the amount of cane that must be carried over to the next season (Ravno and Purchase, 2005).

Ravno and Purchase (2005) conclude that dextran levels follow a predictable pattern over the harvest season. Dextran levels are high at the start of the season and drop to low levels during winter. When spring rains start there is a sharp increase in dextran levels. Figure 3.3 illustrates the predictable pattern of monthly dextran levels of sugar delivered to Durban and Maputo sugar terminals over five seasons. Although all milling areas exhibit similar shaped curves the absolute levels vary significantly between mills.

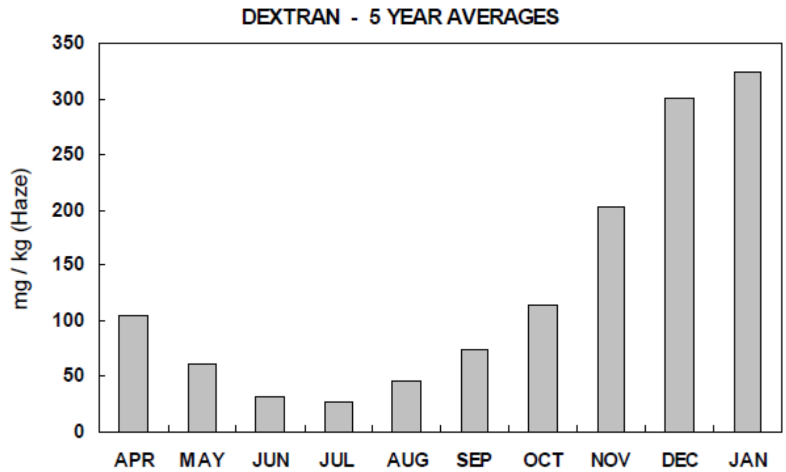

Figure 3.3 Five year average monthly dextran levels in VHP sugar delivered to the Durban and Maputo sugar terminals (Ravno and Purchase, 2005).

Ravno and Purchase (2005) found that the production of dextran is a function of temperature, moisture and delays between burning/harvesting and crushing. Rainfall leads to increased levels of dextran, most likely due to the result of rain induced delays between burning and crushing (Grunow *et al.,* 2007). The deterioration rate increases exponentially as temperatures increase (Rangel *et al.,* 2010). Mechanical harvesting that billets cane causes increased rates of deterioration (Ravno and Purchase, 2005). Burnt cane deteriorates faster than un-burnt cane (Ravno and Purchase, 2005; Bernhardt and Arnold, 2011). It appears that burnt wet cane also deteriorates faster than burnt dry cane (Ravno and Purchase, 2005). Also, burnt cane that is left standing deteriorates faster than harvested burnt cane (Wood, 1973). Burning areas for cutting that are too large to be harvested within a day or two must be avoided because this increases deterioration due to a longer burn to crush delay (Weekes, 2004).

3.4 Transport Capacity and Season Length

There are many different transport systems used to move sugarcane from the field to the mill. The aim of any sugarcane transport system is to deliver sugarcane in the shortest possible time-frame and at the lowest cost (Stutterheim, 2006). Transportation accounts for 20-25 per cent of the total cost of producing sugar (Lyne, 2007; Giles *et al.*, 2009). Increasing transport cost is a major factor in the decreasing profitability of sugarcane production (Milan *et al.*, 2006). The daily logistics of mill supply and particularly transport has been a focus of much research (Lejars *et al.*, 2008).

Transport capacity refers to the total tonnage of cane that can be transported at any point in time. The transport capacity available at a mill area determines the rate of delivery to the mill (Higgins and Muchow, 2003). Greater transport capacity is needed when the length of milling season is reduced.

3.4.1 Transport utilisation

Better usage of existing transport can allow a shorter milling season (Le Gal *et al.*, 2004). For example, Giles *et al.* (2005) simulated a central fleet control system at the Sezela mill area, which suggested the potential to reduce the fleet size by at least 60 per cent.

Payload efficiency is a measure of the actual tons of cane delivered compared to the maximum allowable payload of the vehicle. Increasing payload efficiency can allow a shorter milling season. Factors that affect payload efficiency include the level of trash present in the cane, the physical characteristics of the cane stalks, loading methods used and the skill of the loader operator (de Beer *et al.*, 1989; Wynne and van Antwerpen 2004; Giles *et al.*, 2009; Bernhardt and Arnold, 2011).

3.4.2 Reliable deliveries

An effective transport system is one that provides a constant supply of sugarcane to the mill (Milan *et al.*, 2006). Sugarcane deliveries to the mill must be reliable to allow a 24-hour operation without excessive stockpiling (Weekes, 2004). Often transport operations will run day and night while harvesting is only done during the day.

Transport is vulnerable to disruptions caused by wet weather and break downs (Higgins and Davies, 2005). Substantial disruptions can lead to costly mill stops. Wet weather is especially disruptive when cane trucks are driven into the field for direct loading, instead of being loaded at a trans-loading zone (Weekes, 2004). When the cane is irrigated, sufficient drying-off periods before harvesting are also important.

3.4.3 Cane yard delays

Long delays in the cane yard increase the burn/harvest to crush delay and can interrupt the whole system. The loading and transport systems found in a mill area influence the offloading system used (Weekes, 2004). There are many different types of offloading systems but some are far more efficient than others. Quick offloading of trucks at the mill is needed to meet transport requirements (Grunow *et al.*, 2007).

3.4.4 Stockpiling

Stockpiling reduces the risk of no-cane stops and can help ensure constant levels of mill operation, but is constrained by cane deterioration (Barnes *et al.*, 2000; Weekes, 2004; Boote *et al.*, 2011). However, Weekes (2004) states that a level of reserve cane is important to smooth out small disruptions in cane flow to the mill. The reserve cane is used to ensure continuous and even flow of cane to be crushed. This can prevent a large number of no-cane stops.

Stockpiling is unavoidable when cane is only cut during daylight hours but the mill operates through the night (Higgins and Davies, 2005). Ideally, a stockpile should be large enough to reduce the chances of the mill stopping due to interruptions in cane supply, but not so big that deterioration impacts mill throughput and extraction efficiency. Cane must be used from a stockpile in a first-in/first-out manner (Weekes, 2004).

3.5 Mill Throughput and Production

The throughput of the sugar mill is a key determinant of the length of the harvest season. Season length also has an effect on how much sugar the mill produces and how efficiently it operates. The aim is towards the mill operating at optimum capacity throughout the milling season. Mill throughput can determine season length in three ways (Hildebrand, 1998; Moor and Wynne, 2003):

a) Varying mill throughput for a fixed crop of sugarcane,
b) Varying the size of the sugarcane crop for a fixed mill throughput, or,
c) Varying both mill throughput and crop size.

Throughput is calculated from hourly crushing capacity, number of working hours, maintenance time and frequency of breakdowns (Guilleman *et al.,* 2003; Gaucher *et al.,* 2004). The need for scheduled maintenance, occurrence of public holidays, mill breakdowns and cane supply fluctuations must be taken into account when evaluating the crushing potential (Hildebrand, 1998).

This section will cover (a) milling restrictions, (b) mill stops and Overall Time Efficiency, (c) sugar extraction, and, (d) diversions to other mills.

3.5.1 Restrictions to mill throughput

Mill throughput is influenced by cane quality and cane supply (Gaucher *et al.,* 2004; Le Gal *et al.,* 2004; Lejars *et al.,* 2008). The mill is usually designed to process cane of an average quality across the length of the season. This can result in bottlenecks at different processes of the factory since quality varies during the season (Stutterheim, 2006).

Fibre per cent affects crushing and diffuser capacity (Lejars *et al.,* 2008; Bezuidenhout, 2010). According to Graham and Gunn (1971), fibre is a controlling factor in milling through put and thus high levels of fibre extend the milling season. Lower levels of fibre and a shorter season would reduce the wear and tear on mill equipment and save maintenance costs.

However, sufficient fibre is required to run the mill's boilers without needing supplementary fuel. Schorn *et al.* (2005) describe how high fibre levels and the size of the extraction plant can limit throughput at one point of the season. Hildebrand (1998) states that fibre limits throughput towards the end of the season, but Wynne and Groom (2003) state that fibre constraints occur at the start of the season.

Lejars *et al.* (2008) state that brix percent affects the evaporator and crystalliser throughput. In South Africa, restrictive brix loading is often experienced in the middle of the season (Hildebrand, 1998).

Maximum sucrose levels and the size of the high grade portion of the boiling house restrict throughput (Schorn *et al.,* 2005; Bezuidenhout, 2010). Restrictions due to sucrose occur in the middle of the harvest season (Wynne and Groom, 2003)

Wynne and Groom (2003) state that non-sucrose restrictions occur towards the end of the season. Non-sucrose percent affects the crystalliser capacity (Lejars *et al.,* 2008). Schorn *et al.* (2005) and Bezuidenhout (2010) state that non-sucrose levels and the size of the low grade portion of the boiling house restricts throughput.

If mills are effectively designed, restrictions due to fibre, sucrose and non-sucrose will occur over equal lengths of time during the season (Schorn *et al.* 2005). Mill components should not be oversized to meet peak requirements that only occur for a short time during the season (Schorn *et al.* 2005).

3.5.2 Mill stops and Overall Time Efficiency

Mill Overall Time Efficiency (OTE) is a measure used to quantify the amount of time that the mill operates out of the potential time that it can operate (Hildebrand, 1998). OTE changes with cane quality and is also influenced by other factors through the season. Multiplying milling capacity by the OTE gives mill throughput (Hildebrand, 1998; Guilleman *et al.,* 2003).

Mill stops should be minimised because they are costly in terms of idle labour, wasted fuel, and lost juice quality (Weekes, 2004). Wynne and Groom (2003) found that mill stops can be caused by several factors occurring simultaneously. This adds complexity to recording mill stops which can make modelling mill stoppages difficult. Mill stops include stops to allow maintenance, stops caused by a disruption in cane supply, stops caused by the breakdown of milling equipment and stops caused by contaminated cane.

Maintenance stops are scheduled mill stops where the mill is stopped completely (or partly-when there is more than one line) to allow preventative maintenance and cleaning. The stops are important as maintenance keeps mills running at an acceptable level and reduces the chances of expensive mechanical breakdowns. Fewer unpredictable stops increase mill Overall Time Efficiency. These stops are normally less than a month apart and differ between mills. Milan *et al.* (2006) give an example where technical maintenance is carried out every 10 days at a certain mill necessitating a complete stop of the sugar mill. Maintenance stops are not always of the same duration.

A no-cane stop occurs when there is a long enough interruption of cane supply to the mill to cause the mill to stop processing. These stops are more common at the beginning and end of the milling season when rainfall disrupts cane supply (Le Gal *et al.,* 2004; Boote *et al.,* 2011; Kadwa, 2012). Slow crushing refers to when the crush rate is slowed down to prevent a complete stop, but there is a minimum threshold below which cane cannot be crushed (Wynne and Groom, 2003; Kadwa, 2012).

Foreign matter mill stops can be caused by large objects delivered with the sugarcane, such as rocks and pieces of metal (Mann, 1996). Mann (1996) states that although larger objects such as rocks and pieces of metal can cause considerable damage to sugar milling equipment, it is sand that is the greatest problem. Graham and Gunn (1971) point out that soil is nearly always present in cane delivered to the mill. Wienese and Reid (1997) estimated that on average mill stoppage caused by soil in cane was 50 hours per million tons of cane crushed.

Soil is highly abrasive and damages cane knives, hammers, rollers, pump impellers, pipes and boiler tubes (Graham and Gunn, 1971; Mann, 1996; Wienese and Reid, 1997). Soil also leads to increased sucrose losses, reduces time efficiency of the mill and requires additional equipment and processes not normally necessary (Wienese and Reid, 1997). More soil is delivered to sugar mills during wet weather (Neethling, 1982; Reid, 1994).

Ash percentage of sugarcane can be used as a measure of contamination by soil, but not all ash is due to soil (Wienese and Reid, 1997). Solid residue from fibre, trash and cane tops makes up a portion of the ash present. For normal quality, soil-free cane, ash was estimated to be in the range of 0.4 to 1.2 per cent by Brokensha and Mellet (1977).

Sugarcane with an ash content of greater than 2% causes severe problems at mills that use diffusers. Ash levels of 10% will block a diffuser immediately (Mann, 1996). High ash in the bagasse can extinguish the mill furnaces. An extension of the harvest season increases maintenance stops due to ash as there are increased mill stoppages towards the end of the season when percentages of ash increase (Kadwa, 2012).

3.5.3 Sugar recovery

Sucrose, non-sucrose and fibre affect milling process efficiency (Gaucher *et al.,* 2004; Le Gal*et al.,* 2004; Le Gal *et al.,* 2008;Lejars*et al.,* 2008). Sugar recovery is partly determined by the decisions growers make when they select their varieties, harvest capacities and management approaches as these choices affect cane quality (Gaucher *et al.,* 2004). Sucrose extraction becomes more difficult as fibre and non-sucrose contents increase (Guilleman *et al.,* 2003).

Sucrose recover rate follows a seasonal pattern that peaks towards the middle of the milling season when quality is highest. Season average sucrose recovery is influenced by the length of milling season (Todd *et al.,* 2004). This effect is illustrated in Figure 3.4. In a shorter season more of the crop is processed when sucrose recovery is near the peak of the curve, which results in a higher season average sucrose recovery rate.

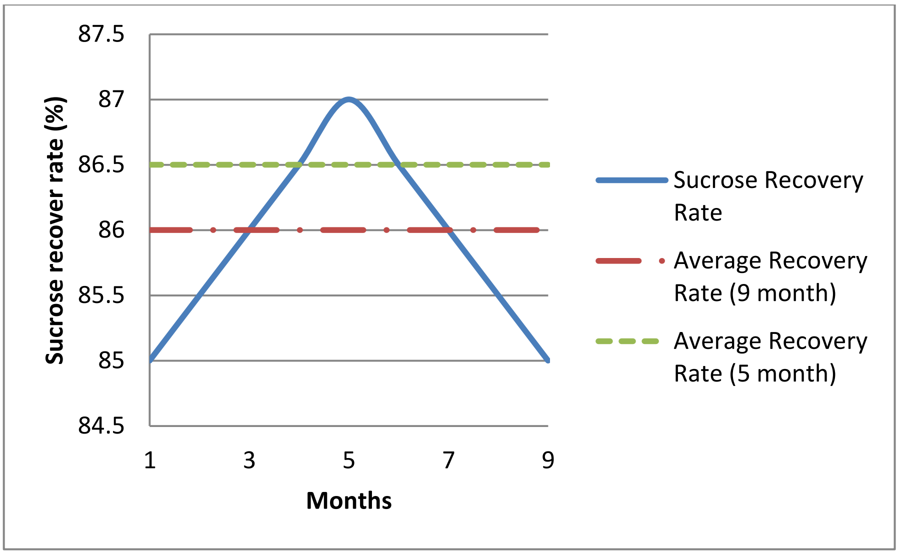

Figure 3.4 Stylised sucrose recovery curve for a typical milling season showing season average recovery rates for different season lengths (Todd *et al.*, 2004).

Lionnet (1996) states that as cane deteriorates, sucrose is lost directly when it is converted to glucose by enzymes and micro-organisms. There is also an indirect loss of sucrose due to the formation of dextrans which reduce sucrose recovery at the mill. Deterioration also increases the colour of the juices which leads to higher refining costs. The ratio of dextran level to sucrose loss is not fixed, but at least 0.4 percent of original sucrose has been lost at a dextran level of 1000mg/kg Brix (Ravno and Purchase, 2005). Figure 3.5 represents an estimated loss curve for overall recovery at different levels of dextran (Ravno and Purchase, 2005).

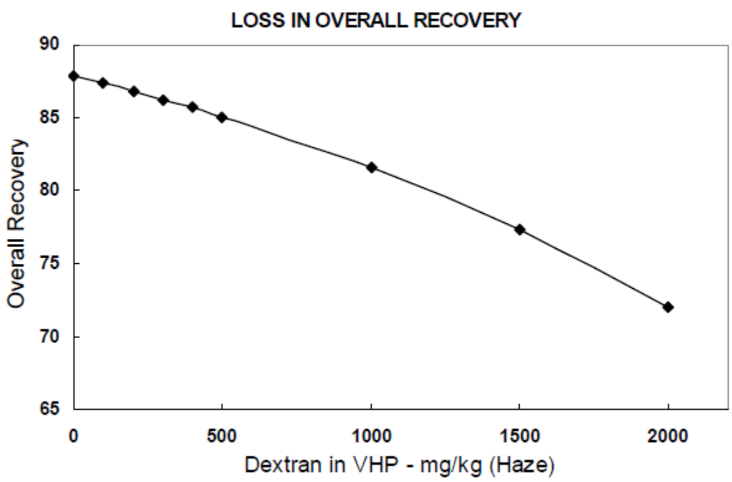

Figure 3.5 Estimated loss in sucrose recovery as a function of dextran content (Ravno and Purchase, 2005).

Normal South African dextran levels are around 200mg/kg Brix, but can be 10000 mg/kg Brix or greater in deteriorated cane (Morel du Boil, 2005; cited by Ravno and Purchase, 2005). Dextran levels above 1000 mg/kg Brix are problematic (Ravno and Purchase, 2005).The higher the normal level of dextran, the more vulnerable the mill will be to problems from badly deteriorated sugarcane (Ravno and Purchase, 2005). Morel du Boil and Wienese (2002) state that the dextran level in mixed juice must be below 750 mg/kg Brix to achieve a level of 150 mg/kg in raw sugar.

3.5.4 Diversions to other mills

Large sugar companies that operate several mills may divert sugarcane from one mill supply area to another to reduce under or over supply and to maintain the viability of mills and downstream products (Kadwa, 2012). This may extend or shorten the milling season respectively.

4. DISCUSSION AND CONCLUSIONS

It is evident that there is considerably complexity involved in selecting an acceptable milling season length. The sometimes conflicting interests of the different sugar supply chain stakeholders should not inhibit a frank discussion of the optimal milling season because it has serious impacts on industry profitability and competitiveness. The study identified many factors that must be accounted for when attempting to determine an acceptable milling season length and timing.

Mill and farm ownership are important to consider when studying the length of milling season. It is important for growers and millers to work together to ensure the competitiveness of their sugar industry. Changes to the milling season length are only possible with buy-in from both growers and millers. Cane payment systems and incentives can be used to encourage changes to the length of milling season. There is the danger that relative payment systems that average a grower's revenue out over the season can mask the effects of a drop in cane quality at the start and end of the milling season. Mill Group Boards have the important task of estimating the size of the crop to be processed for the coming season and setting the length of milling season. Good cane supply management can ensure that the crop is harvested within an acceptable timeframe.

Sugarcane, like any agricultural crop, is influenced by the weather. It follows a quality curve that usually peaks sometime around July in South Africa. At this point the sucrose content of the cane is at its highest and the fibre and non-sucrose levels are at their lowest. Sugarcane quality curves vary from year to year depending on the weather conditions experienced. A feasible milling season must balance cane quality against many other factors such as harvest capacity, transport capacity and mill capacity. As the milling season length is increased the seasonal average cane quality drops because more of the cane is harvested when sub-optimal conditions exist. Estimating the size of the crop that must be harvested is crucial as an accurate estimate of crop size allows for the efficient milling of the crop and is used to determine milling season length and timing. Crop size is a function of the area under cane and the weather conditions experienced during the season. Estimating crop size is a difficult task, especially in South Africa where there is a high variation in annual production. The ability to predict the level of error associated with a particular estimate can be valuable.

Weather conditions determine how many days are available for harvesting in a season. Rainfall at the start and end of the season increases disruptions to the supply of sugarcane to mills. A relationship between the depth of rainfall received and the duration of the delay to harvesting can be assumed for a mill area. There can be a compound effect of extending the milling season into the rainy season as higher chances of rainfall can prolong the milling season even further. Other adverse weather conditions such as wind and frost can cause harvest disruptions.

Much of the sugarcane in South Africa is cut by hand. This is hard physical labour and is made unpleasant by high temperatures. Cane cutter performances differ widely between cutters, farms and regions. The type of cutting system used has the biggest impact on cutter output. Labour availability and reliability can prolong the milling season. Strikes can have devastating effects on cane supply and meeting harvesting targets. Shortening the milling season could result in each cane cutter earning less, but more people may need to be employed to meet harvesting demands.

Sugarcane starts to deteriorate immediately after burning and/or harvesting. Deterioration is caused by enzymes present in cane stalks and is worsened by other organisms that enter the cane tissue. These organisms invert sucrose, consume glucose and form other substances including alcohols, acids and gums. The deterioration products that affect mill operation are often lumped under the term dextrans. Dextran levels follow a seasonal pattern and are lowest in winter. Mechanical harvesting and burning both increase the rate of deterioration. Minimising burn to crush delays is important due to the negative effects of deterioration. High temperatures and wet conditions cause a marked increase in deterioration rates, and these conditions are more commonly experienced towards the beginning and end of the milling season. For this reason extending the season into the warm and wet summer months can have serious implications for mill performance and sugar recovery.

Transport capacity that is available at a mill area determines the rate of delivery to the mill. Greater capacity or more efficient use of existing transport is needed as the length of milling season is reduced. Factors that affect efficiency include the level of trash present in the cane, the physical characteristics of the cane stalks, the loading methods used and the skill of the loader operator. A reliable and consistent supply of cane to the mill is needed to prevent the mill from stopping. Transport is vulnerable to disruptions caused by wet weather and breakdowns which indicates that these disruptions will occur more frequently towards the start and end of the milling season and would increase with extensions to the harvest season. Minimising transport time and delays in the cane yard reduces deterioration.

The throughput of the sugar mill helps to determine the required length of milling season. Mills are usually designed to process cane of an average quality across the season. A mill's throughput is inconsistent because crushing is constrained by fibre levels at the start of the season, sucrose levels in the middle of the season and non-sucrose levels towards the end of the season. Mill Overall Time Efficiency (OTE) measures the amount of time that the mill operates out of the potential time that it can operate. OTE changes with cane quality and is also influenced by other factors, such as scheduled maintenance, public holidays, mill breakdowns and cane supply fluctuations. Adjustments to the length of the milling season thus affect the seasonal average throughput of a mill.

Sucrose recovery follows a seasonal pattern that peaks towards the middle of the milling season when quality is highest. Season average sugar recovery is influenced by the length of milling season.

A stockpile of cane reduces no-cane stops and can help ensure constant levels of mill operation, but increases cane deterioration. A correctly sized stockpile should be large enough to reduce the chances of the mill stopping due to interruptions in cane supply, but not so big that deterioration impacts mill throughput and extraction efficiency. The length of the milling season can be shortened or lengthened by diverting cane between different sugar mills.

This review has highlighted the factors that determine the acceptability of a particular length of milling season. Many of the issues identified are different for each milling area and change from season to season. The complexity of the milling season decision makes it difficult to define an optimal length.

5. PROJECT PROPOSAL

The length of milling season is a controversial topic and is widely debated (van der Pol, 1987; Hildebrand, 1998). Whenever it is discussed it is likely to raise conflicting arguments since the different stakeholders in a sugar supply chain often have different ideas about what the milling season length should be. It is, however, an extremely important debate which must be facilitated to ensure the continued profitability and competitiveness of any sugar producing region (van der Pol, 1987; Muchow *et al*., 1998; Wayne and Groom, 2003).

There are various factors that must be taken into account when determining acceptable milling season lengths. These include seasonal variations in cane quality, political and social relationships, optimal growing periods, the effect of the weather, harvesting and transport issues and mill factors such as capacity and throughput (Hildebrand, 1998; Moor and Wynne, 2001; Le Gal *et al.*, 2004; Todd *et al.*, 2004; Boote *et al.*, 2011; Kadwa, 2012).

5.1 Rationale

Narrowly viewed, a suitable milling season is one where the crushing of sugarcane is consistent, maximum benefit is derived from the sugarcane and cost of production is minimised. However, a more realistic perspective of the ideal milling season must take into account trade-offs between the needs of the different stakeholders in the sugarcane supply chain while maintaining the competitiveness of the industry as a whole. One example is the trade-off between a grower's desire to harvest the majority of the sugarcane crop in winter when fields are dry and extraction is relatively easy and the millers desire to extend milling into the wet season to increase mill utilisation, which reduces the cost of milling.

The selection of an acceptable harvesting season for any sugar producing region is complex, but must be answered to improve efficiency and thus to maintain international competitiveness (Le Gal *et al.*, 2008). There are myriad interrelated factors that determine an acceptable harvesting season. So far in the South African sugar industry the published attempts to determine the optimal harvest season through modelling have been based on simple economic models and linear programming (Hildebrand, 1998; Moore and Wynne, 2001). Although they provide valuable insight into the harvesting season, these models fail to take into account the complexity of the sugarcane supply chain.

Therefore, there is scope to review the way in which the sugar harvest season is modelled to include a wider range of variables, risks and uncertainties. A stochastic modelling approach towards the harvest season has not been undertaken in South Africa (and possibly anywhere in the world) and will enable a wider range of factors to be considered. The development of a stochastic simulation framework to analyse the relationships between these factors will provide deeper insight into the harvesting season. The benefit of this approach is that it is easier to calculate risk levels with a stochastic model than with a deterministic one. With proper calibration and prioritization of factors this framework will allow any mill area in South Africa to be modelled at an appropriate temporal and spatial scale.

The proposed project will form part of a larger study of the harvesting season, to be conducted across all South African sugarcane supply areas and possibly also certain supply areas outside South Africa. The wider study is currently in the initialization phase and so the proposed project forms part of the ground work for mill specific studies to be carried out from 2014 onwards.

5.2 Project Aim

This project will investigate the transport and milling factors that affect the length of milling season. These factors have been outlined in the previous chapters. The aim is to incorporate all the relevant factors into a stochastic model that could be used to investigate the different dynamics that regulate season length and risk in different sugar mill areas in South Africa. This will facilitate the recommendation of appropriate harvest seasons for different mill areas.

5.3 Research Question

Previous models of the sugarcane LOMS have been unable to take into account the full complexity, in terms of a wide range of influencing factors, risk and uncertainties, of the decision when providing an optimal timeframe for harvesting. The transport and milling segments of a sugarcane supply chain are important drivers of the LOMS. Adjustments to either the transport or milling capacity can have a direct impact on the LOMS. The many factors that control and feedback into the performance of transport and mill systems result in complexity. The research question is:

How can the transport and milling segments of a sugar supply chain be modelled to help optimise the milling season, taking into account the many interrelated factors that drive these segments, such as milling capacity, climate, cane quality and transport?

5.4 Objectives

The objectives of the proposed project are to:

a) Investigate which factors drive the transport and milling segments in a typical mill area by reviewing relevant scientific literature,
b) Identify the data that are needed from a mill area to statistically calibrate and stochastically model the factors that drive the transport and milling segments,
c) Derive a simulation platform that is flexible, yet can easily be used to investigate the dynamics and calibrations concerning the harvesting season,
d) Calibrate the model for a suitable case study mill area,
e) Once the model has been calibrated, gain an understanding on how these factors interact and thus impact on the length of milling season in any mill area by conducting a series of sensitivity analyses, and,
f) Provide a guide to mill specific stochastic modelling of the transport and milling segments of the sugar supply chain.

5.5 Methodical Approach

A literature review of the LOMS will identify the factors that must be accounted for to determine an optimal season length. From this review the factors which control the transport and milling segments impact on an optimal harvesting season will be used to create a theme map (Bezuidenhout *et al.*, 2012; Sanjika *et al.*, 2012).The transport and milling factors will then be reviewed with the aim of identifying the most appropriate stochastic simulation approaches to describe the relationships between these factors. The model will be constructed in Microsoft Excel. Different spread sheets will represent the different aspects and factors that affect the milling season.

Once the factors and how they relate are compiled into the model it will be calibrated for one of the mill areas in South Africa, probably Eston. After calibration a sensitivity analysis of the model will be conducted. The model will be used to simulate thousands of harvest seasons in a particular context. For example, varying the starting date of the harvest season will illustrate the effect this has on the season length. These results will facilitate the determination of suitable harvest seasons to increase profitability and efficiency.

Specific questions that will be addressed are:

a) How many stochastic simulations are required to gain statistical confidence in the results?
b) To what degree of precision and accuracy should the model be calibrated?
c) What is the relative importance of different variables?

Using the findings from the literature reviews and the questions above a comprehensive guideline to adapting the transport and milling segments of the model for a particular mill area will be developed.

5.6 Resources Required

The proposed project is primarily a desktop study and as such the resources required are minimal. Office space, a desk and a computer have been provided. Funding for the project has been provided through funds administered by Professor Carel Bezuidenhout. A project plan can be seen in **Error! Reference source not found.**.

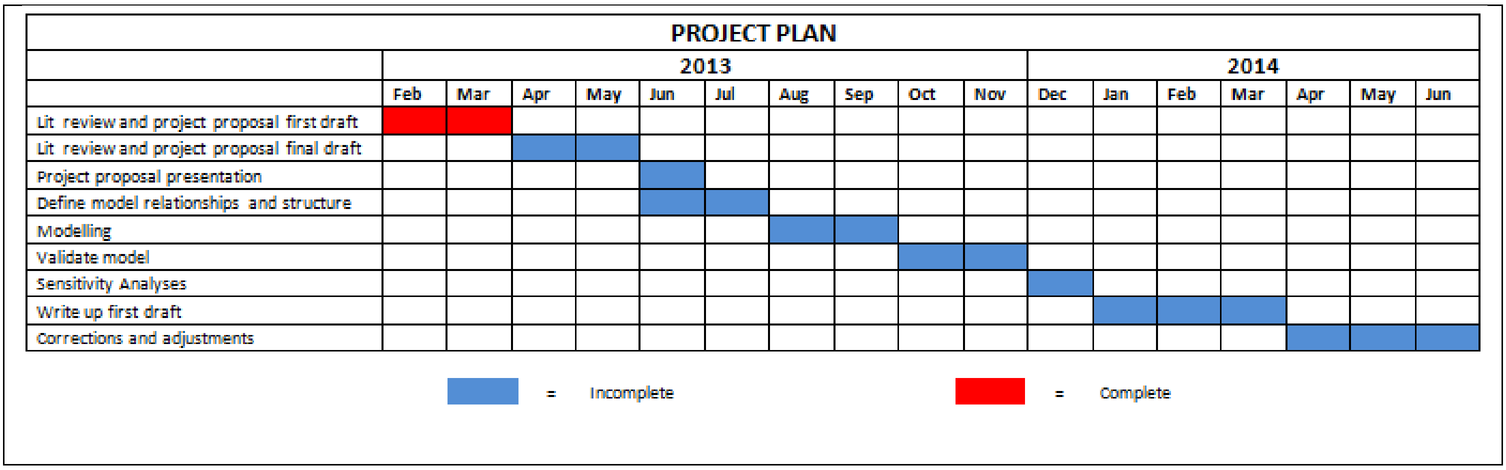

Figure 5.1 Project Plan.

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