THE EFFECTS OF PRECIPITATION ON THE SUGARCANE SUPPLY CHAIN OF SEZELA AND UMZIMKULU

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Submitted for the fulfilment of the requirements
for the degree of Master of Science in Bioresources Systems

School of Engineering
University of KwaZulu-Natal
Pietermaritzburg
2015

ABSTRACT

The length of milling season (LOMS) issue is a very sensitive topic among different stakeholders in the sugar industry. An efficient supply chain is essential in order to maintain and ensure a continuous flow of sugarcane. Wet weather is one of the major challenges in the supply chain of sugarcane, especially the harvesting, transport and milling aspects. A stochastic model called LOMZI was developed to examine stockpiling at the Umfolozi Mill. In this study, LOMZI was adapted and expanded to investigate the LOMS for the Sezela and Umzimkulu mill supply areas (MSA) in South Africa. The LOMZI model consisted of three major components, sugarcane quality, crush rate, and ClimGen, a weather generator. The quality model was based on past daily records of weather and sugarcane quality in the area. The model calibrated 90 coefficients and predicted daily Pol%, Fibre% and Brix% for the Sezela and Umzimkulu areas. Verification of the model showed R^2 values in a range between 0.78 and 0.90 when observed and actual data were compared. The crush model also calibrated 15 coefficients using daily past weather and crush rate data of the areas. The model predicted the daily crush rate of the areas under study. Correlation values for the crush rate model were 0.52 to 0.69. ClimGen was used to predict 1000 years of rainfall and temperature data for the areas of study based on 25 years of historical weather data of the areas. LOMZI used the 1000 seasons of weather data from ClimGen and the calibration coefficients from the quality and crush models to predict 1000 seasons of daily crush rate and sugar produced at the mill areas. Coefficients from the sub models were incorporated in the LOMZI model to simulate daily crush rate and sugar produced for 1000 seasons. The outputs were represented using exceedance profiles as well as decision support graphs. The profiles demonstrated that operating at a very high weekly crush rate is likely to result in low chances of the mill meeting its seasonal crush goal. Therefore it was important to find the crush rate that would achieve the harvest crush target. The support graphs showed that it was recommended for the mill to operate at a 70% probability level as there were relatively high chances of fully utilising the mill capacity. The significance of this study was to provide more information to aid the MGB in making LOMS decisions and to find out where there were high chances of meeting the weekly target with minimum risks involved during the milling season.

DECLARATION

I Precious Dzapatsva declare that

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As the candidate's Supervisor, I have approved this dissertation for submission.

Signed: .... Date: ....

G Lagerwall

As the candidate's co-Supervisors, we have approved this dissertation for submission.

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P Lyne

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CN Bezuidenhout

ACKNOWLEDGEMENTS

Firstly, I wish to thank the God Almighty for providing me with the opportunity and capacity to complete this study.

I further thank the following persons and organizations that made this study possible:

- My family and friends for all your love, support, sacrifices, patience, encouragement and motivation to complete this project.
- Dr G Lagerwall, School of Engineering, University of KwaZulu-Natal, for his commitment to supervising this project and his enthusiasm, assistance and guidance throughout.
- Prof P Lyne, School of Engineering, University of KwaZulu-Natal, for his commitment to supervising this project and his enthusiasm, assistance and guidance throughout.
- Prof CN Bezuidenhout, School of Engineering, University of KwaZulu-Natal, for his commitment to supervising this project and his enthusiasm, assistance and guidance throughout.
- Mr E Jenkins for his commitment and assistance he provided throughout the project.
- The South African Sugar Research Institute (SASRI) for the necessary funding and student subsistence required for the research.
- The National Research Foundation (NRF) for financial assistance towards this research.
- The Sezela Mill Group Board (MGB), the Cane Testing Service (CTS) as well as growers and hauliers in the Sezela area, who provided valuable information.
- The Umzimkulu Mill Group Board (MGB), the Cane Testing Service (CTS) as well as growers and hauliers in the Umzimkulu area, who provided valuable information.
- The staff and students of the School of Engineering, University of KwaZulu-Natal for their motivation and advice throughout the project.

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1. INTRODUCTION

A supply chain can be defined as an interwoven network bringing together people, information, organizations, resources and activities (Lambert and Cooper, 2000). It starts with the production of raw materials and ends with the delivery of the finished product to the consumer. As with any other supply chain system, the sugar production supply chain is sensitive to change. SASA (2014) estimated that the South African sugar industry produces an average of 2.3 million tons of sugar from 18.8 million tons of sugarcane harvested annually. Not only does the South African sugar industry provide sugar for the local market, but it also provides for the international market and must ensure it remains competitive on a global level.

In the sugarcane supply chain, weather conditions play a crucial role in determining the length of the milling season (LOMS). The length of the milling season refers to the length and timing of sugarcane crushing operations at a sugar mill (Jenkins, 2014). It is determined by dividing the total harvest tonnage by the mean throughput of the mill, and is given in weeks or number of days (Hildebrand, 1998). However, there are important considerations to first be made before the LOMS is decided; for example, the crushing capacity of the mill and the cane quality. The total harvest tonnage is estimated by using the growers' estimates and previous records (Le Gal *et al*., 2009). The crushing rate takes into account factors like the weekly maintenance duration, and expected mill breakdowns.

The LOMS issue is a sensitive topic in the sugar industry mainly because some of the major segments in the supply chain are owned by separate entities (Hildebrand, 1998; Wynne and Groom, 2003). Growers prefer a shorter season which usually results in high sucrose purity and drier field conditions, whilst millers prefer a longer season, lower milling capacities and fixed costs spread throughout the season (Le Gal *et al*., 2009). Therefore, LOMS decisions should meet the needs of growers and millers, while at the same time remaining competitive on the global market (Le Gal *et al*., 2009).

The length of the milling season varies widely from country to country (Hildebrand, 1998). The LOMS must maximise both profits and productivity of the mill area. For example, the Australian LOMS runs from early June to late November and experiences mill capacity and transport limitations (Jenkins, 2014). In Venezuela the season starts from October and continues to May (Grunow *et al*., 2007). The mills in Colombia crush sugarcane all year round and there is no limit on the milling season (Hildebrand, 1998).

In South Africa, the LOMS usually runs from April through to December for 30-38 weeks (Bezuidenhout and Singels, 2007; Le Gal *et al*., 2009). The window period maximizes the recoverable sugar produced. The purity of the sugar usually starts out low, increases to its maximum around July-August, and drops towards the end of the season (Le Gal *et al*., 2008; le Gal *et al*., 2009).

The development of computer models to improve the supply chain is not a new approach in the sugar industry (Zhaorong *et al*., 2005; Rangel *et al*., 2010; Boote, 2012). In Morocco, Jorio *et al.,* (2006) developed a simulation model of harvesting, transporting and crushing sugarcane to help reduce the impact of rain and breakdown stoppages on the system. Barnes *et al.,* (1997) also conducted research on the delays between harvesting and crushing, and developed a simulation model of harvesting, transporting and handling as an intended method of reducing crush delays. The model indicated that the process rates for cutting, loading and transporting had to be improved. A statistical optimization approach using a linear programming model was utilised to model the length of the milling season for farms within a mill region in Australia (Zhaorong *et al*., 2005). The approach showed potential gains in profits by maximizing the sucrose content. Grunow *et al.,* (2007) suggested an approach aimed at preserving a constant cane supply while minimizing costs. Two software models were used to model the LOMS using business processes and organizational structures as input parameters to solve the unforeseen problems that affect the LOMS. Boote (2012) developed a stochastic model called the LOMZI model that evaluated stockpiling options at Umfolozi Mill.

From the above discussion, it is evident that several attempts have been made, and are still being made, to optimize the LOMS to suit the specific needs of growers and millers. It is not possible to have a one-size-fits-all milling season, because mills and growers face different challenges depending on the region. In South Africa, the LOMS model was developed more than 10 years ago, however it did not take into account some of the complexities and variabilities in the sugar supply chain (Hildebrand, 1998; Jenkins, 2014), and some of the assumptions used in the model might not be valid anymore. Hence, there is a need for further work on optimizing the LOMS to include important variables such as rainfall and cane quality. The LOMS model developed in this project was based on the LOMZI model by Boote (2012). A stochastic modelling approach was chosen because, compared to other modelling approaches, it improves the risk calculation.

The quality of sugarcane is influenced by seasonal weather patterns (Singels *et al*., 2012). The literature review focuses on the impact of precipitation on the sugarcane supply chain and the LOMS of sugarcane. Note that for this project, the main form of precipitation that was investigated was rainfall. The topic is quite broad and the factors affecting the supply chain are interlinked. The supply chain refers mainly to the growing, harvesting, transporting and milling of sugarcane. Several studies have already been done on the influence of rainfall on the length of the milling season in relation to the yield, quality, performance of harvesting and transport logistics (Higgins and Muchow, 2003; Chen and Yano, 2010; Kadwa *et al.*, 2012).

The aims of the project are:

- To review literature on the effects of precipitation on the sugarcane supply chain; and
- To assess the viable length of milling season opportunities existing in the KwaZulu-Natal South Coast milling areas of Sezela and Umzimkulu.

The objectives of the project are:

- To conduct a literature review of the impact of precipitation on the supply chain, and ultimately the length of the milling season;
- To perform a blind survey to determine issues affecting the length of the milling season in the Sezela and Umzimkulu milling areas;
- To adjust the LOMZI model and perform data calibration for each of the above milling areas;
- To model the data over a variety of seasons and conditions;
- To interpret the data and package it using exceedance profiles and decision support graphs to present to industry; and
- To find possible areas of improvement on the model and provide recommendations.

Chapter 2 identifies and discusses the effects of precipitation on the supply chain. These include no-cane stops, cane deterioration, soil on cane, crop lodging, water logging, cane growth, the burning of cane and the impacts of hailstorms on sugarcane. The scope of this review will not cover frost damage to cane. Rainfall and hail will be considered as the main forms of precipitation affecting sugarcane and its supply chain.

Chapter 3 presents the diagnostic study of the milling areas Sezela and Umzimkulu. The methodology, results and discussion of the LOMZI model are presented in Chapters 4 and 5. LOMS modelling based on rainfall and cane quality forms the focus of this study. The model is thoroughly calibrated for the individual South Coast mills, based on the mills' past weather and quality records. This is shown in the methodology section. The results sections include results from the quality and crush models along with supporting graphs. Conclusions and recommendations for future research are presented in Chapter 6.

2. A REVIEW OF THE IMPACTS OF PRECIPITATION ON THE SUGARCANE SUPPLY CHAIN

Wet weather is one of the core factors that drive the supply chain and the length of milling season of sugarcane. Wet conditions results in cane lodging, water logging, limited infield mobility, cane deterioration and increased soil content in a consignment. Persistent wet conditions also disrupt the harvesting process and supply of cane to the mill which may end up inducing a no-cane stop. The sections that follow in this chapter investigate in more detail the impacts of precipitation on the supply chain. The review will also investigate the stochastic modelling approach of the LOMZI model that was developed to improve the operations of the supply chain of sugarcane.

2.1 Crop Lodging

This section contains a review of the impacts of sugarcane lodging on harvesting operations, sucrose yields and the losses associated with lodging. Crop lodging, as shown in Figure 2.1, occurs when a crop becomes too heavy and falls, due to stem or root failure (Singh *et al.*, 2000). With sugarcane, lodging depends on the variety of cane, as well as the type of soil (Rossler, 1974; Inman-Bamber, 1994). Large and fully-grown crops with yields exceeding $100\ \mathrm{t.ha^{-1}}$ are more prone to lodging than small and poorly-grown crops (Singh *et al.*, 2002; Kadwa, 2013).

Figure 2.1 Lodged cane after a heavy downpour (SASRI, 2014)

According to various studies, lodging slows down the biomass production of a crop, reduces cane quality and may even result in the death of the crop (Inman-Bamber, 1994; Muchow *et al*., 1995; Singh *et al*., 2002; van Heerden, 2011). Sugarcane lodging is greatly affected by environmental conditions (Berding and Hurney, 2005; van Heerden, 2011). Strong winds, followed by rainfall, can cause the damaging of sugarcane stalks, as shown in Figure 2.1 (Muchow *et al*., 1995; Singh *et al*., 2002; van Heerden, 2011). Amaya *et al.* (1996) points out that lodging is positively correlated to the height and the weight of the stalk.

During the harvest season, the occurrence of lodging significantly reduces the cutting, loading and transportation efficiency, especially where mechanical harvesting is predominantly practised (Amaya *et al*., 1996; Cock *et al*., 1993). Lodged cane reduces the cutter machine efficiency, both in burnt and green cane (Meyer, 1984). However, if the cane is lodged in the same direction in which the cutter is moving, there is little or no effect on the efficiency. Pearson (1965) and Meyer (1984) discuss the impacts of broken stalks and poor topping efficiency.

However, manual harvesting of sugarcane has dominated the South African sugar industry since 1848 (Meyer, 2005). The biggest challenge when manually harvesting lodged cane is the difficulty to move infield. Figure 2.1 illustrates this point, with the cane lodged in different directions and twisted together, which makes it difficult to cut.

As a result of cane lodging, additional leaves and cane tops become part of the consignment delivered to the mill. Large amounts of extraneous material result in a higher fibre content and increased colour precursors in crystal sugar (Berding and Hurney, 2005). This increases the milling costs per unit and limits the sucrose extraction efficiency (Pearson, 1965; Amaya *et al.,* 1996; Singh *et al*., 2002). Over time, sugarcane lodging can result in the growth of side shoots and rooting from nodes on the ground, which increases the amount of fibre due to growth whilst reducing the sucrose content (Amaya *et al.,* 1996).

Several studies and experiments have been performed to find ways of preventing cane lodging. In particular, Singh *et al*. (2002) conducted research in Australia and found that installing bamboo scaffolding prevents lodging and significantly increases the sugar yield by 15-35%. Van Heerden (2011) also suggested the use of Ethephon (2-chloroethyl phosphoric acid) and Moddus (Trinexapac-ethyl) to increase cane resistance to lodging. In general, under moderate weather conditions, the selection of a lodging resistant variety is effective in combating cane lodging, which reduces the negative impacts of lodging on both cane production and the quality of juices (Amaya *et al.,* 1996).

The causes and consequences of cane lodging have not been extensively studied (Singh *et al.,* 2000; Berding and Hurney, 2005). Berding and Hurney (2005) state that cane lodging is an ongoing challenge that is unavoidable in the sugar industry. However, it is possible to reduce the impacts of lodging by strategically scheduling the harvest season, taking into consideration the time most rainfall is experienced (Berding and Hurney, 2005).

2.2 The Impacts of Hail on Yield

This section focuses mainly on the impact of hailstorms on sugarcane. Hailstones, accompanied by strong winds and heavy rains, damage crops and result in financial losses

(Bhardwaj *et al*., 2007). The extent of the damage depends on the size and shape of the hailstones and the strength of the wind.

The effects of hailstorms, accompanied by strong winds and heavy rainfall, are characterised by shredded leaves and damaged stalks. Figure 2.2 shows a field with sugarcane that was damaged after a hailstorm.

Figure 2.2 Damaged sugarcane after a hailstorm (SASRI, 2014)

Hailstones damage the leaves, stalk epidermis and the rind of sugarcane, leaving the cane vulnerable to pathogens that cause diseases (SASRI, 2013). The damaged area opens a way for pathogens to penetrate into the stalk, resulting in rotting. The greater the damage, the more difficult it is for the stalks to recover. Symptoms of a fungal infection become visible about five days after the hail event. If the stalk is millable, the fields must be examined to find the percentage of stalks affected by diseases. The damage will negatively affect the cane quality and hence, revenue (SASRI, 2013).

To manage the damage by hail, extremely bruised and damaged stalks with broken tops must be harvested as early as possible, starting with the most damaged cane, because it deteriorates faster (SASRI, 2013). Lightly damaged cane with shredded leaves, can recover on its own (Bezuidenhout, 2014). Although the occurrence of hailstorms can be predicted by weather forecasts, little can be done to reduce their impact. There appears to be no literature specifically concerning the impact of hailstorms on sugarcane.

2.3 Mobility, Water Logging and Soil Compaction

Mobility is very important in the supply chain of sugarcane. The efficient mobility of sugarcane vehicles helps to maintain a consistent supply of cane at the mill. The onset of rainfall has a negative impact on traffic mobility and cane supply because the roads become slippery and dangerous to drive on. This section reviews the impacts and effects of wet weather on the soil structure, the harvesting process and the movement of loading trucks. Another interesting result of excessive rainfall that is discussed in this is water logging.

Water logging is the saturation of the soil with water due to heavy rainfall or irrigation that floods the fields, as shown in Figure 2.3. The severity of waterlogging can be significant in high rainfall areas. For example, in Pakistan almost 40 000 hectares of land can be lost to waterlogging per annum (Roach and Mullins, 1985). Waterlogging affects harvesting operations and changes the soil and plant structure (Roach and Mullins, 1985; Muchow *et al*., 1995; Kingston, 2010).

Wet and boggy fields make it difficult to use mechanical harvesters by limiting infield access (Rivière *et al*., 1996). Fields are severely damaged, especially when driving out loaded hauliers and there is wear and tear to tracks and tractors (Morris, 1959). Under wet conditions, tyres deform and compact the soil. Severe cases of rainfall result in more serious conditions, such as water logging which is shown in Figure 2.3.

Figure 2.3 A waterlogged sugarcane field after a rainfall event (SASRI, 2014)

When the fields are under water, it delays harvesting because the infield mobility of traffic is retarded. During the 2010 harvest season in Australia, Kingston (2010) found that the time lost due to delays in waterlogged fields resulted in approximately 25% of the sugarcane not being harvested during the season. This resulted in the extension of the milling season and financial losses.

Soil compaction in fields is exacerbated when traffic moves in the field under wet conditions. As shown in Figure 2.4, it is caused by heavy infield traffic compressing the soil, which reduces the size and number of air pores between soil particles. The soil becomes hard and impermeable and restricts root growth, which reduces the mass of the sugarcane stalk by up to 22% (van Antwerpen *et al*., 2008). Compaction by infield traffic is more severe under wet conditions and depends on the size of tyres of the vehicle, the soil type, as well as the amount of load on the vehicle (Marx, 2006; SASRI, 2013).

Breakdowns are regularly encountered due to a lack of traction and the sinking of trucks into the mud (Morris, 1959). Other consequences of waterlogging are soil erosion and the leaching of nutrients due to surface runoff, especially on steep slopes (Ghiberto *et al*., 2009). However, this review does not include soil erosion and leaching, as it is beyond the scope of the research.

Morris (1959) recommended that permanent and efficient drainage systems be put in place in wet fields, so that tractors can manoeuvre easily in the fields. However, this suggestion comes with significant additional capital costs to the grower. In addition, SASRI (2013) also recommended the use of low-pressure tyres, to reduce sinking into the soil.

The severity of soil compaction depends on a number of soil properties, namely, the structural strength, bulk density and soil aeration (Harris, 1971; Sands *et al.,* 1979; Lowery and Schuler, 1994; Marx, 2006). Marx (2006) stated that, in wet weather, sandy soils with a clay content of less than 30% are compacted to a greater extent than soils with clay content greater than 30%. The higher the moisture content in the soil, the greater the degree of compaction. Koolen and Kuipers (1983) stated that, in wet conditions, high organic content in soil gives it more resistance to compaction, compared to soils with a low organic content (Tweddle, 2013).

Figure 2.4 The impact of compaction on soil under wet conditions (SASRI, 2014)

2.4 Burning Sugarcane Trash under Wet Conditions

When sugarcane is mature, it is either harvested green or the leaves are burned first and then harvested. To burn sugarcane leaves, the field is set alight in a controlled way, preferably on a day with no wind, to prevent runaway fires. Figure 2.5 shows a field being burnt before harvesting (SASRI, 2013). Many studies have been done on the burning of sugarcane in relation to sugarcane quality and deterioration, gas emissions and harvesting methods (Eggleston *et al*., 2008; Solomon, 2009; Eustice *et al*., 2011). However, not much research has been done which mainly focusses on the impact of wet weather on the burning of sugarcane.

Figure 2.5 A sugarcane field set alight to burn leaves (SASRI, 2014)

A sugarcane plant consists of a stalk and leaves. Sugar is extracted from the stalk and the leafy material that is left is known as “trash” (Scott, 1977; Kadwa, 2013). Burning sugarcane before harvesting reduces about two-thirds of the trash (Wynne and van Antwerpen, 2004). However, some trash is still delivered and processed at the mill (Wynne and van Antwerpen, 2004; Kadwa, 2013). In Australia, Scott (1977) found that a 1% increase in trash can lead to a 2.75% increase in fibre content, which negatively affects cane bulk density and decreases the amount of sugar recovered after extraction (Amaya *et al.,* 1996; Kadwa, 2013).

By burning, harvesting becomes easier and the cutting efficiency improves, hence more cane can be harvested in a shorter period. Trash from unburnt cane hinders the growth of new shoots and makes it difficult to work the soil. Burning trash reduces the bulk density and increases the sugar recovered per consignment, as well as increasing the overall quality of the sugar (SASRI, 2013).

Extreme wet conditions during the harvest season impact negatively on burning, especially after a heavy rainfall event. Under extremely wet conditions, burning sugarcane is not possible and it requires some time before the conditions return to normal. Such events negatively affect the cane supply to the mills, which can give rise to no cane stops.

The inability to burn and delays caused by wet weather can be avoided by practising alternative harvesting methods that do not involve burning such as, "green cutting" also known as "trashing". Smithers (2014) and Rees (2013) provide more detail on a number of ways that were investigated to separate the cane from the trash. Trashing reduces the delays caused by the inability to burn and maintains a more consistent cane supply to the mills. Trashing reduces water evaporation by covering the soil and is practised in areas such as the north and South Coast of KwaZulu Natal, where moisture conservation is critical (du Toit and Murdoch, 1966).

Green harvesting of cane can be advantageous because the mulch layer of trash also enriches the soil and increases the humus content (Thomson, 1966, van Antwerpen *et al*., 2006). If trashing is performed effectively, it can result in cane with a higher sucrose quality, compared to burnt cane (SASRI, 2013).

2.5 Cane Deterioration

Cane deterioration is the loss of recoverable sugar between the time of burning or cutting and the time of crushing (Hilton, 1997). The main indicators of cane deterioration are juice purity, dextran levels and recoverable sugar.

Weather has a profound impact on the quality and deterioration of sugarcane. High temperatures and wet conditions increase deterioration and reduce the quality of sugarcane (Solomon, 1996; Uppal and Sharma, 1999; Uppal *et al*., 2000; Solomon *et al*., 2006; Solomon, 2009). Rainfall in itself has little effect on cane deterioration, but the muddy soils caused by rainfall affect the supply chain and contaminate the sugar juices. More detail on the effects of mud and sand on sugarcane deterioration are given in the Section 2.6.

Deterioration of sugarcane can have varying degrees of severity, for example, stale cane and sour cane (Solomon, 2009). Both of these act together in deteriorating cane and juice quality. Enzymes and microbes metabolically convert stored sucrose into other products, such as polysaccharides, gums and ethanol (Eggleston *et al*., 2008; Solomon, 2009). Stale cane is the ageing of stalks and the depletion of sucrose through continuous inversion and respiration (Alexander, 1973). Sour cane is due to the microbiological deterioration of stalks by a bacterium called *Leuconostoc mesenteroides* to produce a product known as dextran (Eggleston *et al*., 2008; Solomon, 2009).

The formation of dextran in sugarcane uses up sucrose, while accumulating impurities. Bacteria act on the glucose-fructose bond in sugar to get energy to form dextran (Rivera, 2009). Eggleston *et al.* (2008) found that in the USA, particularly in the state of Louisiana, where humid conditions are prevalent, the infection of sugarcane by the bacterium *Leuconostoc mesenteroides* is one of the major causes of cane deterioration. This bacterium plays a pivotal role in reducing the recoverable sugars in cane and milled juices (Solomon, 2009). Apart from temperature and humidity, other factors create a favourable environment for dextran formation. These include poor mill hygiene, long harvest-to-crush delays, and the amount of mud in the consignment.

The accumulation of dextran affects the quality of sugar that is extracted in the backend of the mill. Dextran results in sugar crystals bunching together and elongating (Eggleston *et al*, 2008). Elongated crystals break easily, especially after separation from molasses (Eggleston *et al*, 2008). Dextran impurities also increase the viscosity of molasses that is formed (du Clou and Walford, 2012). The high viscosity of molasses reduces the crystallisation of the sugar crystals and sugar refineries in the USA penalise factories for excessive dextran in the raw sugar (Eggleston *et al*, 2008).

Impurities also make it difficult to dry sugar crystals and result in sticky or ‘gummy’ soft sugars. Gums are carbohydrates that precipitate from sugar processing solutions such as alcohol (Jennings, 1965; du Clou and Walford, 2012). They result from metabolic activities within the sugarcane plant and from external microbial activity during cane handling and processing (du Clou and Walford, 2012). Gums concentrate in the final molasses streams and affect the polarisation, viscosity and filterability of sugar solutions.

2.6 Soil and Foreign Matter in Cane

During the harvest season, the highest levels of soil in cane are found during the rainy season (Wienese and Reid, 1997). Most of the soil that comes to the mill is either fine loose sand or soil that sticks onto the cane stalks. This is mostly unavoidable, especially under wet conditions the quantity of soil depends on the soil type (Wienese and Reid, 1997). However, the loading practice that is chosen can make a big difference to the amount of soil that gets into the consignment.

Solomon (2009) notes that muddy conditions, due to heavy rainfall create a favourable environment for the multiplication of dextran-producing polysaccharide bacteria, similar to *Leuconostic*. Mud also limits the amount of available oxygen, so these bacteria respire anaerobically, hence using up the sucrose whilst producing lactic acid, which deteriorates the cane quality (Solomon, 2009).

In the laboratory, soil is allocated to the ash component of sugarcane. The fibrous matter is called sugarcane bagasse and is one of the by-products that remain after sugarcane stalks are crushed to extract their juice (Qureshi *et al.*, 2002; Tran, 2012). After sugarcane bagasse is burnt in the boilers, it is referred to as bagasse ash, so that when there is soil in the fibre, more ash will be produced in the process, hence increasing waste products (Qureshi *et al.,* 2002). Wienese (2001) states that an increase of sand in the ash content results in a significant increase in the erosion of the tubes in boilers.

In the mill, sand has a profound effect on cane preparation, filtration and milling. Soil is responsible for the wear and tear of hammers, knives, mill rollers, trash plates and chains (Solomon, 2009). During the milling process, the mud, also referred as filter cake, is filtered from the sugarcane juice. By the clarification process, the juice is separated into a clear juice and the mud collects at the bottom of the tanks (Tran, 2012). The soil that also collects at the bottom of the tank during filtration can cause the corrosion of the tanks and this increases the number of breakdowns that the mill experiences.

A study performed at Tongaat-Hulett Sugar Ltd., in South Africa, showed that the mill experienced several breakdowns due to an increase of sand in the cane (Wienese and Reid, 1997). In addition, the presence of sand is associated with a need for more frequent maintenance on mill equipment. This ultimately has a negative impact on the profits made from sugar production. Filter screen blockages and the severe jamming of agitators are other problems that are frequent, if mud is part of the consignment that is brought into the mill for crushing (Wienese and Reid, 1997).

Rocks and boulders, examples of foreign matter, can also be delivered with the cane and this has serious consequences. A boulder can damage mill knives and this requires immediate attention, inducing a mill stop.

In addition to the financial losses due to breakdowns, soil in the juices result in the deterioration of sucrose levels, due to mill stoppages (Dedekind, 1965). Even though the presence of soil in sugar juices has many disadvantages, Godshall *et al* (2002) found that cane juice colour significantly decreased, when soil was added. These observations run contrary to the expectation that soil will degrade juice quality.

There are measures that can be taken to reduce the impact of soil in cane. The most effective way is to remove the soil manually during the harvesting and loading processes but this is very difficult. In addition, keeping the loading zones clean and well drained, as well as cutting and bundling the cane instead of leaving it spread on the ground helps to reduce soil content accumulation. This is more difficult during the rainy season, but it helps to some extent. Dry cleaning and wet cleaning methods have also been used (Wienese and Reid, 1997). Dry cleaning involves blowing soil and extraneous matter with pressurized air. Wet cleaning uses water to wash away any soil. Another measure that might result in less soil at the mill would be to reduce the LOMS to avoid the wet winter months.

2.7 No-cane Stops

A no-cane stop is a scenario that brings the mill to a halt due to the unavailability of sugarcane. No-cane stops can result from labour absenteeism, growers not meeting their allocations, unreliable transport systems and wet weather (Thomson and Turvey, 2004; Kadwa *et al.,* 2012). Wet weather is one of the major causes of an inconsistent cane supply to the mills (Boote *et al*., 2011; Kadwa *et al*., 2012; Kadwa, 2013).

The supply chain in Australia allows for expected disruptions due to weather (Kadwa, 2013). Severe cases of rainfall may have devastating impacts and complications across the supply chain of sugarcane (Higgins, 2006; Bezuidenhout *et al.*, 2013). Weather conditions determine the length of the harvesting period. Lengthy periods of rainfall reduce the number of days for harvesting, especially for countries that rely mainly on mechanical harvesting such as Australia (Higgins and Muchow, 2003).

No-cane-stops result in financial losses due to the deterioration of cane, depending on the length of the stop. Deterioration of cane only happens if the cane is already harvested. Dedekind (1965) found that after a factory shut down of four days at Sezela Mill, caused by a shortage of cane due to heavy rainfall, the filterability of sugars of cane that was at left uncrushed at the mill yard just before the shutdown dropped by 8.8%. This was an indication that the sugarcane deteriorated during the shutdown.

The problems of inconsistent cane supply and no-cane stops can, to some extent be mitigated by stockpiling (Barnes *et al*., 2000; Boote *et al*., 2011). Stockpiling also helps to maintain a 24-hour operation at the mill, especially if there are a few deliveries at night (Higgins and Davies, 2005). However, the stockpile should remain at a reasonable size because of cane deterioration (Grunow *et al*., 2007). Weekes (2004) suggests that a first-in-first-out protocol must be followed to lessen the deterioration of cane while awaiting crushing.

In Venezuela, the sugar industry also faces the problem of inconsistent cane supply and the deterioration of the stockpile (Grunow *et al*., 2007). Grunow *et al.* (2007) suggested an approach which aims at preserving a constant cane supply at the same time as minimising costs. The approach uses two software models to model the LOMS, using business processes and organizational structure as input parameters to solve the unforeseen problems that affect the LOMS.

2.8 Vehicle Scheduling

The transport system of the sugar industry in South Africa faces the challenge of inefficiencies in the loading and supply of cane to the mills. Hence, vehicle scheduling is of utmost importance, in order to identify the transport needs and then try to balance the needs with the available transport and to maximise vehicle utilisation. This is crucial for maintaining a consistency of cane supply and sustainability on the international market (Giles *et al*., 2005). Several studies have been performed on ways to improve the sugarcane transport system (Giles *et al.,* 2005; 2006; 2009). Giles *et al.* (2009) noted that the sugarcane transport system in South Africa is under-utilised, poorly coordinated and poorly managed. This results in distrust among the growers, millers and transporters, as well as unnecessary overcharging.

Giles *et al.* (2005) devised a vehicle scheduling system that favourably affected the transport rates and mill deliveries which potentially lowered the queuing times at the Sezela Mill on the South Coast, however it was not implemented. Such a system is very important for managing deliveries, especially under extreme conditions such as wet weather. In the absence of an efficient vehicle management system, the transport system is prone to more frequent no-cane stops, the under-utilisation of vehicles and long time-consuming queues (Giles *et al*., 2006).

Dines *et al.* (1999) developed a vehicle-dispatching program called FREDD, which was implemented at two sugar mills in New South Wales. FREDD uses a global positioning system (GPS) and wireless transmission to communicate actual time information to a control centre (Giles *et al*., 2006). The system involves the following:

a) GPS monitors fitted on all trucks,
b) updates on the cane stocks at the zones, using high frequency radio,
c) trucks that are scanned on the weighbridge and in the mill yard are tagged with a remote frequency identity, and
d) fast inter-computer communication with mill computers and weighbridge, using LAN facilities.

After a truck delivers cane, the FREDD system automatically updates and issues schedule instructions to the truck for its next delivery. Using the GPS information, the system automatically adjusts the schedule in the case of unplanned variations. It also updates the mill station computers, so that the crushing rate and delivery match (Giles *et al*., 2006).

When the FREDD system was implemented at the Darnall Mill in South Africa, improvements in the supply efficiency were seen and there was a significant reduction in the length and times of queue. However, due to the complexity of the supply chain, the FREDD system had to be customised to fit the supply chain needs of the South African mills before it could be implemented (Giles *et al*., 2009). The scheduling system was implemented at the Darnall (Tongaat Hulett), Maidstone (Tongaat Hulett) and Malelane (TSB) mills and it proved to be a success in South Africa. Vehicle delays and queues were significantly reduced. The system also improved vehicle utilisation and reduced the number of vehicles in the fleet. The occurrence and duration of no-cane stops decreased by as much as 50% (Giles *et al*., 2009). Feedback reports from the Maidstone and Malelane mills revealed that they were impressed by the fact that they could move more cane without adding more vehicles into the fleet, hence saving the industry a lot of money (Giles *et al*., 2009).

2.9 Discussion and conclusion

The goal of the sugar industry is to achieve maximum profits from the supply chain of sugarcane and sugar production (Hildebrand, 1998). One of the ways to maximise profits is for growers to deliver fresh cane, because this maximises the potential for sugar extraction. Hence, a very efficient supply chain system has to be in place. However, in reality there are avoidable and unavoidable factors that affect cane supply and cane quality, eroding away profits in the process. These factors include unreliable transport, harvest to crush delays and environmental factors, to name a few.

The impact of precipitation on sugarcane depends on the amount of rainfall, as well as the stage of growth of the cane. The review focused on cane lodging, waterlogging, limited infield access, the inability to burn, cane deterioration, soil in cane and no-cane stops. All of these can result in an inconsistent cane supply to the mill.

Heavy rainfall causes the cane to lodge. Large and heavy cane is more susceptible to lodging than small and poorly-grown cane. If cane lodges, it means that it is tall, heavy and usually mature for harvest. Therefore, it is best to harvest the cane immediately. However, harvesting lodged cane is a challenge, because it is very difficult for the cutters to move through the field with the cane lying in all direction and leaves tangled together. More severe rainfall events, accompanied by hailstones, are more damaging to sugarcane at any stage of growth. Cane damaged by hailstones is characterised by broken tops and shredded leaves. It is also best to harvest the cane immediately after the hail event, if the cane is mature enough.

Mobility is an important concept in the sugar industry, to ensure a sustainable and consistent cane supply. The onset of rainfall negatively affects the mobility of infield traffic. This is more severe for countries that only practice mechanical harvesting of their cane, such as Australia. Waterlogging also results from high rainfall amounts and, in this case, the whole soil profile is covered in water. This results in delays in the harvesting operations and if the wet weather persists, the LOMS might be extended due to these delays. Under such wet conditions challenges such as soil compaction are also prevalent. Suggestions such as using low pressure tyres have been made, however, it does not completely eradicate the problem of waterlogging and its damage to fields. There is still a need for further studies, to find ways of reducing the impact of waterlogging that are economical in most environments that experience this challenge.

Most sugarcane growers in South Africa burn their cane before harvesting. Burning is done to remove leaves and, under wet conditions, burning cane properly is difficult. This delay in burning means harvesting is also delayed, until the conditions become favourable. If the wet weather persists, the mill might experience cane shortages and eventually a no-cane stop. The review discussed an alternative that not many South African growers practise, namely, “green cutting”. This alternative method helps maintain the supply to the mill and reduce the occurrence of no-cane stops.

The quality of sugarcane is very important for profitable sugarcane growing, especially in South Africa, where growers are paid according to the recoverable sugar and sucrose in their cane. Cane deterioration is mainly indicated by the juice purity, dextran level and recoverable sugar in the cane. Wet weather and high temperatures increase the rate of cane deterioration and deplete the quality of juices. The review also showed that mud from wet weather creates favourable conditions for *Leuconostic* bacteria that produce dextran by using up sucrose in the cane. Soil in cane does not only aid with deterioration in cane, it is also responsible for the wear and tear of hammers, knives, mill rollers and corrosion of tanks. This increases the occurrence of mill breakdowns and the need for more frequent mill maintenance.

Another major disruption that results from persistent wet weather is no-cane stops. No-cane stops result in financial losses for the mill because it is expensive to keep the mill running with a shortage of cane and even more expensive to shut down and start up again at regular intervals. The review investigated a very effective method that helped reduce inefficiencies in the loading and supply of cane in Australia, and later in South Africa, namely, the FREDD vehicle scheduling system. The FREDD system brought about significant reductions in the length and number of queues. The system also improved vehicle utilisation and reduced fleet size.

All the issues highlighted in this review form a complex network that reduces profits in the supply chain of sugarcane. To improve the supply chain operations, Boote *et al*. (2011) developed a stockpiling stochastic model that successfully modelled the factors that affect the supply chain. The following sections outline more detail about the LOMZI model.

3. A STUDY OF SEZELA AND UMZIMKULU MILLING AREAS

This section provides an overview of the areas, Sezela and Umzimkulu milling areas. These areas are found on the South Coast of the KwaZulu-Natal province in South Africa.

3.1 Introduction

The South Coast of KwaZulu-Natal stretches from Durban South to the start of the Eastern Cape wild coast. Sezela and Umzimkulu milling areas are part of the South Coast which is characterized by sandy beaches, popular tourist attractions and vast golf courses. There are agricultural activities as well and most of it is sugarcane farming. The LOMZI project only focuses on the mills in the Sezela and Umzimkulu areas.

The South Coast terrain consists largely of steep topography with an altitude of about 400-500 meters above sea levels, and generally low soil fertility (SASRI, 2015). The rainfall season usually starts from October and continues until March. The South Coast receives a mean annual rainfall of about 864 mm and the temperature of the area ranges from $21 - 25$ ℃ (SASRI, 2015).

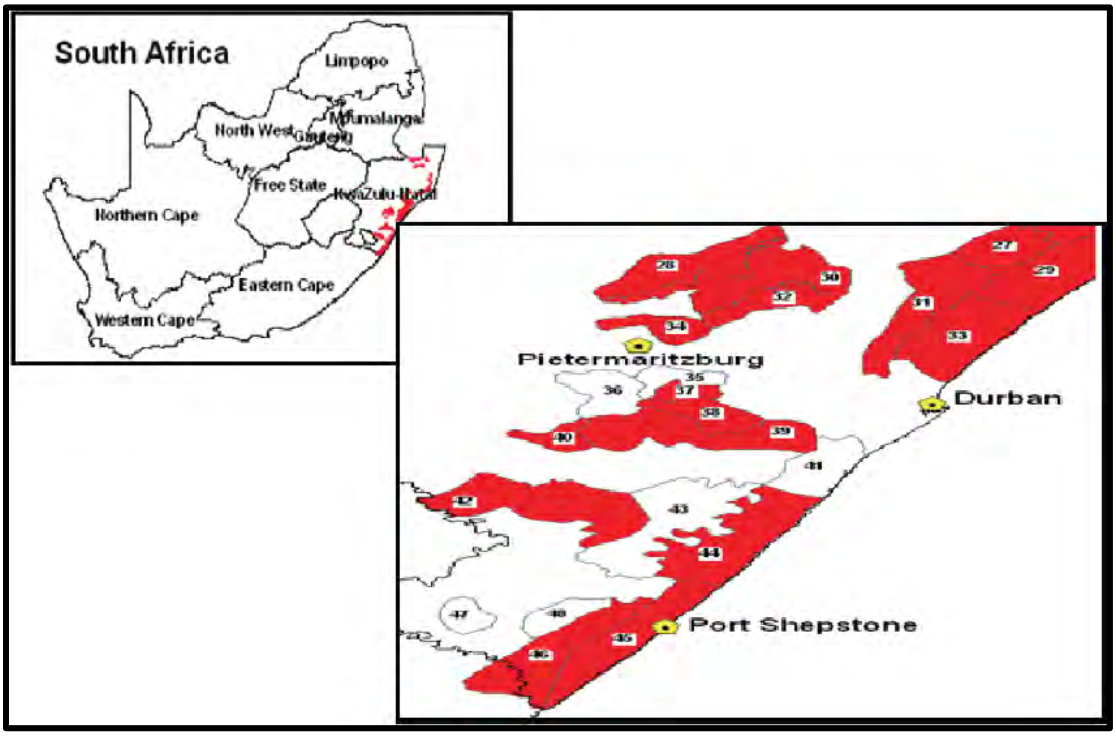

Figure 3.1 Map of homogenous climatic zones in the KwaZulu-Natal province (SASRI, 2014)

Figure 3.1 is a map of the KwaZulu-Natal homogenous climatic zones (HCZ) as indicated by numbers. The areas that fall under Sezela milling areas are numbered 41, 42, 43, 44 and these are Illovo, High flats, Dumisa and Sezela respectively. The Umzimkulu milling areas are indicated by 45, 46, 47, 48 which are Umzimkulu Coastal/North Bank, Paddock, Hluku/Nqabeni and Oribi respectively. The map shows that Illovo, Sezela and North Bank are on the coast. High Flats, Oribi and Hluku are inland. Lastly Dumisa and Paddock are the hinterland.

The aim of this section was to carry out the objective of the project to perform blind surveys to identify issues affecting the length of milling season at Sezela and Umzimkulu milling areas. The subsections that follow illustrate how the surveys were performed and how the results were represented as theme networks maps. Some of the issues that were highlighted include wet weather, labour shortage and harvest-crush delays.

3.2 Survey Structure

Fifteen different stakeholders at each milling area were contacted to perform semi-structured telephonic interviews. These stakeholders were selected and they represented important parts of the supply chain of sugarcane from the field to the mill. Interviewees had to have at least 2 years' experience in their roles. They ranged from small-scale growers growers, transport contractors and Mill Group Board members.
Each interview lasted about 25 minutes and addressed two main questions, which were:

- What is your role in the milling area?
- Looking at the mill from a holistic view, what according to you, are the main areas that are causing inefficiencies and eroding profits in the supply chain of sugarcane?

The interview was conducted by Prof Carel Bezuidenhout and the author. The conversations were recorded with the permission of the interviewee first. This later helped when analysing the information and pinpointing the important issues affecting the mills. Before the whole process began, an ethics clearance was provided by the University of KwaZulu-Natal.

The data from the interviews was analysed and incorporated using the Theme Network and Domain Network approaches developed by Bezuidenhout *et al*. (2012). This was important as it gave a picture of the issues affecting the mills, and how they are interlinked. The networks also aided in identifying the major issues that drive the LOMS.

To develop the theme networks maps for the Sezela and Umzimkulu milling areas, a few steps had to be followed. Firstly, the issues from the interviews were compiled into a list. For example, an interviewee from Sezela mentioned that, “Our trucks are experiencing long delays at the mills in long queues hence we are not delivering as much consignments as we should to the mill because much time is spend on the queues”. This statement revealed that the main issues were, “harvest-crush delays”, “long queues” and “slow turnaround times”. Hence this is how the issues were identified and added to the list. After this, vertices for each issue were developed and connections between the vertices were done based on the principle mentioned earlier in this paragraph. Figure 3.2 showed that “wet weather” resulted in increased “mud and sand” in the consignments which resulted in “poor cane quality” being delivered and eventually “low payloads”. This is because the growers were paid based on the sucrose content from their cane, so having mud and sand reduced the sucrose content, hence low payments.

The networks were energised using transformations by Kamada and Kawii (1989) in a software called Pajek. The central issues that had many connections such as, “inconsistent cane supply” were represented by large vertices as indicated on the maps in Figures 3.2 and 3.3. The system also placed closely together vertices that were directly linked. The detailed report of results from the interviewees that was presented to the mill group board members to provide feedback about their milling areas is shown in the section that follows.

3.2.1 Sezela

The length of milling season is mainly being affected by the low crushing rate of the mill and the inconsistent cane supply. The issues were put in 4 categories as shown in the map, namely field issues, transport and mill issues, cane quality and cane supply issues.

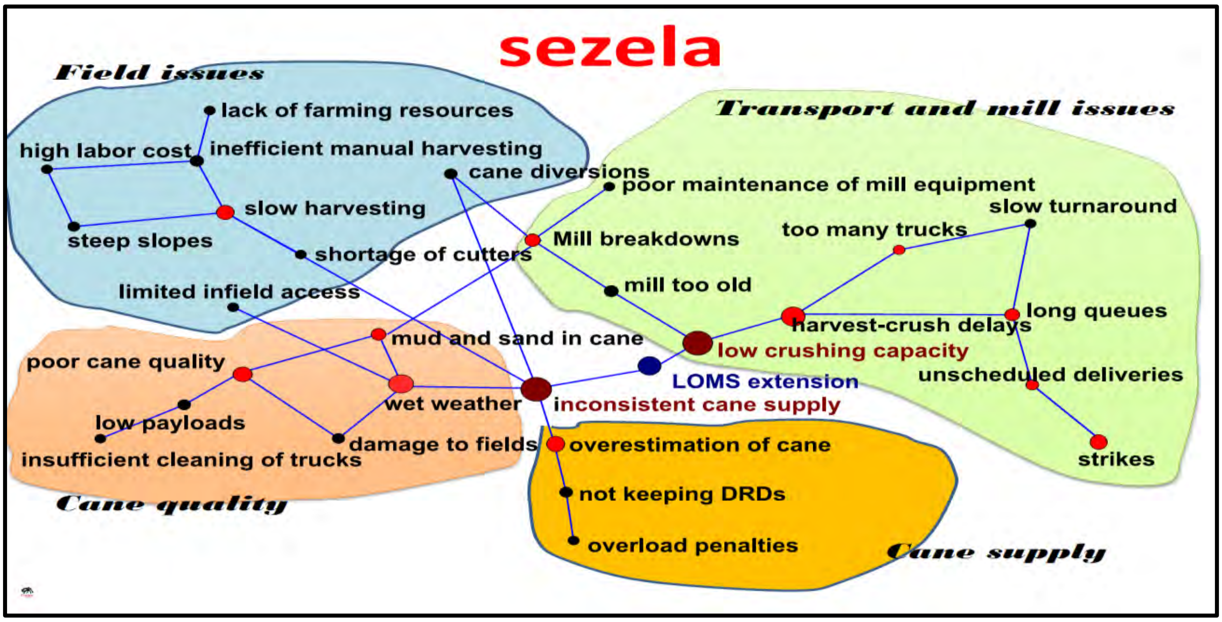

Figure 3.2 Sezela milling area theme networks map.

The theme networks above shows the issues that were emphasized at Sezela milling area during the interviews. The issues are represented by dots on the map. The size of the dot shows the amount of emphasis that was placed on the issue during the interviews, the bigger the dot the more emphasis was placed on the issue by different people. The main categories are discussed below.

3.2.1.1 Field issues

The growers are mainly being affected by the shortage of manual labour. Due to the mostly steep topography of the Sezela area, it is difficult to use mechanical harvesters in the fields (Bezuidenhout, 2014). Therefore, manual labour is needed to harvest the sugarcane. This also imposes financial strains on the growers because manual labour is not only expensive but it is also slow (Meyer and Fenwick, 2003).

3.2.1.2 Transport and mill issues

Transport and mill issues are mainly affecting the mill throughput, which in turn is affecting the length of milling season in the area. Growers are not delivering cane on their schedule and this is causing long queues at the mills. Long queues are also caused by the system being over fleeted, as too many trucks in the system results in slow turnaround times. Strikes were the major issue affecting the sugar industry during the time of this study, and were one of the causes of harvest to crush delays. Mill breakdowns and poor maintenance of mill equipment were also reducing the efficiency of the mill.

3.2.1.3 Cane quality

As stated in section 2, wet weather during the cane cutting process had a huge impact on the quality of sugarcane delivered at the mill. Wet conditions increased the amount of sand and mud being delivered to the mill as part of the consignment. Mud and sand reduced the cane quality due to dextran production in the cane. Poor cane quality resulted in lower payloads for the growers. Wet weather caused damage to fields due to soil compaction which reduced the productivity of the soil.

3.2.1.4 Cane supply

Growers were overestimating their yield estimates in order to get larger time allocations for supplying the mill. As a result, they failed to keep to the daily rateable delivery (DRD) amount that was allocated to them. In addition, to avoid penalties for overloading, growers are not keeping to the DRDs, and instead under loading their trucks. All of this is causing inconsistent cane supplies, which is one of the reasons for extending the length of milling season.

3.2.2 Umzimkulu

The length of milling season extension was mainly being caused by inconsistent cane supplies and the slow crushing rate at the Umzimkulu mill. The issues are categorized into 4 groups which are cane quality, cane supply, field issues and mill issues.

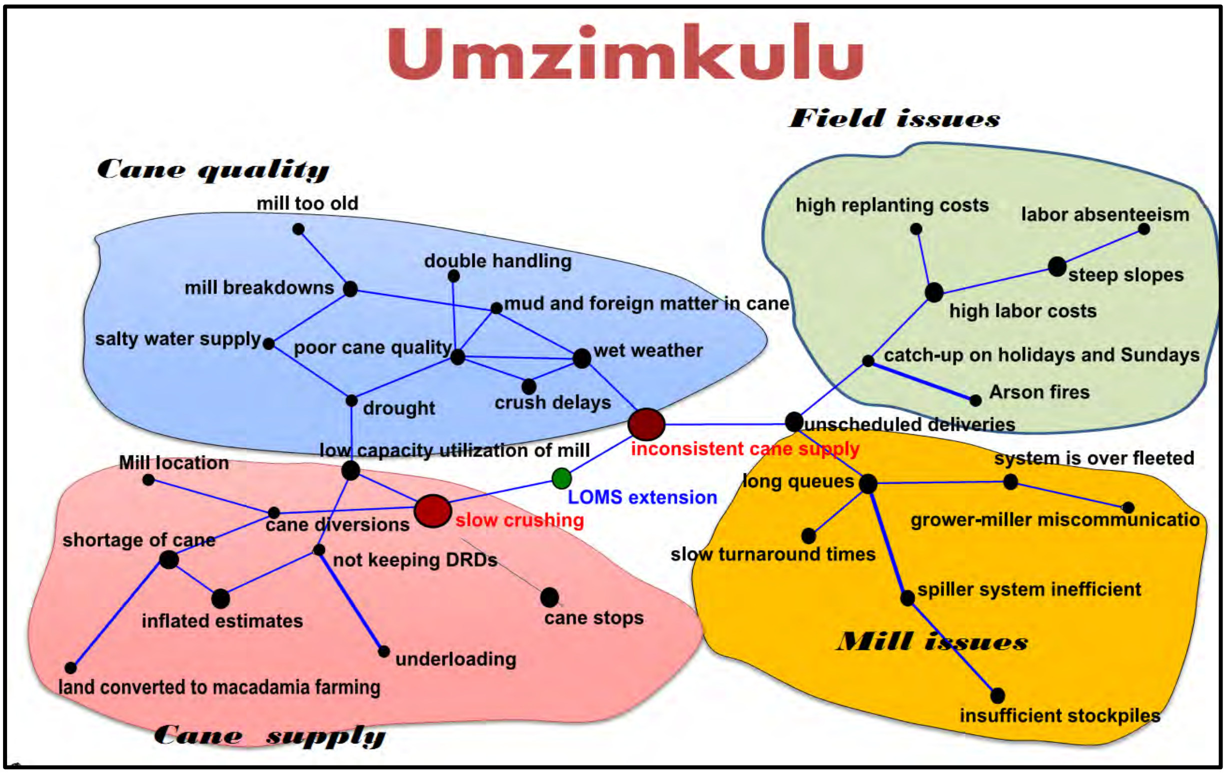

Figure 3.3 Umzimkulu milling area theme networks map.

Figure 3.3 above shows the results that were obtained after interviewing different stakeholders from Umzimkulu milling area. The main categories are discussed in detail below.

3.2.2.1 Field issues

Inefficiencies in the supply chain began in the field. Some parts of the Umzimkulu area are characterised by steep slopes, so mechanical harvesting would not be favourable on such terrain. Therefore, manual labour is required to harvest the cane. However, the shortage of labourers in the area and their high wages resulted in growers not replanting as often as they should.

3.2.2.2 Cane supply

Inefficient cane supply reduced the crushing rate at the mill. One of the major issues affecting the supply of cane was the diversion of some of Umzimkulu's cane to the Sezela mill. Growers sometimes overestimated cane quantities and ended up under loading and not keeping to DRDs. Other enterprises are growing in the area and some of the land is being converted to macadamia farming and tourism. All of these issues resulted in the shortage of cane and the mill not being utilized to its full capacity.

3.2.2.4 Mill issues

The system was over fleeted with too many trucks that bring cane to the mills, caused mainly by miscommunication between growers and the miller. This resulted in long queues and slow turnaround times for the hauliers. The spiller system that the mill used resulted in a stockpile at the mill yard insufficient to maintain a 24 hour operation, which again created long queues.

3.2.2.5 Cane quality

Wet weather during the harvest season affects the quality of the cane, and the fields become inaccessible to machinery and labourers. This results in delays in harvesting and the cane deteriorates, especially if it has already been burnt. The mud in the cane increases the deterioration due to dextran accumulation. Rocks and foreign matter increase the chances of mill breakdown and the maintenance reduces profits. Sometimes there are seasons of drought and the sugarcane produced is of poor quality.

3.3 Summary of Survey

At the feedback sessions at Sezela and Umzimkulu with the Mill Group Board members, the maps were thought to be very useful and there was agreement concerning issues represented on the maps approved of. The board members agreed to cooperate and provide data needed for the next phase of the project. After the survey was done, it was time to embark on the modelling roadmap. The next section discussed how the crush rate and quality of cane was simulated using two separate models.

4. METHODOLOGY

LOMZI is a mill scale stochastic model that simulates the sugarcane supply chain from the time of harvesting to the delivery of cane at the mill yard. The original version of the LOMZI model was developed by Boote *et al*. (2011) and later improved by Jenkins (2013). Boote highlighted that stockpiling sugarcane outside the mill would be a major disadvantage, especially when taking into account the issue of cane deterioration. The goal of the model was to simulate the amount of sugarcane crushed and produced information that aided decision makers about seasonality and variability that may influence planning for the length of the milling season. Daily records of crush rate, rainfall and temperature and cane quality were used to calibrate the model and improve its ability to predict the daily sugarcane crushed. Other factors that can also be modelled include strikes, transport capacity, and pay weekends. The section that follows provides a description of the structure of the LOMZI model.

4.1 LOMZI model structure

The LOMZI model assumed that for a particular season, the total amount of sugarcane to be harvested remained constant throughout the season. Sugarcane was cut and arranged in a stockpile in the field. Depending on the operations of the mill supply area (MSA), the cane was either extracted to a loading zone or it was delivered directly to the mill. The model simulated the daily extraction capability which determined the amount of cane to be extracted from the infield stockpile. In addition, the amount of sugarcane delivered at the mill was controlled by the simulated transport capability of that particular day. Figure 4.1 shows a diagrammatic representation of the movement of sugarcane from the field to the mill yard.

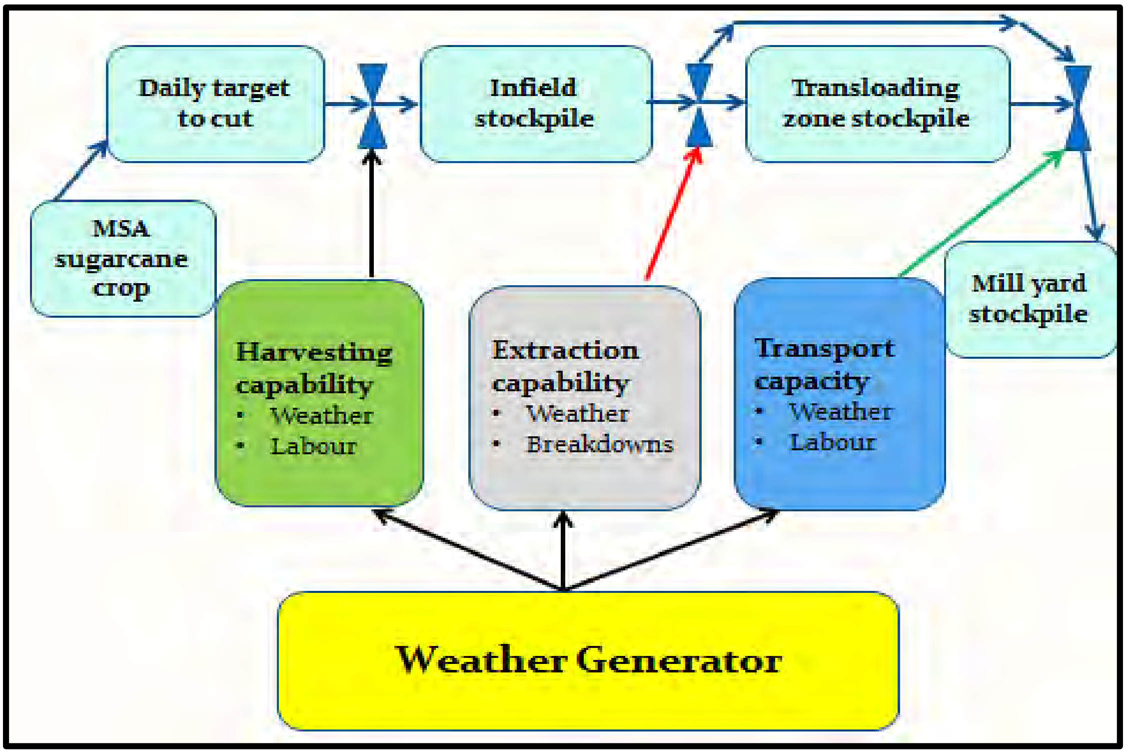

Figure 4.1 LOMZI model supply line framework (Jenkins, 2013)

Figure 4.1 shows that weather conditions played a pivotal in the supply line of sugarcane. The weather generator in the diagram is linked to the harvesting, extraction and transport capabilities. Weather conditions experienced at the mill have a significant impact on the supply line of sugarcane (Higgins and Davies, 2005). The weather generator ensures consistency in the model, for example, on a particular day rainfall should reduce the harvesting and extraction capabilities. Figure 4.2 represents the overall structure of the LOMZI model when applied to a mill supply area.

The total sugarcane harvest is divided amongst different supply lines of a MSA. The supply lines represent several zones with similar characteristics. There are different possibilities that exist for dividing a mill into supply zones such as rainfall and temperature, different ownership and management structures.

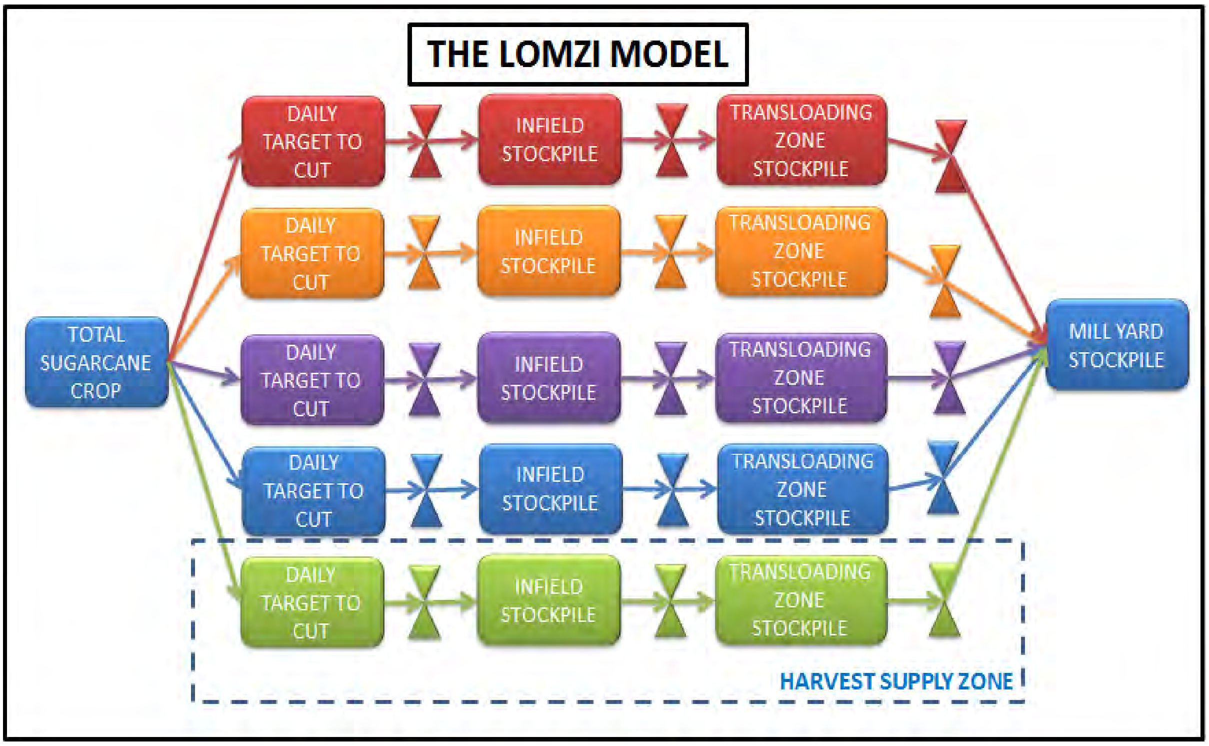

Figure 4.2 LOMZI model structure for a MSA (Jenkins, 2013)

For each harvest zone, the model simulates and records the daily tons of sugarcane cut, extracted and delivered to the mill. The model aims to simulate real life situations of a mill supply area. The model also gives a detailed accounting of the total cane delivered to the mill. It displays the days of the planned season as well as the tons of sugarcane left to cut. A daily budget of cane cut, extracted and delivered is recorded along with the daily size of the stockpile at the mill yard.

4.1.1 Weather generator

The LOMZI model requires realistic daily rainfall and temperature, hence there is need to include a weather generator into the model. There are several types of weather generators that predict different weather parameters. For the LOMZI project, the ClimGen weather generator was chosen to predict daily rainfall and temperature. This generator is appropriate because it is user friendly and is applicable to any location in the world (McKague *et al.,* 2003).

Rainfall and temperature are some of the key factors that drive the length of milling season. (Boote *et al.,* 2011; Singels *et al.,* 2012). A stochastic weather generator is defined as a mathematical model that uses historical weather data to develop a time series of synthetic climate data (Ndoro, 2014). When applied to a specific area the output from a weather generator is supposed to be similar to the actual observed climate data of the area (Kevin *et al*., 2005; Semenov, 2002). The weather generator requires actual input weather data to calculate statistical properties such as, standard deviation, variance, frequency, and daily mean. The input data and statistical properties are then used to produce new synthetic weather data (Safeeq and Fares, 2011; Ndoro, 2014).

Temperature values are calculated from a continuous multivariate stochastic process. The process also determines the daily means and standard deviations by the dry or wet state of the day. Wet and dry days are generated by a first order Markov chain and values for precipitation are generated using a Weibull distribution (Stöckle *et al.,* 1999; McKague *et al.,* 2003; Safeeq and Fares, 2011).

4.1.2 LOMZI model data

Sugarcane quality and crush rate data for the South Coast sugar mills, Sezela and Umzimkulu, were provided by the Cane Testing Services Manager (Naidoo, 2014) and Autolab (Ramuhuyu, 2014). This was after the respective Mill Group Boards granted the permission to obtain the data from Cane Testing Services (CTS). CTS provided daily averages of cane deliveries, Pol%, Brix% and Fibre% of cane for the 2007 to 2013 seasons. Diverted cane delivery and quality data to Sezela and Umzimkulu was not used to calibrate the model, but only data of cane that originated from the mills was used in the project.

On the South Coast, the cane supply area was divided into three climatic regions, namely coastal, hinterland and inland. These three regions experience different climatic conditions; hence, the cane grows and matures at different rates. The seasonal data was randomly divided into two groups for model calibration and verification purposes at each mill. For Sezela Mill, the 2007, 2009, 2011 and 2013 seasons' data were used to calibrate the model. The remaining seasons, 2008, 2010 and 2012 were used to verify the accuracy of the model. For Umzimkulu, 2007, 2008, 2010 and 2013 seasons were used to calibrate the model, then 2009 and 2012 were used to verify the model. Umzimkulu data had 2011 missing because all the cane from Umzimkulu was diverted to Sezela.

The temperature and rainfall data for Umzimkulu and Sezela Mill areas were obtained from the SASRI Weather Web (SASRI, 2015). The SASRI Weather Web provided rainfall and temperature readings from different weather stations and in the mill supply area the rainfall and temperature were an average of the weather stations' recordings.

4.2 Research method

This section of the project consists of seven main sections that formed the LOMZI model. Even though the quality and crush model both require rainfall as one of the major input parameters, they are presented in this section separately. This is because the models were developed separately and had different functions. The quality and crush models are more like sub-models making up one model. Hence, the models were best presented separately. Another component that was used in the model was the K-NN nearest neighbour technique. This technique was used to synthetically generate weather data to fill in the missing gaps in the actual historical weather data sets for the areas of study.

4.2.1 Quality model description

The main inputs in the quality model were the historic records of daily rainfall, temperature and quality data of the mill supply area. The model simulated the cane quality and took into account relationships between cane quality and short term and long-term rainfall. There is a strong relationship between cane quality and recent rainfall and temperature (Inman-Bamber *et al*., 2002). The key quality indicators that are used in the sugar industry are the Pol%, Brix%, and Fibre%. These three terms are defined in Table 4.1 and it also shows how they are related to rainfall (Rein, 2016).

Table 4.1 Definitions of the quality indicators

Quality Parameter	Definition	Relation to Rainfall
Brix%	Total solids present in the juices expressed as a %	High rainfall = Low Brix%
Pol%	Total sucrose content in the juices as a %	High rainfall = Low Pol%
Fibre%	Residue after extraction of sugar juices	High rainfall = High Fibre%

Brix is a measure of solids (sugars and non-sugars) present in the sugar juices. Pol is the actual sucrose present in the sugar juices. As rainfall increases, Brix and Pol values decrease because the sugarcane plant starts to grow. When a cane plant grows it uses up sucrose and sugars stored in the plant. Hence, the fibre content increases. Fibre is the dry fibrous insoluble structure of the cane plant.

The quality model estimates the average Pol%, Fibre% and Brix% of cane on a daily time step, based on the preceding 10 weeks of rainfall and temperature records of the mill supply area. The model uses inputs of daily rainfall of the previous seven days and weekly average rainfall of the previous 10 weeks, based on the drying off recommendations approach (Donaldson and Bezuidenhout, 2000). According to Sibomana and Bezuidenhout (2013), the cane quality varies depending on the day of the week. Therefore, the model has a day-of-the-week adjustment factor.

Weather has long term and short term effects on the quality of sugarcane, in particular Malik and Tomar (2003) noted that cane quality is, to a large extent, dependent on recent rainfall events. The literature review revealed that disruptions on the supply chain due to wet weather include limited infield access of traffic, delays to burn and harvest and crop lodging.

The quality model comprises of three components, namely, rainfall, temperature and other variables. The rainfall component can be further subdivided into the effective precipitation for a day and the effective precipitation for a week. Altogether the rainfall component is calculated by:

$$Rainfall = \sum_{d=0}^{6} \propto_d PF_d + \sum_{i=1}^{10} \gamma_i \bar{P}_i \quad (4.1)$$

Where $\propto_d$ (mm^{-1}) is the calibrated weighing factor for day d in week 0 (where day of prediction $d = 0$, to up to six days before $d = 6$. PF_d (mm) is the effective precipitation for day d in week 0. γ_i (mm) is the calibrated weighing factor for week i. $\bar{P}_i$ (mm^{-1}) is the average daily effective precipitation for week i

After a rainfall event, not all the rain drains into the soil, some is lost to surface runoff, interception and evaporation (McGlinchey, 1998). The sugarcane plant has a limit on the amount of water that it is able to use. Hence, the term PF_d refers to the fact that the cane is unable to use all the rain.

The model uses a threshold of the amount of water that the cane uses after each rainfall event and this maximum is indicated by the terms PF_{max} and P_{max}. For example, assuming that for a certain mill scale area, the effective precipitation is 10 mm, if the area receives 100 mm of rainfall, the model recognises it as 10 mm of rainfall. Based on empirical investigations there is no lower limit of the effective rainfall. The equation 4.2 shows the effective rainfall for a day in week 0:

$$PF_d = \begin{cases} P_d & |P_d < PF_{max} \\ PF_{max} & |P_d > PF_{max} \end{cases} \quad (4.2)$$

where, P_d is the total rainfall in mm. PF_{max} is the daily effective rainfall limit in week 0, also measured in mm. The weekly effective average rainfall is given by:

$$\bar{P}_i = \frac{1}{7} \sum_{j=0}^{6} \begin{cases} P_j & |P_j < P_{max} \\ P^* & |P_j > P_{max} \end{cases} \quad (4.3)$$

Where, P_j of rainfall on day j of week i is measured in mm. P_{max} is the effective rainfall threshold during weeks 1-10 (mm).

Warm temperatures above 10°C are essential for proper growth of sugarcane. To achieve maximum quality of cane, sugarcane requires temperatures above a certain limit. The model uses heat units to quantify the average amount of heat the cane receives and uses per day. The average effective daily heat units $\overline{HU_i}$ for week i is given by:

$$\overline{HU_i} = \frac{1}{7}\sum_{j=0}^{6}\begin{cases} T_j - HU_{base} & |T_j > HU_{base} \\ 0 & |T_j \leq HU_{base} \end{cases} \qquad (4.4)$$

Where: T_j : average temperature for day j in week i (°C)

HU_{base} : a calibrated base temperature (°C)

and $T_j = \frac{T_{max} + T_{min}}{2}$

4.2.2 Crush model

The crush model simulates the amount of cane crushed at a particular mill per day and is based on recent rainfall events that the mill experiences. The crush rate per day was calculated as follows:

$$C_i = \left(MC_i - \left(\sum_{z=0}^{n} R \propto_z \right) \right) \times \theta_{DOW} \qquad (4.5)$$

Where

C_i : Potential total tons of sugarcane crushed index for day i ($t.d^{-1}$)

MC_i : Calibrated maximum tons of cane crushed on any given day ($t.d^{-1}$)

z : Corresponds to the homogenous climatic zone for each mill.

$R \propto_z$: Rainfall reduction value for HCZ z on a particular day i (t.d^{-1})

θ_{DOW} : An adjustment determined by the day of the week (%)

The value of the maximum tons of cane crushed per day (MC_i) component of the equation differs from mill to mill and in the crush model, Solver was used to determine this. Solver is a Microsoft Excel add-in that finds solutions to mathematical problems (Frontline Systems, 2014). The model was calibrated using the Generalised Reduced Gradient (GRG) non-linear function in Solver within Microsoft Excel. The GRG algorithm is used by Solver to optimise non-linear problems (Frontline Systems, 2014). The function uses advanced algorithms to find globally optimum solutions to problems. Each calibration was performed 100 times, using random initial resampling points.

The crush rate is also dependent on the day of the week. This daily fluctuant constant takes into account the fact that weekly dynamics, such as pay weekends and mill maintenance schedules, affect cane supply. This is called the day of the week adjustment θ_{DOW} (%). This factor is based on the historical pattern that the mill follows when it comes to crushing each day of the week. The idea of the day of the week factor is supported by Sibomana and Bezuidenhout (2013) who found that at Felixton sugar mill the crush rate followed a weekly pattern. The adjustments were represented by θ_1 for Sunday, θ_2 for Monday, and so on.

The rainfall reduction $R \propto_z$ is the tons of sugarcane crushing lost for each mm of effective rainfall received in the different HCZs. For each zone, the model uses rainfall of the preceding 3 days. The amount of rainfall received in each HCZ for the current day, previous day and the day before yesterday [C_0, C_{-1} and C_{-2}] were used to determine the impact on mill operations. This is important because recent rainfall events do affect components of the supply chain such as burning, harvesting and transporting sugarcane. The rainfall reduction value $R \propto_z$ (t.d^{-1}) for each zone was determined according to Equation 4.6:

$$R \propto_z = \sum_{i=0}^{-2} ER_i \times C_i \tag{4.6}$$

Where

$R \propto_z$: Is the rainfall reduction value for HCZ z day i (t.d^{-1})

ER_i : Is the effective rainfall value for day i (mm.d^{-1})

C_i : Is the calibrated rainfall factor for day i (t.mm^{-1})

Where, ER_i (mm) is the effective rainfall for day i. The effective rainfall was included in the crush model to try and predict the amount of rainfall disrupting the supply of sugarcane to the mill and the daily crush rate. As the amount (mm) of rainfall increases, the crush rate at the mill reduces. For example, when there is only 1 mm of rainfall only a couple of hundred tons of crush capacity are lost. But when 5 mm of rainfall, then maybe 1000 tons of cane crushed is lost because the farmers cannot deliver the sugarcane to the mill due to wet and muddy fields. However, there is a point when even if more rainfall falls, the crush rate is not reduced more than it is already. The model takes this into account by taking the rainfall threshold value if the zone rainfall is above the threshold value. If the zone rainfall is below the threshold value then the model uses the zone's rainfall value. Equation 4.7 outlines how ER_i was calculated.

$$ER_i = \begin{cases} R_i, & R_i < R_{thresh} \\ R_{thresh}, & R_i > R_{thresh} \end{cases} \tag{4.7}$$

Where, ER_i is the effective rainfall value for day i (mm.d^{-1}), R_i is the actual rainfall amount received in each HCZ for day i (mm.d^{-1}) and R_{thresh} is the rainfall threshold value for the HCZ in question (mm.d^{-1}).

4.2.3 ClimGen

The LOMZI model used weather data imported from a stochastic weather generator called ClimGen. ClimGen is spatial weather generating software that makes it possible to model future climatic conditions at regional scale based on past weather patterns of the region (Osborn, 2015). For the LOMZI project, ClimGen was used because it is user friendly and can be applied in any area around the world as long as past records of weather data are available (Stöckle *et al.,* 2001; McKague *et al.,* 2003). ClimGen has been used for a variety of purposes. For example, Tingem *et al*. (2007) used ClimGen in Cameroon to model precipitation, temperature, wind speed, solar radiation and humidity. In Canada, Mckague *et al* (2003) used ClimGen to simulate rainfall and temperature successfully. ClimGen has also been used in South Africa to model wet and dry months and air temperature (Pasi, 2014).

ClimGen was designed to explore the uncertainties in future weather conditions. Temperature data is generated from an endless multivariate stochastic process and the daily mean and standard deviation are determined by the wet and dry conditions of the day (Jenkins, 2014). The Markov chain generates the wet and dry days in first order and the values for precipitation using a Weibull distribution (Stöckle *et al.,* 2001; McKague *et al.,* 2003; Safeeq and Fares, 2011; Jenkins, 2014).

Rainfall and temperature play a crucial role in determining the cane quality, growth, yield and length of the milling season (Weekes, 2004; Boote *et al*., 2011; Singels *et al*., 2012; Kadwa, 2012).

4.2.4 K-NN nearest neighbour

Incorporating synthetically generated weather data is important in an agricultural simulation model. To ensure reliable results, spatial and temporal output of a climatic model must be matched (Bannayan and Hoogenboom, 2008; Jones *et al*., 2000). The modelling roadmap for the LOMZI model led to the adoption of the K-NN nearest neighbour (K-NN) technique which was adapted by Lagerwall et al., (2015) for this study. The K-NN technique is a non-parametric technique that has been used in several prediction studies such as remote sensing and traffic forecasting (Bannayan and Hoogenboom, 2008). The K refers to the number of nearest neighbours that are under study. The K-NN method recognizes similar weather trends within the target file based on its historical observed weather data. The basic assumption of this method is that the actual observed weather during the target year, to some extent replicates that of the previous year.

For each mill, the main contributing homogeneous climatic zone was termed as the driving zone and the less contributing zones were called slave zones in terms of cane supply. The driving zone had to have a complete 25 years of weather data from 1989 to 2014. The K-NN technique synthetically generated a thousand years of rainfall, minimum and maximum air temperature for the driver zone of study. Using K-NN, similar datasets were generated for the neighbouring slave zones. The purpose of this was to retain the spatial correlation of the various zones. The missing data in any of the slave zones' data was filled out using that of the geographically closest zone as they experience more or less similar conditions. The observed weather data of the driving and slave zones was first arranged by the K-NN and then used by

ClimGen to simulate more weather data. Each day was compared to the actual days in the historical data until a closest match was found. After that, the rainfall and temperature of the match from the actual data became the simulated weather data for the slave zone for that same day.

4.2.5 Calibration and verification

The quality and crush models were calibrated for the Sezela and Umzimkulu milling areas. The quality model used average daily Pol%, Fibre% and Brix% values for both mills recorded from 2007 to 2013. Four years were then randomly selected for calibrating purposes and the rest for verifying the model.

The quality and crush models calibrated the GRG-non-linear approach in Microsoft Solver Excel with about 90 calibrating coefficients and 15 coefficients, respectively. The goal of Solver was to maximise the R^2 value between the observed and simulated crush quantity and cane quality. This was achieved by concurrently calibrating α_i R_i, R_d, z , n , C, PF_d, P_{max}, HU_{base}, α_d, γ_i, δ_i and θ_{dow} for each crush quantity and cane quality parameter. A total of 126 coefficients were calibrated for each mill.

As part of the verification procedure on independent data, the quality model had R^2 values ranging from 0.52 to 0.81. For the crush model the R^2 values ranged from 0.52 to 0.70. All the ranges mentioned were for both mills.

To determine the driver zone, quality calibrations were performed using Excel Solver to find the contribution of each zone or station. The quality parameters used in the calibrations were Pol%, Brix% and Fibre%. The major contributing zone's data was used to generate 1000 years using the ClimGen weather generator. ClimGen weather generator requires 25 years past records of rainfall, minimum and maximum temperature, solar radiation and minimum and maximum relative humidity.

Sezela area had three contributing zones namely Sezela, Dumisa and Illovo. Umzimkulu had for contributing zones and these were Hluku, Oribi, Paddok and North bank/Coastal. Calibrations showed Sezela to be the most contributing zone in terms of supply of cane to the mill. For Umzimkulu, North Bank was found to be the greatest contributor of cane to the mill. Therefore, the next step was simulating a thousand years of weather data using the weather generator, ClimGen. However, a challenge was encountered. The SASRI Weather Web did not have the full set of weather data for the Dumisa area and there were no other sources to obtain the data. Only Sezela zone had the full data set of 25 years. Hence, the K-NN nearest neighbour technique was then used produce weather data for the missing gaps for Dumisa using historic data of the neighbouring zones Sezela and Illovo.

For Sezela and Umzimkulu mill zones, it was a challenge to determine the most contributing zones. The weather data varied significantly because some of the zones are on the coast by the ocean, some are hinterland and some are inland but too far from the coast. For this reason, the zones experience very different weather conditions. Problems experienced with the non-availability of weather data could have had some implications on the accuracy of the model in predicting crush and sugar produced.

4.2.6 Calibrating the sugar produced

Daily crush rate and sugar made by the mill were some of the key results from this study. The daily amount of sugar produced at the mill was quantified in two forms. Firstly, the sugar produced was estimated using the Estimated Recoverable Crystal (ERC) formula. Secondly, the sugar produced was also quantified using a cane to sugar ratio. Van Hengel (1994) developed the ERC formula which is used to calculate the daily sugar produced at a mill. The formula expresses the relationship between the sugar quantity and the sucrose content in the cane in terms of crystal % cane. The ERC equation is illustrated below in Equation 4.8 (Van Hengel, 1994)

$$ERC\% = aP - bN - cF \tag{4.8}$$

Where

a	:	Recovery of sucrose from sugar production ($\%$)
P	:	Pol in sugarcane ($\%$)
b	:	Sugar lost during production per unit of non-sucrose ($\%$)
N	:	Non-sucrose in cane ($\%$)

c : Sucrose lost from sugar production per unit of fibre (%)

F : Fibre content in cane (%)

For this study, the values of a, b and c coefficients were acquired from literature (Munsamy, 2013). After calculating the ERC, the daily estimate of the sugar produced by the model calculated by Equation 4.9.

$$Daily\ sugar\ produced = \frac{ERC}{100} \times tonnes\ crushed \tag{4.9}$$

Where the daily sugar produced and tons crushed were measured in $t.d^{-1}$. The second form of quantifying the sugar produced was the cane to sugar ratio. The cane to sugar ratio is used by the mills to find out the proportion of sugar produced from the milled cane (Shange, 2014). For example, if a mill estimates a ratio of 9, it implies that the mill produces 1 ton of sugar from crushing 9 tons of sugarcane. The mills use this ratio and the ERC method to compare and quantify their sugar production. The cane to sugar ratios that were obtained from the results of this study, are presented in Section 5.4.

4.2.7 Validating the LOMZI model

After the LOMZI model had simulated the daily crush rate and sugar produced, there was still a need to check if the results were realistic. This was carried out by comparing the simulated data against the actual observed data. Since 7 years of data were used by the model, 4 years of the data were randomly selected to calibrate the model and the rest were used for the verification of the results. The comparisons were then expressed as graphs for both crush rate and quality as illustrated by Figures 4.3 and 4.4.

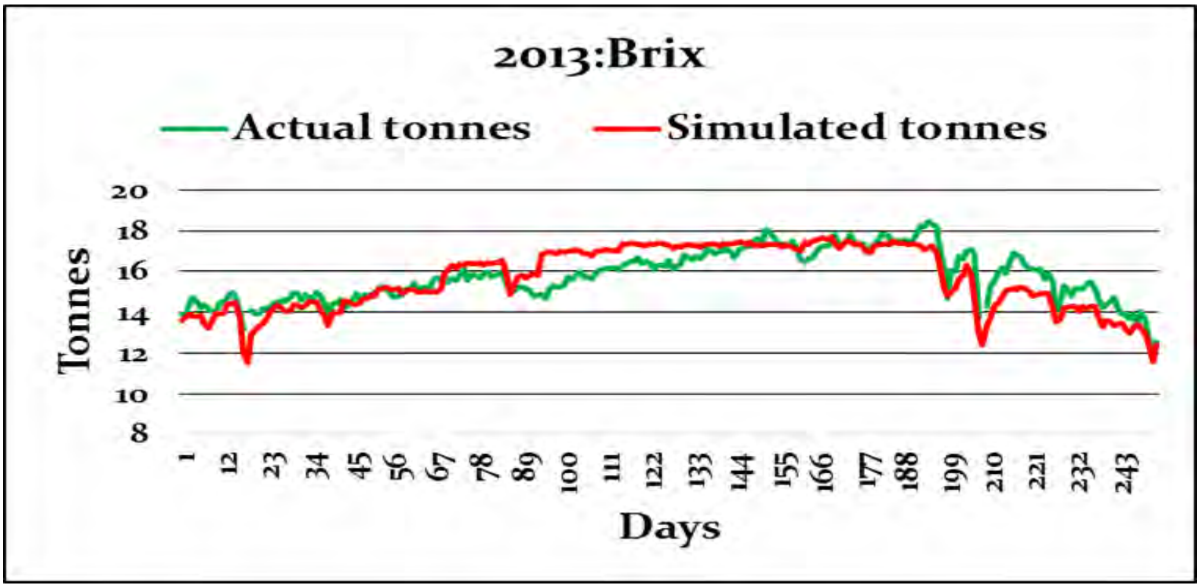

Figure 4.3 Actual and simulated 2013 brix data graph for Sezela mill

Figure 4.3 is a plot showing the simulated brix data plotted on the same axis as the actual observed brix data of 2013 for Sezela mill. There was an 80% correlation between simulated and actual data for the 2013 season for Sezela. The high correlation value suggested that rainfall was having a significant impact on the Brix component of cane quality at Sezela. The plot showed that the model performed well in following the patterns in the data. However, the model failed to pick or follow some of irregularities in the data that caused higher peaks and dips in the plots.

Figure 4.4 shows a plot that verifies the crush rate data from the model. Here, actual data for year 2012 season for Sezela was plotted on the same graph with the simulated data. A correlation of 58% was found between the simulated and actual data. This meant the model performed satisfactorily as shown on the plot. The model did manage to follow the trend in the actual data well. However, the model also did not perform well when it came to extremes such as peaks and dips in the actual data. These anomalies depicted in Figures 4.3 and 4.4 shows that this might have been due to the fact that apart from rainfall, there are other significant issues affecting cane quality and crush rate at the mills. Examples of these issues include mill yard delays, mill breakdowns, labour absenteeism due to pay weekends and harvest over estimations and under estimations (Kadwa, 2011).

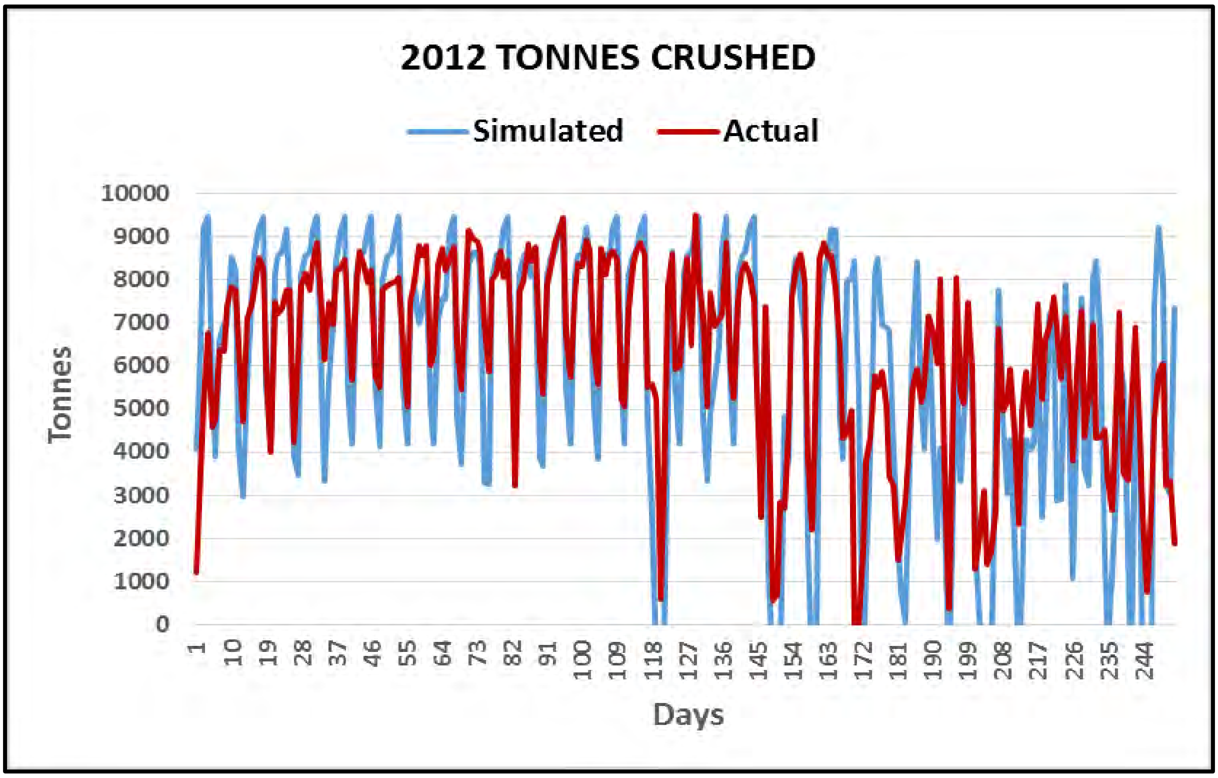

Figure 4.4 Actual and simulated 2012 crush rate graph for Sezela mill

Additional statistical validations were performed to further verify the performance of the model in terms of the crush rate and sugar made results. The validations included comparing the mean, standard deviation, minimum and maximum between the simulated and actual data. Tables 4.2 and 4.3 represent the statistical properties of observed and simulated daily tons crushed, and sugar produced for both mills. The model error that is indicated in both Tables was calculated as indicated in Equation 4.10.

$$\%Error = \frac{|O - S|}{O} \times 100\% \qquad (4.10)$$

Where, O is the observed quantity and S is the simulated quantity. The highest values in Tables 4.2 and 4.3 were for the standard deviation values for the Sezela mill. This showed that a large percentage of values in the data were significantly dispersed away from the mean values. This meant that there were extreme variations in the data. However, the model performed well in reproducing the mean and maximum values for all the mills.

Table 4.2 Evaluation of the LOMZI model for all crush data (tons)

		Maximum	Minimum	Mean	Standard Deviation
Umzimkulu	Observed	8 684.08	0.00	5 277.73	2 207.17
	Simulated	4 667.64	0.00	3 806.45	897.83
	% Error	46.25	0.00	27.88	59.32
Sezela	Observed	15 843.38	0.00	7 565.29	2 946.01
	Simulated	9 237.56	0.00	6 099.07	2 557.82
	% Error	41.69	0.00	19.38	13.18

Table 4.3 Evaluation of the LOMZI model for all sugar data (tons)

		Maximum	Minimum	Mean	Standard Deviation
Umzimkulu	Observed	4 497.11	1.02	699.00	990.89
	Simulated	814.58	0.00	556.07	149.42
	% Error	81.89	0.00	20.45	84.92
Sezela	Observed	1 554.02	5.20	885.34	305.40
	Simulated	1 648.44	0.00	994.29	425.12
	% Error	6.08	0.00	12.31	39.20

The model generally performed well in simulating the data for Sezela and this is indicated by the low percentage differences. The high values of percentage differences indicated in the tables showed that the LOMZI model performed poorly in simulating the data mainly for Umzimkulu for both the crush and sugar quantity. As stated by Ndoro *et al*. (2015), this is most likely because the South Coast homogenous climatic zones are separated into three different areas, which are inland, coastal and intermediate. The three zones experience completely different weather conditions, especially rainfall. Hence, the variability in rainfall might have resulted in the model producing less accurate predictions. In addition, the length of the milling season of the South Coast mills is greatly affected by other issues such as harvest-to-crush delays, transport inefficiencies and poor cane quality. These tie with the challenges that were mentioned in the methodology, section 4.2.

4.2.7.1 Developing the probability of exceedance profiles

After validating the feasibility of the results, exceedance graphs were then drawn up to present the crush rate in tons and sugar made in tons for the 1000 seasons that were simulated. Firstly, the weekly crush rate and sugar made were calculated by summing up data for every seven days. The weekly data was then tabulated into exceedance tables. Figure 4.5 is an exceedance table for crush rate results for Sezela sugar mill. The numbers on the topmost row of the table represent the weekly crush rate that the mill can choose to operate at. For example, depending on availability of cane and other factors the mill can choose to crush 15000 tons per week or 20000 tons per week and so forth. The first column on the table represents the 52 weeks within a 12 month season. The dates on the column are for every seventh day of every week.

The numbers in the profile can be represented in two forms. The first form is shown in Figure 4.5 which shows columns of numbers between 0 and 1000. These numbers represent the 1000 seasons that were simulated by the LOMZI model. For example, the number in Figure 4.5 highlighted by a circle means that 906 of the 1000 seasons that were simulated by the model resulted in the mill crushing 40000 tons of sugarcane in week 24 of the season. This is the same interpretation that goes for the exceedance profile for sugar produced.

The numbers in the exceedance profile can also be presented in another form as percentages. The percentage numbers depicted in Figure 4.6 represent the chances of the mill achieving the weekly target in the corresponding week of the year. For example, the number highlighted in Figure 4.6 depicts that there is 90.6% chance of the mill crushing 40 000 tons in week 24 of the season. The profiles in 4.5 and 4.6 have different shades of colours depending with the value of the probabilities. High probability values mostly above 50% are indicated in the green shade, as the values decreases the green becomes lighter and values below 50% fell in the yellow range and very low values below 20% fell in the red zone.

Wk end No	15000	20000	25000	30000	35000	40000	45000	50000	51000	51500	52000	52500	52600	52800	52900	52950
	Weekly Tons crushed% _SEZELA															
1/1/2014 Week 1	1000	994	972	916	788	613	405	157	106	89	66	39	32	19	14	7
1/2/2014 Week 2	982	956	904	797	631	433	236	76	46	37	27	16	14	8	7	4
1/3/2014 Week 3	989	963	913	824	687	492	285	90	66	47	33	20	15	9	6	4
1/4/2014 Week 4	988	968	920	836	693	511	318	115	84	67	44	27	22	16	8	4
1/5/2014 Week 5	990	968	923	838	688	504	314	109	67	51	30	17	15	14	9	5
1/6/2014 Week 6	990	969	917	853	708	532	319	113	70	54	30	18	15	8	6	3
1/7/2014 Week 7	989	973	931	860	718	530	313	96	66	54	33	23	19	12	7	5
1/8/2014 Week 8	991	965	919	834	702	510	307	94	61	45	29	13	10	7	5	2
1/9/2014 Week 9	992	975	927	835	695	533	320	95	65	51	36	21	20	14	12	7
1/10/2014 Week 10	992	973	930	860	734	552	337	136	96	69	44	27	25	21	11	7
1/11/2014 Week 11	990	971	931	846	696	537	349	137	102	83	59	36	30	19	15	9
1/12/2014 Week 12	993	970	940	859	722	554	362	144	109	83	61	37	30	22	16	11
1/13/2014 Week 13	994	982	957	894	791	621	429	194	141	116	87	61	55	42	28	18
1/14/2014 Week 14	995	985	966	921	841	691	516	244	194	164	128	83	74	54	42	27
1/15/2014 Week 15	997	992	962	924	856	735	560	315	253	211	158	113	105	75	54	38
1/16/2014 Week 16	999	999	985	955	901	773	634	387	314	262	221	163	146	112	88	58
1/17/2014 Week 17	998	994	990	960	913	816	663	442	369	309	252	191	176	137	106	79
1/18/2014 Week 18	1000	999	992	977	924	854	733	487	421	377	301	232	217	166	144	104
1/19/2014 Week 19	999	995	992	979	940	882	768	574	505	456	376	299	270	201	175	136
1/20/2014 Week 20	999	997	993	986	955	904	797	584	531	489	414	328	298	238	211	156
1/21/2014 Week 21	1000	997	993	987	973	932	856	666	602	567	494	378	344	273	235	180
1/22/2014 Week 22	1000	1000	1000	997	976	930	850	659	602	558	480	412	381	300	268	212
1/23/2014 Week 23	1000	1000	996	987	959	911	828	643	592	555	488	397	361	285	250	200
1/24/2014 Week 24	1000	998	992	983	949	906	822	632	585	548	441	363	342	264	236	195
1/25/2014 Week 25	1000	996	993	988	973	927	862	662	615	576	500	411	372	305	267	208
1/26/2014 Week 26	1000	1000	998	993	973	923	841	657	608	564	483	403	373	318	281	219
1/27/2014 Week 27	1000	998	995	987	969	940	859	668	617	582	513	424	399	337	304	244
1/28/2014 Week 28	999	998	998	985	967	926	862	653	597	558	484	409	383	328	297	246
1/29/2014 Week 29	998	998	995	988	964	927	858	663	619	587	506	422	392	321	282	216
1/30/2014 Week 30	1000	999	996	987	961	913	844	645	584	544	461	356	326	254	223	164
1/31/2014 Week 31	1000	998	992	976	948	902	839	643	592	543	462	356	329	253	222	166
2/1/2014 Week 32	1000	999	997	991	972	928	841	620	552	512	437	327	303	222	197	146
2/2/2014 Week 33	1000	1000	1000	991	972	919	822	587	514	471	393	307	286	229	178	135
2/3/2014 Week 34	1000	998	992	976	944	888	757	517	450	392	313	241	224	161	137	96
2/4/2014 Week 35	997	995	985	976	946	875	755	476	404	349	276	198	175	119	96	61
2/5/2014 Week 36	998	993	986	956	910	814	674	423	345	297	234	162	137	98	78	49
2/6/2014 Week 37	999	992	975	947	882	781	625	362	277	229	181	120	100	63	45	29
2/7/2014 Week 38	997	992	971	932	855	747	558	294	239	191	143	89	76	57	35	21
2/8/2014 Week 39	999	988	970	918	838	716	510	258	189	161	105	65	56	40	29	16
2/9/2014 Week 40	993	975	943	859	758	617	426	170	126	101	69	37	32	25	16	12
2/10/2014 Week 41	995	980	944	866	749	580	394	165	121	96	59	35	31	21	17	13
2/11/2014 Week 42	985	962	914	825	708	536	329	132	87	65	42	23	18	15	12	7
2/12/2014 Week 43	991	960	904	820	693	512	317	126	83	63	41	19	16	11	8	4
2/13/2014 Week 44	987	961	899	804	675	475	286	88	62	44	29	15	14	8	6	4
2/14/2014 Week 45	996	971	915	833	685	493	272	91	56	43	25	12	9	4	3	0
2/15/2014 Week 46	991	962	907	831	662	489	290	80	56	36	17	11	11	9	5	2
2/16/2014 Week 47	990	963	912	799	637	442	258	76	48	36	25	10	8	6	3	3
2/17/2014 Week 48	985	954	897	795	625	415	230	64	38	31	20	11	8	6	1	1
2/18/2014 Week 49	982	957	889	802	644	464	259	68	46	38	24	13	10	8	7	3
2/19/2014 Week 50	991	969	905	810	640	452	225	63	41	28	18	9	9	5	3	3
2/20/2014 Week 51	991	962	888	775	619	420	215	55	35	25	16	7	5	2	0	0
2/21/2014 Week 52	986	963	898	796	653	445	243	64	51	33	21	10	7	4	2	1

Figure 4.5 Exceedance profile for crush rate results of Sezela mill

		Weekly Tons crushed% _SEZELA															
Date	Week	15000	20000	25000	30000	35000	40000	45000	50000	51000	51500	52000	52500	52600	52800	52900	52950
1/1/2014	1	100	99.4	97.2	91.6	78.8	61.3	40.5	15.7	10.6	8.9	6.6	3.9	3.2	1.9	1.4	0.7
1/8/2014	2	98.2	95.6	90.4	79.7	63.1	43.3	23.6	7.6	4.6	3.7	2.7	1.6	1.4	0.8	0.7	0.4
1/15/2014	3	98.9	96.3	91.3	82.4	68.7	49.2	28.5	9	6.6	4.7	3.3	2	1.5	0.9	0.6	0.4
1/22/2014	4	98.8	96.8	92	83.6	69.3	51.1	31.8	11.5	8.4	6.7	4.4	2.7	2.2	1.6	0.8	0.4
1/29/2014	5	99	96.8	92.3	83.8	68.8	50.4	31.4	10.9	6.7	5.1	3	1.7	1.5	1.4	0.9	0.5
2/5/2014	6	99	96.9	91.7	85.3	70.8	53.2	31.9	11.3	7	5.4	3	1.8	1.5	0.8	0.6	0.3
2/12/2014	7	98.9	97.3	93.1	86	71.8	53	31.3	9.6	6.6	5.4	3.3	2.3	1.9	1.2	0.7	0.5
2/19/2014	8	99.1	96.5	91.9	83.4	70.2	51	30.7	9.4	6.1	4.5	2.9	1.3	1	0.7	0.5	0.2
2/26/2014	9	99.2	97.5	92.7	83.5	69.5	53.3	32	9.5	6.5	5.1	3.6	2.1	2	1.4	1.2	0.7
3/5/2014	10	99.2	97.3	93	86	73.4	55.2	33.7	13.6	9.6	6.9	4.4	2.7	2.5	2.1	1.1	0.7
3/12/2014	11	99	97.1	93.1	84.6	69.6	53.7	34.9	13.7	10.2	8.3	5.9	3.6	3	1.9	1.5	0.9
3/19/2014	12	99.3	97	94	85.9	72.2	55.4	36.2	14.4	10.9	8.3	6.1	3.7	3	2.2	1.6	1.1
3/26/2014	13	99.4	98.2	95.7	89.4	79.1	62.1	42.9	19.4	14.1	11.6	8.7	6.1	5.5	4.2	2.8	1.8
4/2/2014	14	99.5	98.5	96.6	92.1	84.1	69.1	51.6	24.4	19.4	16.4	12.8	8.3	7.4	5.4	4.2	2.7
4/9/2014	15	99.7	99.2	96.2	92.4	85.6	73.5	56	31.5	25.3	21.1	15.8	11.3	10.5	7.5	5.4	3.8
4/16/2014	16	99.9	99.9	98.5	95.5	90.1	77.3	63.4	38.7	31.4	26.2	22.1	16.3	14.6	11.2	8.8	5.8
4/23/2014	17	99.8	99.4	99	96	91.3	81.6	66.3	44.2	36.9	30.9	25.2	19.1	17.6	13.7	10.6	7.9
4/30/2014	18	100	99.9	99.2	97.7	92.4	85.4	73.3	48.7	42.1	37.7	30.1	23.2	21.7	16.6	14.4	10.4
5/7/2014	19	99.9	99.5	99.2	97.9	94	88.2	76.8	57.4	50.5	45.6	37.6	29.9	27	20.1	17.5	13.6
5/14/2014	20	99.9	99.7	99.3	98.6	95.5	90.4	79.7	58.4	53.1	48.9	41.4	32.8	29.8	23.8	21.1	15.6
5/21/2014	21	100	99.7	99.3	98.7	97.3	93.2	85.6	66.6	60.2	56.7	49.4	37.8	34.4	27.3	23.5	18
5/28/2014	22	100	100	100	99.7	97.6	93	85	65.9	60.2	55.8	48	41.2	38.1	30	26.8	21.2
6/4/2014	23	100	100	99.6	98.7	95.9	91.1	82.8	64.3	59.2	55.5	48.8	39.7	36.1	28.5	25	20
6/11/2014	24	100	99.8	99.2	98.3	94.9	90.6	82.2	63.2	58.5	54.8	44.1	36.3	34.2	26.4	23.6	19.5
6/18/2014	25	100	99.6	99.3	98.8	97.3	92.7	86.2	66.2	61.5	57.6	50	41.1	37.2	30.5	26.7	20.8
6/25/2014	26	100	100	99.8	99.3	97.3	92.3	84.1	65.7	60.8	56.4	48.3	40.3	37.3	31.8	28.1	21.9
7/2/2014	27	100	99.8	99.5	98.7	96.9	94	85.9	66.8	61.7	58.2	51.3	42.4	39.9	33.7	30.4	24.4
7/9/2014	28	99.9	99.8	99.8	98.5	96.7	92.6	86.2	65.3	59.7	55.8	48.4	40.9	38.3	32.8	29.7	24.6
7/16/2014	29	99.8	99.8	99.5	98.8	96.4	92.7	85.8	66.3	61.9	58.7	50.6	42.2	39.2	32.1	28.2	21.6
7/23/2014	30	100	99.9	99.6	98.7	96.1	91.3	84.4	64.5	58.4	54.4	46.1	35.6	32.6	25.4	22.3	16.4
7/30/2014	31	100	99.8	99.2	97.6	94.8	90.2	83.9	64.3	59.2	54.3	46.2	35.6	32.9	25.3	22.2	16.6
8/6/2014	32	100	99.9	99.7	99.1	97.2	92.8	84.1	62	55.2	51.2	43.7	32.7	30.3	22.2	19.7	14.6
8/13/2014	33	100	100	100	99.1	97.2	91.9	82.2	58.7	51.4	47.1	39.3	30.7	28.6	22.9	17.8	13.5
8/20/2014	34	100	99.8	99.2	97.6	94.4	88.8	75.7	51.7	45	39.2	31.3	24.1	22.4	16.1	13.7	9.6
8/27/2014	35	99.7	99.5	98.5	97.6	94.6	87.5	75.5	47.6	40.4	34.9	27.6	19.8	17.5	11.9	9.6	6.1
9/3/2014	36	99.8	99.3	98.6	95.6	91	81.4	67.4	42.3	34.5	29.7	23.4	16.2	13.7	9.8	7.8	4.9
9/10/2014	37	99.9	99.2	97.5	94.7	88.2	78.1	62.5	36.2	27.7	22.9	18.1	12	10	6.3	4.5	2.9
9/17/2014	38	99.7	99.2	97.1	93.2	85.5	74.7	55.8	29.4	23.9	19.1	14.3	8.9	7.6	5.7	3.5	2.1
9/24/2014	39	99.9	98.8	97	91.8	83.8	71.6	51	25.8	18.9	16.1	10.5	6.5	5.6	4	2.9	1.6
10/1/2014	40	99.3	97.5	94.3	85.9	75.8	61.7	42.6	17	12.6	10.1	6.9	3.7	3.2	2.5	1.6	1.2
10/8/2014	41	99.5	98	94.4	86.6	74.9	58	39.4	16.5	12.1	9.6	5.9	3.5	3.1	2.1	1.7	1.3
10/15/2014	42	98.5	96.2	91.4	82.5	70.8	53.6	32.9	13.2	8.7	6.5	4.2	2.3	1.8	1.5	1.2	0.7
10/22/2014	43	99.1	96	90.4	82	69.3	51.2	31.7	12.6	8.3	6.3	4.1	1.9	1.6	1.1	0.8	0.4
10/29/2014	44	98.7	96.1	89.9	80.4	67.5	47.5	28.6	8.8	6.2	4.4	2.9	1.5	1.4	0.8	0.6	0.4
11/5/2014	45	99.6	97.1	91.5	83.3	68.5	49.3	27.2	9.1	5.6	4.3	2.5	1.2	0.9	0.4	0.3	0
11/12/2014	46	99.1	96.2	90.7	83.1	66.2	48.9	29	8	5.6	3.6	1.7	1.1	1.1	0.9	0.5	0.2
11/19/2014	47	99	96.3	91.2	79.9	63.7	44.2	25.8	7.6	4.8	3.6	2.5	1	0.8	0.6	0.3	0.3
11/26/2014	48	98.5	95.4	89.7	79.5	62.5	41.5	23	6.4	3.8	3.1	2	1.1	0.8	0.6	0.1	0.1
12/3/2014	49	98.2	95.7	88.9	80.2	64.4	46.4	25.9	6.8	4.6	3.8	2.4	1.3	1	0.8	0.7	0.3
12/10/2014	50	99.1	96.9	90.5	81	64	45.2	22.5	6.3	4.1	2.8	1.8	0.9	0.9	0.5	0.3	0.3
12/17/2014	51	99.1	96.2	88.8	77.5	61.9	42	21.5	5.5	3.5	2.5	1.6	0.7	0.5	0.2	0	0
12/24/2014	52	98.6	96.3	89.8	79.6	65.3	44.5	24.3	6.4	5.1	3.3	2.1	1	0.7	0.4	0.2	0.1

Figure 4.6 Exceedance profile of crush rate percentages for Sezela mill

4.2.7.2 Decision support graphs

More graphs were then made in order to further support and explain the findings of the LOMZI model specifically for Sezela and Umzimkulu sugar mills. This was done so that the results can be presented to industry and to help answer some of the questions that are frequently encountered by the mill group board members when making the length of milling season decisions. Each mill is specific but some of the regularly asked questioned that this project aimed to address were:

a) Is the mill being fully utilised?
b) What is the recommended weekly crush rate that will help achieve the season crushing goal?
c) How can we optimize LOMS to benefit both millers and growers?

Three target estimates of tons of cane to be crushed per season were selected to illustrate the use of decision support graphs. The targets are based on the historic average tons of cane crushed per season for each mill, as summarised in Table 4.4.

Table 4.4 Estimates of tons of cane crushed for each mill

	Actual average tons of cane crushed per season (tons)	**Target values of tons of cane crushed (tons)**		
		Minimum	Medium	Maximum
Umzimkulu	1 300 000	1 000 000	1 100 000	1 300 000
Sezela	2 200 000	2 000 000	2 100 000	2 200 000

At the beginning of each season, sugarcane growers provide the MGB with estimates of the cane they are expecting to harvest that season (de Lange and Singels, 2003). The board then makes a decision on the LOMS based on the given estimates. The graphs from this project provided more information from a different point of view that might further aid in the LOMS decisions. For example, the graphs visualised different weekly crush rates scenarios chosen randomly for demonstrating purposes. The plots showed how the chances of crushing the seasons target are varying at these different weekly crush rates. This was important information to aid decide on the recommended weekly crush rate that was associated with high profits and low risks. The graphs also illustrated that at a fixed crush goal, when they would expect to finish crushing their harvest estimate. This would help in giving an indication whether the LOMS would be in the 30-40 week range. This would also provide an indication of if the mill was being fully utilised or not. Plots of sugar produced were also presented based on the harvest estimates chosen in Table 4.4.

5. RESULTS AND DISCUSSION

This chapter consists of four sub-sections. The first sub-section discusses the correlation values results from the quality and crush models. The sub-sections that follow consist of exceedance graphs and discussions for crush rate and sugar produced for the areas of study. Decision support graphs and their discussions form the bulk of the results section. It is important to note that some of the results presented in this section also form a small part of a paper by Ndoro, *et al*., 2015. However, this paper focused on six milling areas in South Africa. This section provides detailed results and discussion of Sezela and Umzimkulu sugar milling areas.

5.1 Cane Quality and Cane Crushed

Table 5.1 shows correlation values for the quality parameters and cane crushed for the areas of study, Sezela and Umzimkulu. The R^2 values for the quality parameters ranged between 0.69 and 0.90. The main reason for the relatively high values could be that rainfall is one of the key factors that influence the cane quality parameters at the mill areas. This is consistent with results obtained from the research conducted by Jenkins (2014).

Table 5.1 Correlation values between predicted and actual for quality and crush models for both mills

	Sezela				**Umzimkulu**			
	Crush	**Brix%**	**Fibre%**	**Pol%**	**Crush**	**Brix%**	**Fibre%**	**Pol%**
R^2	0.52	0.87	0.78	0.87	0.69	0.88	0.84	0.90

The ultimate goal of the LOMZI Model was to simulate daily tons crushed, and sugar produced by the mill. It was therefore important to verify the performance of the model before packaging the results for industry. Hence, the correlation values between the simulated and the actual crush rate were 0.52 and 0.69 for Sezela and Umzimkulu respectively as indicated in Table 5.1.

The correlation values were verified against independent data. The values were relatively high which suggested that rainfall had a significant impact on the crushing operations at the areas of study. The discrepancies that were exhibited in the correlation values for both mills could be due to the fact that the homogenous climatic zones for the two areas experienced very different climatic conditions. The areas were separated into three zones namely, coastal, Hinterland and inland zones as shown earlier in Figure 3.1. As a result, the cane in these areas matured at different times. So, this could be one of the reasons why the model did not completely follow and simulate the trends in the data.

Furthermore, apart from rainfall, there are other factors affecting the crush rate of both mills and some of these include such as harvest-crush delays, transport delays, mill fluctuations, mill maintenance, mill breakdowns, labour shortages, pay weekends and strikes. The quality component of the LOMZI Model also did not take into account other issues, such as pests e.g. Eldana (Kadwa, *et al*., 2014). Since the LOMZI model did not take into consideration any of these factors, including them could be an area of further research.

5.2 Probability of Exceedance Graphs

After the LOMZI model was used to simulate data for crush rate and sugar produced at the two mills, the results were then outlined as profiles that showed the distribution of crush rate and sugar made throughout the milling season. Figures 4.5 and 4.6 are examples of the profiles that were obtained and they were explained in detail in the respective section. A typical South African LOMS is between 30-38 weeks (Bezuidenhout and Singels, 2007). However, the LOMZI model used a 52 week season (from January to December) to maintain consistency and not create gaps in the results.

Figures 5.1 and 5.2 depict the probabilities of achieving a set weekly crush target for Sezela and Umzimkulu respectively. For example, Figure 5.1 shows that starting with a crush rate of 15 000 tons/week, there is almost a 100% probability of the mill achieving its target throughout the season. However, a low weekly crush rate will only achieve a low seasonal target. Therefore, if the harvest is high, a high weekly crush rate is needed to meet the seasonal goal. As the value of the crush rate increases the probability of meeting the target is decreasing. The profile has different shades of colours depending with the value of the probabilities. High probability values mostly above 50% are indicated in the green shade, as the values decreases the green becomes lighter and values below 50% fell in the yellow range and very low values below 20% fell in the red zone. High probability zones indicate lower risk for the mill, and low probability zones indicate that the mill will be taking a higher risk in terms of not meeting its target. For example, in Figure 5.1, a crush rate of 52 950 tons/week is in the red zone meaning that there is a very low chance of the mill achieving that target and therefore has a high risk associated with it. The middle 45 000 tons/week crush rate fell in the yellow range which depicted average to low (45%-65%) chances of the mill not attaining its crush target. Lastly, a 15 000 tons/week demonstrated in the green zone of the profile, represented higher than average chances of the mill attaining its crush goal with low risks involved. Therefore, the profile demonstrated a general trend that the higher the weekly crush rate, the lower the chances of meeting the goal and the higher the risks involved.

A typical South African length of milling season usually starts from April to December and that is from week 15-50 on the profiles. Figure 5.1 demonstrates that if the Sezela MGB decides to operate at a minimum of 80% probability, the crush rate will range from 30 000 - 45 000 tons/week (average of 37 000 tons/week). To find this indicated in Figure 5.1, the model took values closest to the 80% probability level and these closest values were either equal or greater than 80%. Operating at the above mentioned crush rate range will potentially result in the mill achieving a seasonal crush that ranges between 1 050 000 – 1 575 000 tons of sugarcane.

Weekly Tons crushed%_SEZELA																
Wk end No	15000	20000	25000	30000	35000	40000	45000	50000	51000	51500	52000	52500	52600	52800	52900	52950
Week 1	100	99.4	97.2	91.6	78.8	61.3	40.5	15.7	10.6	8.9	6.6	3.9	3.2	1.9	1.4	0.7
1/2/2014 Week 2	98.2	95.6	90.4	79.7	63.1	43.3	23.6	7.6	4.6	3.7	2.7	1.6	1.4	0.8	0.7	0.4
1/9/2014 Week 3	98.9	96.3	91.3	82.4	68.7	49.2	28.5	9	6.6	4.7	3.3	2	1.5	0.9	0.6	0.4
1/16/2014 Week 4	98.8	96.8	92	83.6	69.3	51.1	31.8	11.5	8.4	6.7	4.4	2.7	2.2	1.6	0.8	0.4
1/23/2014 Week 5	99	96.8	92.3	83.8	68.8	50.4	31.4	10.9	6.7	5.1	3	1.7	1.5	1.4	0.9	0.5
1/30/2014 Week 6	99	96.9	91.7	85.3	70.8	53.2	31.9	11.3	7	5.4	3	1.8	1.5	0.8	0.6	0.3
2/6/2014 Week 7	98.9	97.3	93.1	86	71.8	53	31.3	9.6	6.6	5.4	3.3	2.3	1.9	1.2	0.7	0.5
2/13/2014 Week 8	99.1	96.5	91.9	83.4	70.2	51	30.7	9.4	6.1	4.5	2.9	1.3	1	0.7	0.5	0.2
2/20/2014 Week 9	99.2	97.5	92.7	83.5	69.5	53.3	32	9.5	6.5	5.1	3.6	2.1	2	1.4	1.2	0.7
2/27/2014 Week 10	99.2	97.3	93	86	73.4	55.2	33.7	13.6	9.6	6.9	4.4	2.7	2.5	2.1	1.1	0.7
3/6/2014 Week 11	99	97.1	93.1	84.6	69.6	53.7	34.9	13.7	10.2	8.3	5.9	3.6	3	1.9	1.5	0.9
3/13/2014 Week 12	99.3	97	94	85.9	72.2	55.4	36.2	14.4	10.9	8.3	6.1	3.7	3	2.2	1.6	1.1
3/20/2014 Week 13	99.4	98.2	95.7	89.4	79.1	62.1	42.9	19.4	14.1	11.6	8.7	6.1	5.5	4.2	2.8	1.8
3/27/2014 Week 14	99.5	98.5	96.6	92.1	84.1	69.1	51.6	24.4	19.4	16.4	12.8	8.3	7.4	5.4	4.2	2.7
4/3/2014 Week 15	99.7	99.2	96.2	92.4	85.6	73.5	56	31.5	25.3	21.1	15.8	11.3	10.5	7.5	5.4	3.8
4/10/2014 Week 16	99.9	99.9	98.5	95.5	90.1	77.3	63.4	38.7	31.4	26.2	22.1	16.3	14.6	11.2	8.8	5.8
4/17/2014 Week 17	99.8	99.4	99	96	91.3	81.6	66.3	44.2	36.9	30.9	25.2	19.1	17.6	13.7	10.6	7.9
4/24/2014 Week 18	100	99.9	99.2	97.7	92.4	85.4	73.3	48.7	42.1	37.7	30.1	23.2	21.7	16.6	14.4	10.4
5/1/2014 Week 19	99.9	99.5	99.2	97.9	94	88.2	76.8	57.4	50.5	45.6	37.6	29.9	27	20.1	17.5	13.6
5/8/2014 Week 20	99.9	99.7	99.3	98.6	95.5	90.4	79.7	58.4	53.1	48.9	41.4	32.8	29.8	23.8	21.1	15.6
5/15/2014 Week 21	100	99.7	99.3	98.7	97.3	93.2	85.6	66.6	60.2	56.7	49.4	37.8	34.4	27.3	23.5	18
5/22/2014 Week 22	100	100	100	99.7	97.6	93	85	65.9	60.2	55.8	48	41.2	38.1	30	26.8	21.2
5/29/2014 Week 23	100	100	99.6	98.7	95.9	91.1	82.8	64.3	59.2	55.5	48.8	39.7	36.1	28.5	25	20
6/5/2014 Week 24	100	99.8	99.2	98.3	94.9	90.6	82.2	63.2	58.5	54.8	44.1	36.3	34.2	26.4	23.6	19.5
6/12/2014 Week 25	100	99.6	99.3	98.8	97.3	92.7	86.2	66.2	61.5	57.6	50	41.1	37.2	30.5	26.7	20.8
6/19/2014 Week 26	100	100	99.8	99.3	97.3	92.3	84.1	65.7	60.8	56.4	48.3	40.3	37.3	31.8	28.1	21.9
6/26/2014 Week 27	100	99.8	99.5	98.7	96.9	94	85.9	66.8	61.7	58.2	51.3	42.4	39.9	33.7	30.4	24.4
7/3/2014 Week 28	99.9	99.8	99.8	98.5	96.7	92.6	86.2	65.3	59.7	55.8	48.4	40.9	38.3	32.8	29.7	24.6
7/10/2014 Week 29	99.8	99.8	99.5	98.8	96.4	92.7	85.8	66.3	61.9	58.7	50.6	42.2	39.2	32.1	28.2	21.6
7/17/2014 Week 30	100	99.9	99.6	98.7	96.1	91.3	84.4	64.5	58.4	54.4	46.1	35.6	32.6	25.4	22.3	16.4
7/24/2014 Week 31	100	99.8	99.2	97.6	94.8	90.2	83.9	64.3	59.2	54.3	46.2	35.6	32.9	25.3	22.2	16.6
7/31/2014 Week 32	100	99.9	99.7	99.1	97.2	92.8	84.1	62	55.2	51.2	43.7	32.7	30.3	22.2	19.7	14.6
8/7/2014 Week 33	100	100	100	99.1	97.2	91.9	82.2	58.7	51.4	47.1	39.3	30.7	28.6	22.9	17.8	13.5
8/14/2014 Week 34	100	99.8	99.2	97.6	94.4	88.8	75.7	51.7	45	39.2	31.3	24.1	22.4	16.1	13.7	9.6
8/21/2014 Week 35	99.7	99.5	98.5	97.6	94.6	87.5	75.5	47.6	40.4	34.9	27.6	19.8	17.5	11.9	9.6	6.1
8/28/2014 Week 36	99.8	99.3	98.6	95.6	91	81.4	67.4	42.3	34.5	29.7	23.4	16.2	13.7	9.8	7.8	4.9
9/4/2014 Week 37	99.9	99.2	97.5	94.7	88.2	78.1	62.5	36.2	27.7	22.9	18.1	12	10	6.3	4.5	2.9
9/11/2014 Week 38	99.7	99.2	97.1	93.2	85.5	74.7	55.8	29.4	23.9	19.1	14.3	8.9	7.6	5.7	3.5	2.1
9/18/2014 Week 39	99.9	98.8	97	91.8	83.8	71.6	51	25.8	18.9	16.1	10.5	6.5	5.6	4	2.9	1.6
9/25/2014 Week 40	99.3	97.5	94.3	85.9	75.8	61.7	42.6	17	12.6	10.1	6.9	3.7	3.2	2.5	1.6	1.2
10/2/2014 Week 41	99.5	98	94.4	86.6	74.9	58	39.4	16.5	12.1	9.6	5.9	3.5	3.1	2.1	1.7	1.3
10/9/2014 Week 42	98.5	96.2	91.4	82.5	70.8	53.6	32.9	13.2	8.7	6.5	4.2	2.3	1.8	1.5	1.2	0.7
10/16/2014 Week 43	99.1	96	90.4	82	69.3	51.2	31.7	12.6	8.3	6.3	4.1	1.9	1.6	1.1	0.8	0.4
10/23/2014 Week 44	98.7	96.1	89.9	80.4	67.5	47.5	28.6	8.8	6.2	4.4	2.9	1.5	1.4	0.8	0.6	0.4
10/30/2014 Week 45	99.6	97.1	91.5	83.3	68.5	49.3	27.2	9.1	5.6	4.3	2.5	1.2	0.9	0.4	0.3	0
11/6/2014 Week 46	99.1	96.2	90.7	83.1	66.2	48.9	29	8	5.6	3.6	1.7	1.1	1.1	0.9	0.5	0.2
11/13/2014 Week 47	99	96.3	91.2	79.9	63.7	44.2	25.8	7.6	4.8	3.6	2.5	1	0.8	0.6	0.3	0.3
11/20/2014 Week 48	98.5	95.4	89.7	79.5	62.5	41.5	23	6.4	3.8	3.1	2	1.1	0.8	0.6	0.1	0.1
11/27/2014 Week 49	98.2	95.7	88.9	80.2	64.4	46.4	25.9	6.8	4.6	3.8	2.4	1.3	1	0.8	0.7	0.3
12/4/2014 Week 50	99.1	96.9	90.5	81	64	45.2	22.5	6.3	4.1	2.8	1.8	0.9	0.9	0.5	0.3	0.3
12/11/2014 Week 51	99.1	96.2	88.8	77.5	61.9	42	21.5	5.5	3.5	2.5	1.6	0.7	0.5	0.2	0	0
12/18/2014 Week 52	98.6	96.3	89.8	79.6	65.3	44.5	24.3	6.4	5.1	3.3	2.1	1	0.7	0.4	0.2	0.1

Figure 5.1 A probability of exceedance graph for the weekly tons of sugarcane crushed for Sezela sugar mill.

Weekend	18000	19000	21000	22000	23000	25000	26000	26500	27500	28000	28500	29000	29250	29500	29600	29650	29700
					Weekly Tons Crushed%_UMZIMKULU												
1/7/2014 week1	99.9	99.9	98.3	95.4	91	72.8	59.8	52.6	38.1	29.2	21.8	13.5	10	6.2	4.1	1.9	0
1/14/2014 week2	97.3	95.9	87.4	82.1	73.6	51.4	38	31.4	19.6	13.3	8	4.7	3.3	2.2	1.1	0.5	0
1/21/2014 week3	97.6	95.8	89.3	82.1	76.1	56	43.1	36.9	24.6	17.7	12.7	6.5	4.6	2.1	1	0.6	0
1/28/2014 week4	97.5	95.1	88.1	83.9	77	57.2	42.7	35	24.1	17.7	11	6.8	4.2	2.4	1.4	0.9	0
2/4/2014 week5	98.3	96.9	91.1	85.6	78.7	59.5	46.3	39.5	28.1	21.1	14.7	8.3	5.6	2.8	1.6	0.7	0
2/11/2014 week6	98.1	97	90.3	84.1	75.9	55.9	42.3	36	24.6	18.7	12.8	7.3	5.7	2.9	1.8	1	0
2/18/2014 week7	97.6	96.9	90.5	85.1	78.7	59.1	44.9	39.3	25.3	19.6	13.3	7.8	5.4	3	2	1.2	0
2/25/2014 week8	97.9	96.9	91.6	86	80.2	61.4	47.6	41.3	27.5	20.4	15.1	9.1	6.1	2.8	1.9	0.8	0
3/4/2014 week9	98	96.9	91.1	87.7	79.9	58.9	46.2	39.5	26.5	19.7	13.8	8.8	6.1	3.2	1.5	0.8	0
3/11/2014 week10	97.7	95.9	89.5	84	76.4	55.8	43.9	35.9	23.6	18.1	12.6	7.3	5.1	2.6	1.4	0.8	0
3/18/2014 week11	97.4	95.6	90.4	84.5	76.6	55.3	42.4	36.2	23.9	18.1	12.6	7.7	4.7	2.6	0.9	0.5	0
3/25/2014 week12	97.2	96.1	90	83.9	76.2	55.6	42.8	36.2	25.2	19.8	15.2	8.3	6.2	4.1	2.9	1.8	0
4/1/2014 week13	98.2	97.7	93.2	89.9	84	65.1	51.9	45.8	31.9	24.7	18.6	12.7	9	5.6	3.2	1.9	0
4/8/2014 week14	98.8	97.7	95.9	93.4	89.6	72.9	62.5	54.9	42.7	35.2	26.9	20	15.4	9.2	6	3.9	0
4/15/2014 week15	100	99.9	98.7	97.1	94.6	84.4	74.4	67.5	51.5	43.1	34.7	25.2	18.9	11.4	6.3	3.9	0
4/22/2014 week16	99.8	99.6	98.9	97.3	94.9	85.8	77.3	72	59.5	52.9	43.6	34.1	25.2	17.1	11.9	8.2	0
4/29/2014 week17	99.9	99.6	98.5	97.6	95.8	89.1	80.9	76.7	65.2	58.2	50.2	39.8	31.6	22.9	16.7	13	0
5/6/2014 week18	99.9	99.7	99.5	99	98.2	91.9	86.7	82.6	71.7	64.7	56.7	47.5	38	28.5	20.6	15.4	0
5/13/2014 week19	100	100	99.8	99.6	98.4	94.6	90.1	87	79.5	73.3	65.3	57.2	47.6	36.5	29.8	24.6	0
5/20/2014 week20	100	100	100	99.7	99.3	95.8	91.7	89.8	82	75.6	68.3	58.5	48.2	39	30.9	26.1	0
5/27/2014 week21	100	100	99.9	99.9	99.6	97.2	94.3	90.9	84.8	79.7	74	63.6	54.2	44.7	36.3	31.1	0
6/3/2014 week22	100	100	100	100	99.9	97.3	95.6	93.5	88.8	84.6	78	67.3	58.3	47.1	37.7	33.1	0
6/10/2014 week23	100	99.9	99.7	99.7	99.6	97.5	93.2	89.7	82.3	76.7	71.7	65	53.5	44.4	36.1	31.4	0
6/17/2014 week24	100	100	99.6	99.5	99.4	96.9	94.5	91.6	84.4	80.5	75.9	66.6	57.2	46.8	39.3	34.5	0
6/24/2014 week25	100	100	99.9	99.9	99.5	96.2	92.7	91	83.7	78.1	72.7	63	54.1	44.5	37	33.3	0
7/1/2014 week26	100	99.9	99.7	99.7	99.1	96.2	93.4	91.5	85.1	79.9	75	66.8	56.8	45.9	40	37.3	0
7/8/2014 week27	100	100	99.8	99.7	99.2	96.9	93.2	91.5	85.1	80.1	76.9	66.5	56.1	45.6	38.7	35.7	0
7/15/2014 week28	100	100	99.8	99.7	99.1	96.6	93.7	92.6	85.5	80.2	76	67.9	60.8	50	43.1	40.3	0
7/22/2014 week29	100	99.9	99.9	99.6	99.1	97.2	94.5	93.3	86.7	82.3	78.4	67.5	59.2	49.9	42	39.4	0
7/29/2014 week30	100	100	99.8	99.5	98.9	96.6	93.8	91.7	86.1	81.8	76.8	66.8	57.3	46.9	38.2	35.1	0
8/5/2014 week31	100	100	100	99.7	99.4	97.2	94.2	91.4	85.1	80.9	75.1	63.9	54.8	45.5	38.8	35	0
8/12/2014 week32	100	100	100	99.8	99.4	96.5	94.2	92.1	84.4	79.7	74.2	61.9	50.2	40.9	35	32.1	0
8/19/2014 week33	100	100	99.9	99.8	99.5	96	93.2	90.7	81.2	76.3	70.2	60.2	48	36.9	30.4	26.5	0
8/26/2014 week34	100	100	99.8	99.8	99.3	96.3	92.9	88.7	80.6	74.6	67.5	55.6	43.9	33	27.1	22.6	0
9/2/2014 week35	100	100	99.7	99.4	98.6	95.4	89.1	85.2	74.7	68.7	62.2	48.1	35.6	27.3	22.2	19.3	0
9/9/2014 week36	100	99.9	99.8	99	98.1	92.6	85.9	82.5	72.3	64.9	55.5	42.6	33.7	24.5	18.1	14.3	0
9/16/2014 week37	100	99.6	99	98	96	89.7	83	77.5	66.2	59.1	49.7	37	26.8	19.1	14.3	11.4	0
9/23/2014 week38	100	99.6	98.4	97.6	95.1	86.2	78.6	72.4	60.1	53.5	44.3	33	24.8	17.4	13	10.1	0
9/30/2014 week39	99.5	99	98	97.1	95.1	85.3	75.7	70.9	59.9	52	40.6	29.9	22.1	13.9	10.7	8.2	0
10/7/2014 week40	99.8	99.3	97.3	95.9	92.2	81.9	73	67.9	54.3	45.4	34.2	22.7	15.5	9	6.5	4.7	0
10/14/2014 week41	99.7	99.5	98.3	95.5	92.7	80.4	69.7	62.5	47.4	38.4	30.4	17.4	11.8	7	4.6	2.7	0
10/21/2014 week42	99.4	98.8	96.2	93	89	75.2	64.9	58.2	43.3	33.9	24	13.2	8.4	4.8	2.8	1.5	0
10/28/2014 week43	99.3	98.9	96.9	94.1	89.3	71.3	59	52.8	36.4	28.8	20.5	12.4	8.1	4.8	2.7	2	0
11/4/2014 week44	99.2	98.2	94.1	90.3	86	67	55.2	49	33.5	24.4	14.9	7.4	4.8	2.7	1.9	1.2	0
11/11/2014 week45	99.1	97.9	93.7	89.9	84.8	64.4	53.7	46.7	32.3	24.8	17	10.5	6.2	3	1.8	1.2	0
11/18/2014 week46	98.5	97.4	92.5	87.8	82.8	63.1	49.6	42.9	28.8	20.6	13.4	6.7	3.5	1.7	1	0.7	0
11/25/2014 week47	97.9	96.5	91.3	87	80.7	60.4	45.9	39.1	27.3	20	13.6	7.1	4.3	1.9	0.6	0.4	0
12/2/2014 week48	98.4	96.2	90	83.8	77.7	56.5	43.3	37.1	24.2	17.6	11.4	6.4	3.7	2.4	1.1	0.9	0
12/9/2014 week49	97.9	96.8	89.6	84.5	76.7	55.8	42.8	35.7	21.4	15.7	10.3	5.5	4.2	1.5	1.1	0.7	0
12/16/2014 week50	98.5	96.9	90.1	84.9	78.2	54.7	41.1	34.6	22.5	17.1	11.8	6.5	4	1.9	0.8	0.3	0
12/23/2014 week51	97	95.4	88.8	82.8	75.6	53.8	41.6	34.8	23	17.4	10.5	5.7	3.8	1.1	0.4	0.3	0
12/30/2014 week52	97.2	95.7	89	83.5	75	52.8	40.8	34.3	21.1	15.3	10.1	6.1	3.3	1.2	0.7	0.4	0

Figure 5.2 A probability of exceedance graph for the weekly tons of sugarcane crushed at Umzimkulu sugar mill.

The profiles in Figures 5.1-5.4 outlined a trend that the green shaded area follows a bell shape throughout the season. This shape is outlined by a black line in Figure 5.2. It shows the green shade of high probabilities and low risk is least at the beginning of the season, then rises to a maximum in the middle and declines as the season ends. This is due to the fact that high rainfall is experienced mostly in January to March and this disrupts the harvesting operations which has a ripple effect in disrupting the supply of cane to the mills. As the winter months approaches in the middle of the season, the dry conditions mean fewer disruptions to the harvesting operations; hence more cane can be supplied to the mills. Dry conditions also enhance the maturity of cane to ripen for harvest as well as increasing the sucrose content because the cane stops to grow. The onset of rainfall towards the end of the season disrupts the harvesting operations hence a decline in the green shade of high probabilities on the profiles. Availability of sugarcane is also a contributing factor. Although the majority of the explanations in this section focused on the Sezela mill profiles, a similar approach can also be used to make sense of the crush rate profiles of Umzimkulu in Figure 5.2.
The weekly sugar produced results from the LOMZI model are depicted in Figures 5.3 and 5.4 for Sezela and Umzimkulu sugar mills respectively. The sugar produced profiles followed similar trends to the crush rate profiles.

The profiles illustrated that a higher mill weekly crush rate is associated with low chances of the mill achieving the set season target. Whilst a low weekly crush rate exhibited higher chances of meeting the season crush target but it also increases the risk of the season being extended into the unfavourable wet summer months. Hence, it is important to find the recommended operating weekly crush rate that balances out these factors.

It is important to note that all these results are based on a model that simplified real-world issues; however, the risk profiles generated are valuable. There are other factors apart from rainfall that play an important role in determination of the LOMS. The profiles aid to find out the likelihood of processing a certain amount of cane within a certain period of time based on the patterns depicted in the data records of the mill. This provides more information before deciding how to position the LOMS on a period that minimizes risk and maximizes quality of sugar.

	Weekly Tons Sugar Produced_% Exceeded: SEZELA																
Wk End	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10000
41646 Week 1	100	99.9	99.2	98.2	96.1	92.7	87.6	78.6	59.2	59.2	47	35	21.7	11	1.1	0	0
41653 Week 2	98.3	97.9	95.7	93.1	89.4	82.7	75.5	66.4	44.2	44.2	32.1	22.1	13.4	5.1	0.5	0	0
41660 Week 3	99.2	98.2	96.5	93.5	90.5	85.8	77.7	70.2	49.6	49.6	37	27.3	15.9	7.3	0.8	0	0
41667 Week 4	99.1	98.2	97.1	94.9	91.1	85.8	79.7	71.1	51.2	51.2	40.4	30	18.4	9.1	1.4	0	0
41674 Week 5	99.4	98.4	97.1	95	91.5	86.3	79.7	70.8	51.8	51.8	40.1	29.8	17.6	9	0.7	0	0
41681 Week 6	99.3	98.4	97.3	94.3	90.5	86.6	82.4	73.3	52.8	52.8	41.7	30.9	19.1	9.1	0.8	0	0
41688 Week 7	99	98.5	97.6	95.6	92.7	88.1	82.5	74.2	53.1	53.1	41.7	30.9	17	7.9	0.9	0	0
41695 Week 8	99.4	99	96.9	94.4	91.3	86.7	79.7	72.5	51.8	51.8	41.2	29.4	16.7	7.3	0.7	0	0
41702 Week 9	99.7	98.8	97.5	94.7	91.7	86.4	79.5	71.5	53.3	53.3	41.2	29.6	17.8	7.3	0.7	0	0
41709 Week 10	99.7	98.4	97.5	95.3	91.7	87.6	82.1	74.9	54.5	54.5	42.8	31.5	20.6	10.3	0.9	0	0
41716 Week 11	99.5	98.5	97.2	95.3	92.1	87	79	70.6	51.9	51.9	43	31.7	20.7	9.1	0.7	0	0
41723 Week 12	99.4	98.7	97.1	95.7	92.7	88.4	81.3	73	53.3	53.3	42.5	32.3	21.3	9.8	0.1	0	0
41730 Week 13	99.6	99.1	98.2	96.9	94.3	90.4	86	79.5	59.8	59.8	49.6	37.5	24.4	11.7	0.1	0	0
41737 Week 14	99.7	99.2	98.4	97.7	95.9	93.2	88.7	83.9	66.2	66.2	56.1	43.9	28.1	14.2	0.1	0	0
41744 Week 15	99.7	99.3	99.1	97.7	95.8	92.8	89.6	85	69.8	69.8	61.4	48.2	34.7	16.1	0.1	0	0
41751 Week 16	99.9	99.9	99.8	99.1	97.8	96.3	93	89	74.2	74.2	66.6	56	41.4	19.1	0.1	0	0
41758 Week 17	99.8	99.8	99.4	99.4	98	96.7	93.7	90.4	77.3	77.3	67.9	60.8	46	20.2	0	0	0
41765 Week 18	100	100	99.9	99.5	99.1	98.2	95.7	92.1	82.1	82.1	75.8	64.8	50.5	23.3	0	0	0
41772 Week 19	99.9	99.8	99.5	99.4	98.9	98	96.5	93.6	86.3	86.3	79.4	70.8	59.1	29.1	0	0	0
41779 Week 20	99.9	99.9	99.7	99.5	99.2	98.7	97.5	95.2	87.9	87.9	82.2	73.4	61.1	35.4	0.1	0	0
41786 Week 21	100	99.9	99.7	99.5	99.2	99.1	97.9	97.2	91.8	91.8	87	80.8	68.9	43.4	0	0	0
41793 Week 22	100	100	100	100	99.9	99.7	99	97	92.2	92.2	87.6	80.1	69	46.7	0	0	0
41800 Week 23	100	100	100	99.9	99.5	98.8	97.3	96	89.6	89.6	84.3	78.7	68	49.7	0.1	0	0
41807 Week 24	100	100	99.8	99.6	99.1	98.5	97.3	94.8	89.5	89.5	85	79.4	68.2	48.4	0.2	0	0
41814 Week 25	100	100	99.6	99.6	99.2	99.1	98.2	96.9	91.6	91.6	88.6	83.1	71	52	0.1	0	0
41821 Week 26	100	100	100	99.9	99.7	99.3	98.5	97.4	91	91	86.8	81.2	69.2	52.8	0	0	0
41828 Week 27	100	99.9	99.8	99.5	99.5	98.8	98.7	96.9	93.4	93.4	89.2	82.9	70.9	55.1	0.1	0	0
41835 Week 28	99.9	99.9	99.8	99.8	99.8	99.1	97.6	96.7	92.1	92.1	88.2	83.2	70.3	55.1	0.1	0	0
41842 Week 29	99.8	99.8	99.8	99.5	99.3	98.8	98.1	96.4	92	92	89.1	83.3	72	58.3	0.1	0	0
41849 Week 30	100	100	99.9	99.8	99.5	99	98.1	96.1	90.9	90.9	87.7	82.8	69.5	55.7	0.1	0	0
41856 Week 31	100	99.9	99.9	99.6	98.9	98	97	95.3	89.8	89.8	86.4	82.1	70.1	57.9	0.2	0	0
41863 Week 32	100	100	99.9	99.8	99.6	99.2	98.7	97.2	92.2	92.2	88.1	82.3	69.9	54.4	0.6	0	0
41870 Week 33	100	100	100	100	99.8	99.2	98.8	97.6	91.6	91.6	86.8	79.5	67	53.1	1.6	0	0
41877 Week 34	100	100	99.8	99.5	99.2	97.9	96.7	94.8	88.5	88.5	82.7	73.3	59.5	45.3	1.6	0	0
41884 Week 35	99.9	99.7	99.6	98.8	98.4	97.9	96.9	94.9	87.6	87.6	81.3	73.3	58.7	40.8	1.8	0	0
41891 Week 36	99.9	99.7	99.4	98.8	98.4	96.7	93.8	91.4	81.4	81.4	74.9	63.9	50.7	36.1	2.2	0	0
41898 Week 37	100	99.6	99.2	98.5	97.3	95.2	92.9	88.8	78.1	78.1	70.6	59.4	47.1	29.2	1.5	0	0
41905 Week 38	99.8	99.4	99.2	98.3	96.5	94.4	91.2	86.6	74.7	74.7	64.8	52.1	38.9	24.5	1.2	0	0
41912 Week 39	99.9	99.8	98.9	97.8	96.6	93.7	89.9	84.4	70.3	70.3	61	47.9	34.6	19.5	0.1	0	0
41919 Week 40	99.6	98.9	97.8	95.8	93.1	88.2	82.6	77.2	60.9	60.9	49.8	39	24.6	12.6	0.2	0	0
41926 Week 41	99.5	99.2	98.2	96.2	93.3	89.3	83.3	75.1	57.1	57.1	45.3	34.4	21.4	11.1	0.3	0	0
41933 Week 42	98.8	97.8	96.1	94.3	89.9	84.7	78.3	71.8	52.5	52.5	39.6	30.4	18.6	7.9	0.2	0	0
41940 Week 43	99.2	98.6	95.9	92.9	88.7	84.3	77.7	69.6	50	50	37.7	26.8	16.1	7.6	0	0	0
41947 Week 44	99	98.3	96	93.5	88.2	82	75.3	68.2	45.9	45.9	36.1	23.3	13.9	4.6	0	0	0
41954 Week 45	99.6	98.8	97.3	93.1	90.4	85.1	78.2	69.7	47.4	47.4	35.3	22.9	12.5	4.5	0	0	0
41961 Week 46	99.2	98.4	96	93.1	89.7	85.1	77	67.6	48.1	48.1	36.7	25.7	13.6	4.5	0.2	0	0
41968 Week 47	99.1	98.5	96.3	93.7	89.5	82.9	75.1	65.7	43.6	43.6	33.4	23.1	12.9	5.4	0.3	0	0
41975 Week 48	99.1	97.7	95.4	92.5	88.4	82.2	73.7	64	41.2	41.2	30	20.2	11.1	4.8	0.1	0	0
41982 Week 49	98.8	97.6	95.8	92.3	88	82.6	75.5	66	47	47	35.1	23.2	11	4.7	0.3	0	0
41989 Week 50	99.5	98.5	96.9	94.2	89.2	83.9	76	66	44.8	44.8	31.6	22.1	11.5	4.8	0.1	0	0
41996 Week 51	99.4	98.5	96.3	92	87.4	81.1	73.4	63.5	42.1	42.1	30.4	19.2	11	3.6	0.4	0	0
42003 Week 52	99	98.2	96.8	93.9	88.9	81.8	75.6	67.6	44.6	44.6	32.8	22	11.8	5.2	0.3	0	0
42010 Week 53	98.7	97.4	95.4	93.2	89	82.3	75.3	66.1	44.5	44.5	33.4	23.1	14.8	6.3	0.7	0	0

Figure 5.3 A probability of exceedance graph for the weekly tons of sugar produced at Sezela sugar mill.

	Weekly Sugar% produced_ UMZIMKULU																
Weekend	2000	2200	2500	3000	3600	3800	4000	4200	4500	4550	4600	4650	4700	4800	4900	5000	5050
1/7/2014 week1	99.7	99.7	98.8	88.6	44.8	27.7	13.6	4.8	0.1	0	0	0	0	0	0	0	0
1/14/2014 week2	99	98.3	93.2	74.3	28.5	15.8	7.8	2.3	0	0	0	0	0	0	0	0	0
1/21/2014 week3	99.3	98.2	94.3	76.5	33.3	20	10.8	3	0.1	0.1	0	0	0	0	0	0	0
1/28/2014 week4	99.2	98	93.6	76.7	34.1	21.6	10.3	2.8	0	0	0	0	0	0	0	0	0
2/4/2014 week5	99.4	98.6	96	80.6	39.1	23	11.4	4.4	0.2	0.1	0	0	0	0	0	0	0
2/11/2014 week6	99.4	98.7	95.6	78.2	38.1	23	11.4	5	0.3	0.2	0.1	0	0	0	0	0	0
2/18/2014 week7	99	98.1	95.7	81.3	41.2	25.2	13.7	5.9	0.4	0.3	0.1	0	0	0	0	0	0
2/25/2014 week8	99.5	98.8	96.5	82.2	44.4	29.6	14.5	5	0.5	0.3	0.2	0.1	0.1	0.1	0	0	0
3/4/2014 week9	99.1	98.4	96.8	83.9	44.2	27.5	15.1	6.1	0.3	0.3	0.3	0.2	0	0	0	0	0
3/11/2014 week10	99.3	98.6	95.9	82.3	41	25.9	14.1	5.4	0.7	0.2	0.1	0.1	0.1	0	0	0	0
3/18/2014 week11	99.1	98.7	95.5	80.4	41.4	26.7	13.8	6.9	0.3	0	0	0	0	0	0	0	0
3/25/2014 week12	99.4	98.3	96.3	81.5	41.2	28	15.6	7.7	1.1	0.6	0.5	0.3	0.2	0	0	0	0
4/1/2014 week13	99.4	99	97.8	87	51.1	36.1	20.3	9.1	0.7	0.5	0.3	0.3	0.2	0.1	0	0	0
4/8/2014 week14	99.7	99.2	97.9	91.2	62.2	42.8	26	13.6	2.4	1.6	0.8	0.4	0.2	0	0	0	0
4/15/2014 week15	99.8	99.7	99.3	96.5	69.8	53.4	33	14.9	2.7	1.7	1.3	0.8	0.3	0.1	0	0	0
4/22/2014 week16	99.7	99.7	99.6	96.4	74	60.8	41.6	22.7	4	3	1.7	0.7	0.4	0.1	0	0	0
4/29/2014 week17	99.8	99.7	99.1	97	79.6	66.8	48.8	27.6	4.8	2.8	1.9	0.7	0.3	0.1	0	0	0
5/6/2014 week18	99.7	99.7	99.6	98.6	85.5	74.9	58.5	37	7.6	4.3	2.4	1.3	0.7	0.3	0	0	0
5/13/2014 week19	99.8	99.8	99.8	99.1	91.3	82.2	68.7	48.1	14	9.8	6.3	4.1	2.5	0.5	0	0	0
5/20/2014 week20	99.8	99.8	99.8	100	94.6	88.3	76.5	58.6	20.2	14.2	10.6	7.4	4.6	0.9	0.1	0	0
5/27/2014 week21	99.8	99.8	99.8	99.9	97.6	93.2	84.6	68.1	29.1	22.9	17.7	12.5	8.2	2.8	0.4	0	0
6/3/2014 week22	99.8	99.8	99.8	100	98.3	95.7	90.7	80.5	44.5	37.6	30.7	23.7	17.3	6.3	1.2	0.1	0
6/10/2014 week23	99.8	99.8	99.8	99.9	98.7	96.5	89.2	79.5	51.8	44.9	36.2	29.3	23.1	11.9	2.2	0.1	0
6/17/2014 week24	99.8	99.8	99.8	99.8	99	97.6	93.7	87.2	60.6	54.8	47.8	40.1	32.2	15.5	4.6	0.8	0.2
6/24/2014 week25	99.8	99.8	99.8	99.9	99.1	97	93	88.1	65.3	59	51	44.6	37	20	7.7	1.1	0.2
7/1/2014 week26	99.8	99.8	99.8	100	98.8	97	94.4	88.5	71.8	66.3	59.8	52.6	46.4	27.7	12.6	2	0.3
7/8/2014 week27	99.8	99.8	99.8	100	99.1	98.1	95.5	90	73.2	69	63.6	57.5	51.1	33.7	15.5	3.8	0.8
7/15/2014 week28	99.8	99.8	99.8	99.9	99.1	97.7	95.6	92	77	72.4	67.3	61	54.7	38.9	20.9	5.8	1.9
7/22/2014 week29	99.8	99.8	99.8	99.9	99.1	98.6	96.1	92.9	79.8	74.2	69.4	63.4	56.2	40.3	24	7.5	3.2
7/29/2014 week30	99.8	99.8	99.8	100	99.3	98.1	96.1	92.1	78.4	75.1	71.3	66.3	59.3	44.3	26.1	9.2	3.7
8/5/2014 week31	99.8	99.8	99.8	100	99.6	98.4	96.9	92.7	77.5	74.2	69.5	65.1	60	43	25	11.4	5.1
8/12/2014 week32	99.8	99.8	99.8	100	99.7	98.7	96.1	92.4	77.3	73	68.8	64.3	59	42.6	26.2	10.1	4.9
8/19/2014 week33	99.8	99.8	99.8	100	99.5	98.3	95.7	91.2	75.4	70.9	66.1	60.7	55.8	39.8	25.1	9.8	3.8
8/26/2014 week34	99.8	99.8	99.8	99.9	99.5	98.6	95.9	90.4	73.2	69.4	65.2	59.6	53.3	37.3	21.4	8.1	3.5
9/2/2014 week35	99.8	99.8	99.8	100	98.9	97.2	94.4	87	68.2	63.9	59.2	53.5	47.6	33.7	19.8	7.1	3.2
9/9/2014 week36	99.8	99.8	99.8	99.9	98.1	95.4	91.4	83	63.3	59	53.7	48	42.1	29	16.5	5.8	2.1
9/16/2014 week37	99.8	99.8	99.8	99.5	95.5	92.1	86.8	78.6	55.7	50.7	45.4	39.3	33.4	21.8	11.2	3	1.2
9/23/2014 week38	99.8	99.8	99.8	99.4	94	89.5	81.5	71.6	47.6	42.4	38.2	31.6	26.3	15.5	6.4	1.3	0.5
9/30/2014 week39	99.8	99.7	99.5	98.7	93.4	86.9	79.1	67.1	42.6	36.9	31.6	26.9	21.3	11.4	3.8	0.3	0.2
10/7/2014 week40	99.8	99.8	99.7	98.5	88.8	81.9	72.1	58.4	29.8	24.6	19.8	15	10.5	5.4	2	0.2	0.1
10/14/2014 week41	99.8	99.8	99.6	98.1	86.9	76.3	62.5	45.7	19	15.1	11.1	8.1	5.3	2.1	0.5	0.1	0.1
10/21/2014 week42	99.8	99.8	99.4	96.2	80.4	67.9	53.8	37.7	11.7	9.6	7	5.1	3.2	1.3	0.3	0	0
10/28/2014 week43	99.7	99.6	99.3	96.8	73.3	59.8	44.8	26.4	7.9	5.7	4.6	3	1.7	0.5	0.1	0	0
11/4/2014 week44	99.8	99.7	99.1	93.3	65.9	51.9	35.2	18.5	3	2.4	1.6	0.9	0.6	0.2	0	0	0
11/11/2014 week45	99.8	99.4	98.5	90.6	61.5	45.1	29.5	14.7	2.6	1.7	1.1	0.8	0.3	0	0	0	0
11/18/2014 week46	99.4	98.9	97.5	87.9	53.4	37.7	20.7	9.8	1.3	0.8	0.2	0.1	0.1	0	0	0	0
11/25/2014 week47	99.4	99	96	85.7	48.1	31.8	18.7	8.3	0.8	0.6	0.3	0.1	0	0	0	0	0
12/2/2014 week48	99.6	98.5	96	81.2	38.7	27.5	13.7	4.9	0.4	0.4	0.1	0.1	0.1	0.1	0	0	0
12/9/2014 week49	99.4	99	96	79.2	37.3	22	9.5	4.3	0.5	0.3	0	0	0	0	0	0	0
12/16/2014 week50	99.1	98.2	95.8	78.8	33.6	21.1	10.4	3.8	0.4	0.3	0.2	0.1	0	0	0	0	0
12/23/2014 week51	98.9	97.9	93.8	75.1	33.4	19.5	10.5	3.2	0	0	0	0	0	0	0	0	0
12/30/2014 week52	99.5	97.9	94.5	73.5	30.6	19.1	8.9	2.9	0.1	0	0	0	0	0	0	0	0

Figure 5.4 A probability of exceedance graph for the weekly tons of sugar produced at Umzimkulu sugar mill.

Different LOMS scenarios were evaluated to further illustrate the results from the exceedance profiles. The scenarios represented in Tables 5.2 and 5.3 were done for three probability levels: 50%, 70% and 90%. As mentioned earlier, the term probability level meant the chances of the mill being able to meet its weekly target. For example, 50% meant the mill would be operating at a 50% chance of meeting their weekly target and with this level there is also a 50% risk of them not being able to meet their target. The 70% probability level meant the mill would be operating at a level that gives them a 70% likelihood of achieving their weekly target; a 30% risk is associated with this probability level. The same explanation applies to the 90% probability level and so on. These probability levels were chosen for demonstration purposes and to test the model. These values can easily be changed and adjusted to suit any mill requirements as they are not fixed. The tables were done to get an indication of how the LOMS affects the total amount of cane crushed and sugar produced whilst keeping the probability level constant at a mill.

Table 5.2 Tons of sugarcane crushed per season for different LOMS scenarios

		LOMS(weeks)		
Probability Level	**Area**	20	30	40
50%	**Umzimkulu**	581 250	854 250	1 108 750
	Sezela	1 002 500	1 432 500	1 832 500
70%	**Umzimkulu**	563 500	821 500	1 053 500
	Sezela	890 000	1 265 000	1 590 000
90%	**Umzimkulu**	520 000	748 000	960 000
	Sezela	770 000	1 060 000	1 310 000

Table 5.3 Tons of sugar produced per season for different LOMS scenarios

		LOMS(weeks)		
Probability Level	**Area**	20	30	40
50%	**Umzimkulu**	89 550	128 900	162 300
	Sezela	164 000	233 000	298 500
70%	**Umzimkulu**	85 250	121 650	152 250
	Sezela	150 500	210 000	264 500
90%	**Umzimkulu**	78 400	109 900	136 400
	Sezela	120 000	165 500	204 500

Table 5.2 shows that at a constant probability level, a change in the season length from 20 to 30 weeks for both mills, resulted in a 17-21% increase in the crush rate. An increase in the LOMS from 30 to 40 weeks resulted in a 16-20% increase for cane crushed at the mill. This is consistent with Todd *et al.,* (2004) who notes that in South Africa most of the cane is crushed during the dry winter months, and during this period the sucrose content is high. The same trend was noted for the tons of sugar produced in Table 5.3. The more the cane is crushed the more the quantity of sugar is obtained. Hence, the sugar produced followed the same trend most sugar was produced during the winter months of the milling season.

Table 5.2 however, shows a decrease in the crush rate as the probability level increases at constant LOMS. A change in probability from 50% to 70% resulted in a decrease of 1-11% in the crush rate. Increasing the probability from 70% to 90%, results in a 3-12% decrease in the crush rate. The same trends were also noted for the sugar produced in Table 5.3. The changes are relatively small which suggests that a mill can choose to operate at a medium probability level in this case, (70%) with minimal risks. The statistics apply to both mills, Sezela and Umzimkulu.

To evaluate the tons of cane crushed and sugar produced values in tables 5.2 and 5.3, the model took closest values equal or greater than the specified probability levels (50%, 70% and 90%) and not necessarily the exact probability level only. Hence, this explains the discrepancy on the relationship between cane crushed and sugar produced quantities. This could have had potential impacts on the cane to sugar ratios that were presented in the next discussion.

5.3 Cane to sugar ratio

The ratios in Table 5.4 indicate the proportion between the amount of cane crushed and the actual sugar produced at a 70% risk level. For example, at 20 weeks Umzimkulu mill has a ratio 1:6.61, implying that on average 6.61 tons of sugarcane crushed produces 1 tonne of sugar. For Umzimkulu mill the ratio of tons of cane crushed to tons of sugar made is increasing as the season length increases. This trend is supported by several studies that have confirmed that the sucrose content and recovery rates tend to decrease as the season length increases (Todd *et al.,* 2004; Masuku, 2009; Stray *et al*., 2012). For Sezela mill, the ratio increased for a LOMS of 20 and 30 weeks. However, for the 40 week LOMS the ratio decreased by 0.01, an anomaly which may be due to the fact that apart from rainfall, there are other factors specific only to Sezela, which are not being taken into consideration by the model such as mill breakdowns and inconsistent cane supply.

The mean cane to sugar ratios obtained using the observed data from Tables 4.2 and 4.3 were 8.5 and 7.55 for Sezela and Umzimkulu respectively. The values in Table 5.4 were not in this range. This discrepancy might have been caused by the fact that Table 5.4 shows rations that were taken over a range thousand years at a set static 20, 30 and 40 week LOMS. However, in reality the LOMS is not static and it is usually adjusted depending on rainfall and quality of cane for that season. Furthermore, as mentioned in the previous section, the cane to sugar ratios did not follow the expected trend because the model considered the closest values possible to the probability level (70%) and not the precise probability level.

Table 5.4 Ratios of tons of sugar made to tons of cane crushed

	LOMS/weeks		
	20	**30**	**40**
Umzimkulu	1: 6.61	1: 6.75	1: 6.92
Sezela	1: 5.91	1: 6.02	1: 6.01

5.4 Making LOMS-related decisions based on different cane crushing estimates

To decide upon the LOMS, the MGB uses estimates given by farmers to determine how long the crushing season should be (de Lange and Singels, 2003). The decision support graphs in this section further illustrate how they aid in the LOMS decisions. The terms that were regularly used to explain Figures 5.5 and 5.6 are “probability” and “chance”. Probability in this context refers to likelihood of the mill crushing a set weekly target and chance refers to the likelihood of achieving a set seasonal crush goal. The plots below represent three probability level scenarios and show how at these levels the chances of crushing the seasons target varies. This was important to aid decide on the recommended weekly probability level that was associated with high profits and low risks.

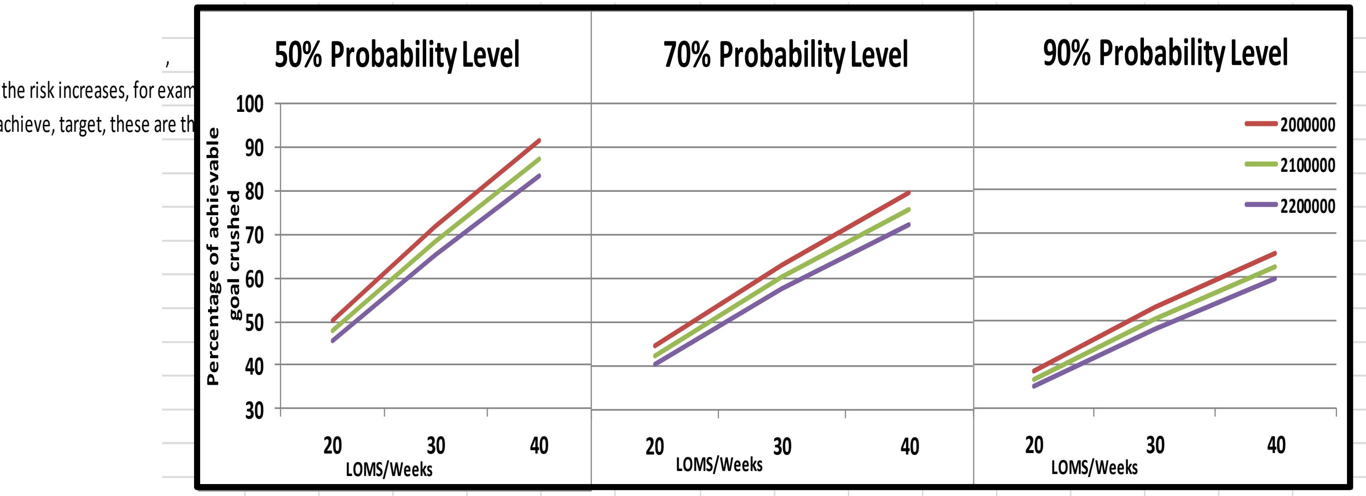

Figure 5.5 Graphs of Percentage of goal crushed versus the LOMS at 50%,70% and 90% probability levels for Sezela mill

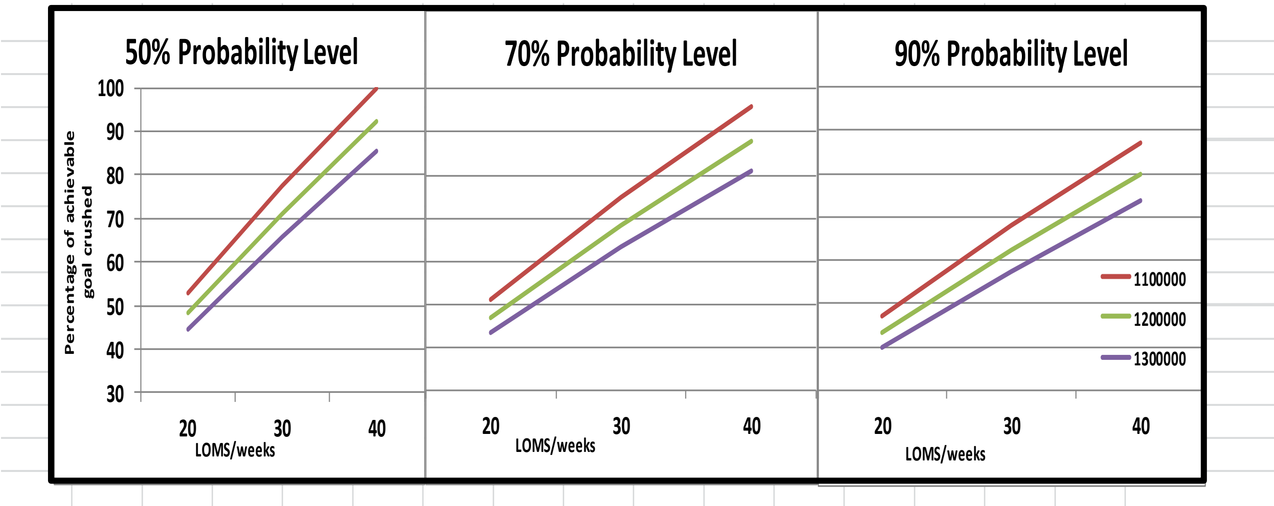

Figure 5.6 Graphs of Percentage of goal crushed versus the LOMS at 50%, 70% and 90% probability levels for Umzimkulu mill

Figures 5.5 and 5.6 show that as the LOMS increases the chances of meeting the crush target increases. This is indicated by the lines that are going up on the plots. Figure 5.5 shows that at Sezela mill there is almost 80% chance of the mill crushing a minimum target of 2 00 000 tons of sugarcane at a 40 week LOMS. On the other hand there is about 72% chance of crushing a maximum target of 2 200 000 tons of cane at 40 weeks LOMS only if using the 70% probability level. The Sezela mill's actual crushing capacity is 2 200 000 tons (Lyne, 2015). The three graphs in Figure 5.5 shows that the highest chance of obtaining the maximum crushing capacity is about 84% at a 50% probability level. The lowest chance of meeting the 2 200 000 tons target is 60% at a 90% probability level. Hence the mill might choose to run at an operating level of 70% probability level where there is a fairly high chance to fully utilise the mill's capacity and a fairly low risk level of 30%. The 50% probability would not be advisable because it also corresponds to a higher 50% risk level. The 90% probability has the least risk of 10% but it has the lowest chances of attaining the crush goal, hence not recommended.

For the Umzimkulu mill, Figure 5.6 shows that there is a 100% chance of meeting the lowest crushing target of 1100 000 tons at a 50% probability level at a 40 week LOMS. In fact, all three graphs indicate about 85-100% chances of meeting the 1 100 000 tons target with a LOMS of 40 weeks. At a 1 200 000 tons crush target, Figure 5.6 shows that there is more than a 80% chance of meeting the target at 50% and 70% and 90% probability levels with LOMS below 40 weeks. The high chances (greater than 70%) at all three probability levels suggests that the Umzimkulu mill is well underutilised and that 300 000 tons cane could be added easily to the annual crop to crush a total of 1 300 000 tons.

The actual average crushing capacity of Umzimkulu mill is 1 300 000 tons per season (Lyne, 2015). Figure 5.6 depicts that the highest chance of this crushing capacity is about 83% at a 50% probability level. At a 70% probability level the chances of attaining the maximum crushing goal (1 300 000 tons) is 80%, and at a 90% probability level the chances are about 75%. Therefore, based on the plots, it is advisable for the mill to run at a 70% probability level as there is a relatively high chance of fully utilising the mill capacity with a low 30% risk involved.

At both Sezela and Umzimkulu mills, the chances of fully utilising the mill are highest with a LOMS of 40 weeks. Logically, a mill crushing at a 90% probability level should have the highest chances of meeting the seasonal goal. The Figures 5.5 and 5.6 showed otherwise. In fact the 90% probability level was associated with the lowest chances of the mill being able to meet its seasonal goal. This is because in reality, a 90% crushing level is very difficult to attain due to several reasons. At the mills, there are factors that influence the day-to-day running of the mill reducing its efficiency. Preliminary results of this research reveal numerous cane supply issues such as overestimation of cane, shortage of cutters, no-cane stops, mill breakdowns, strikes and cane diversions to be some of the factors that could potentially erode the mill's excess milling capacity. These factors were not included in the model. Building up a model that includes some, or all of the mentioned factors might improve the model performance.

Figure 5.7 is a simple a plot that shows the percentage of the total harvest of cane crushed at different intervals during the harvest season. The plot outlines that at a constant mill crush rate of 20 000 tons, the mill takes 40 weeks to crush a harvest of 800 000. Figure 5.8 illustrates three harvests 551 200, 1 102 400 and 2 204 80 tons of cane crushed at Sezela at a constant rate of 30 000 tons per week.

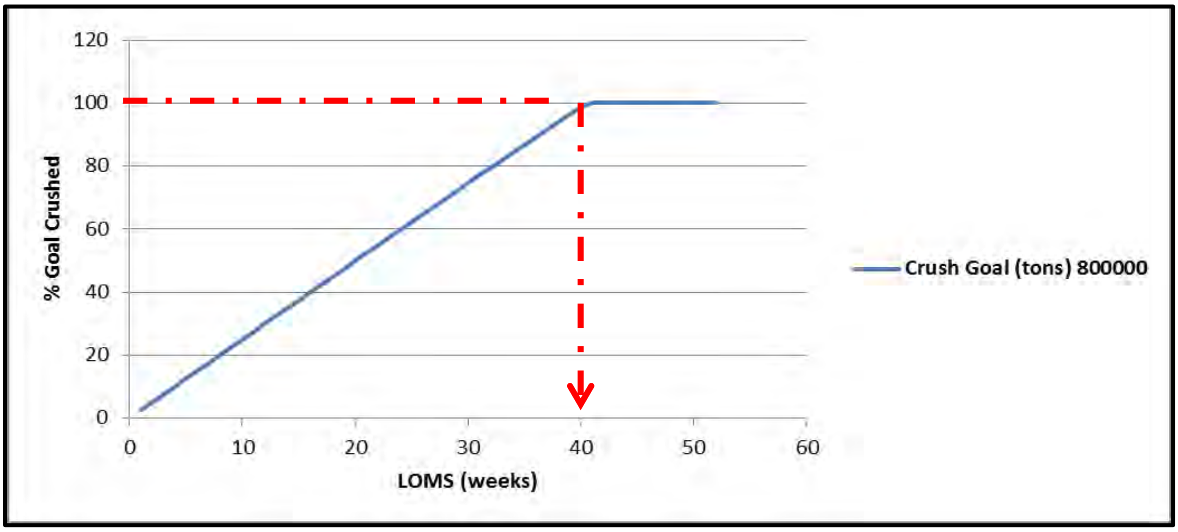

Figure 5.7 A plot showing 800 000 tons of cane crushed at Sezela at a constant rate of 20 000 tons per week

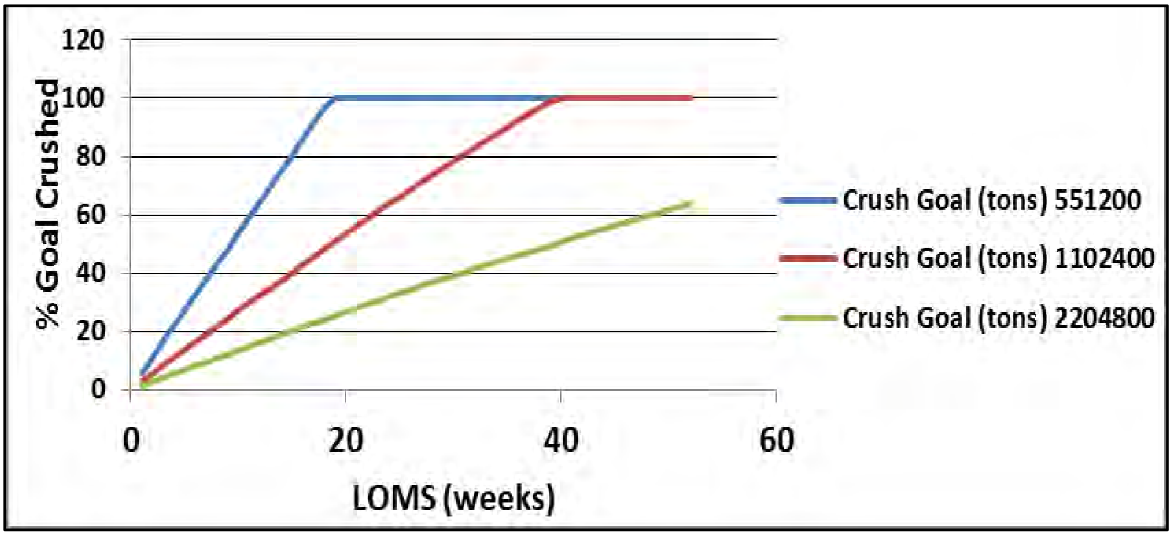

Figure 5.8 Plot showing 551 200, 1 102 400 and 2 204 800 tons of cane crushed at Sezela at a constant rate of 30 000 tons per week

The aim of Figure 5.8 was to find the weekly crush rate that achieved the mills crushing goal within an acceptable LOMS between 30 and 40 weeks. The plot shows that at a weekly crush rate of 30 000 tons, the lowest crush goal of 551 200 tons can easily be attained with a 20 week LOMS but such a short season is not sustainable for the mill. A 1 102 400 tons crush goal is being attained at about 38 weeks and this is within the acceptable LOMS. Lastly, the plot depicts that at such a crush rate it not possible to crush a much higher crush goal of 2 204 800 tons even after 40 weeks. Therefore, depending with the harvest estimation for the season, this means that the mill can only attain a maximum crush goal of 1 102 400 tons running at a 30 000 tons weekly crush rate. Otherwise, for higher crush goals an increase in its weekly crush rate is required if the mill is not being fully utilised. Figure 5.9 illustrates three harvests of 308 880, 617 760 and 1 235 520 tons of cane crushed at Umzimkulu at a constant rate of 18 000 tons per week.

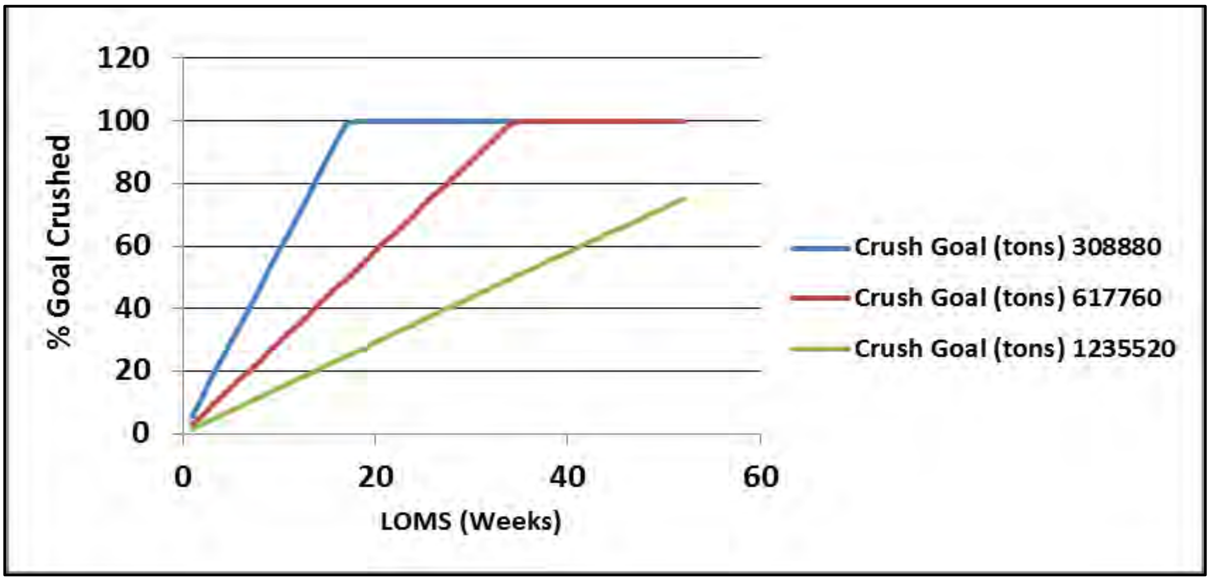

Figure 5.9 Plot showing 308 880. 617 760 and 1 235 520 tons of cane crushed at Umzimkulu at a constant rate of 18 000 tons per week

Figure 5.9 investigates the LOMS based on 3 harvest scenarios at a constant mill crush rate of 18 000 tons. According to the graph, the lowest crush goal of 308 880 is being fully realised at a low 18 weeks. The following crush goal of 617 760 is being attained at a 36 week LOMS. Lastly, the plot shows that only 77% of the 1 235 529 tons of cane can be crushed at a LOMS of about 52 weeks. These values indicate that if the mill anticipates a harvest greater than 1.2 million tons for a particular season, it has to work at a crush rate greater than 18 000 tons for it to attain a sustainable LOMS between 30-40 weeks. The plots also indicate that crushing 18 000 tons/week does not fully utilise the mill capacity; a higher crush rate is required especially for higher crush goals. Figures 5.8 and 5.9 demonstrated the percentages of cane crushed throughout the milling season at a particular constant weekly crush rate. Figures 5.10 and 5.12 demonstrate the percentage of cane crushed throughout the milling season at variable weekly crush rates. The variable weekly rates used in Figures 5.10 and 5.12 were selected from the weekly crush rates used by the model and represented on the top rows of the exceedance profiles shown in Figures 5.1 and 5.2. These rates were multiplied by the respective probability of exceedance for each week to obtain a net cane crushed value relative to that indicated by the Mill Operating Capacity.

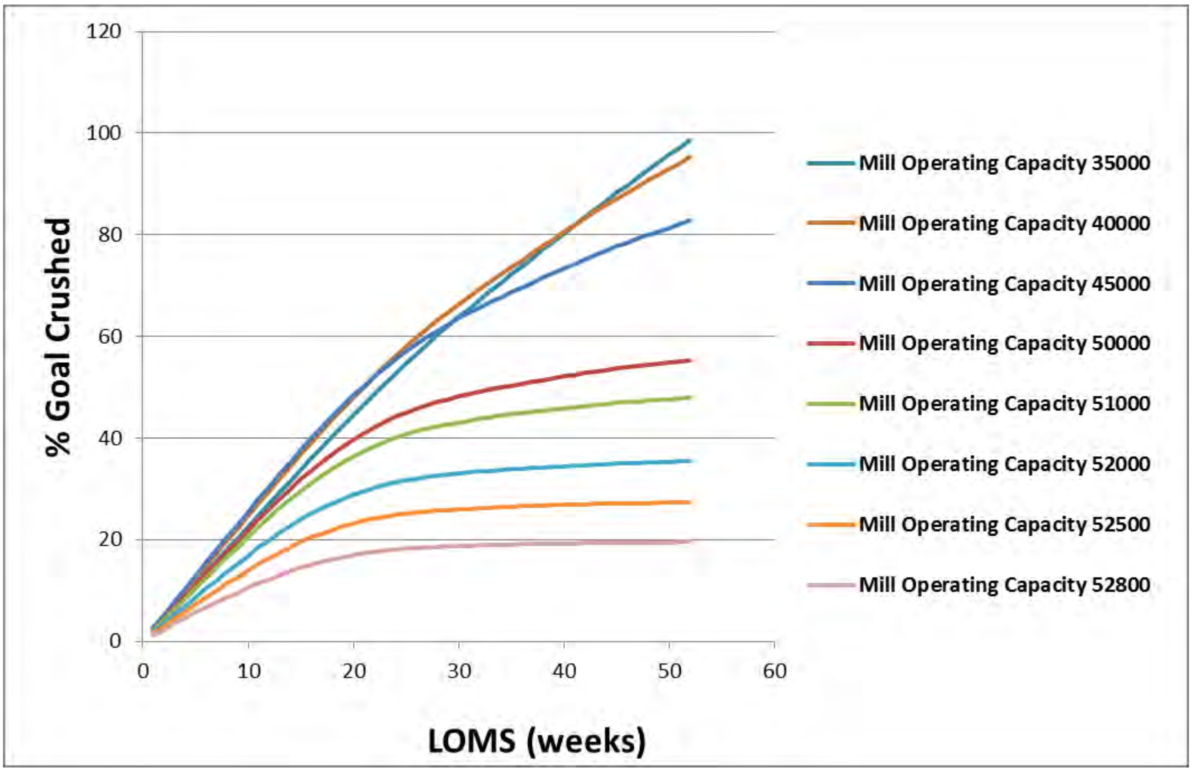

Figure 5.10 Graph indicating percentage of goal of 1 500 000 tons of cane crushed at Sezela with realistically variable weekly crush rates

Figure 5.10 presents several scenarios that show the percentage of the harvest crushed at different intervals of the harvest season at various crush rates. The different weekly crush rates are represented by the different colour coded lines on the plot as well as the legend alongside. The crush rates used on the plot were chosen for demonstration purposes and can easily be changed. For example, Figure 5.10 illustrates that if the MGB decides to crush 35 000 tons per week (indicated by an arrow on the plot), there is almost a 99% chance that they will achieve their crush goal of 1 500 000 tons per season. As the crush rates increase, the percentages of goal crushed are reduced. This might have been due to the reason that at times there is less cane supplied to the mills and with a low crushing rate the mill may need more than 52 weeks to achieve a crush goal of 1.5 million.

Figure 5.11 is the plot of sugar produced corresponding to the crush rate plot in Figure 5.10. The mill produced sugar at a rate of 3500 tons per week for a crush goal of 1 500 000 tons.

The plot indicates for a LOMS that ranges between 30-40 weeks, the corresponding amount of sugar produced ranges between 103 866 to 137 047 tons. The plot just aids to give an estimation of the actual sugar that might be produced from the estimated harvest.

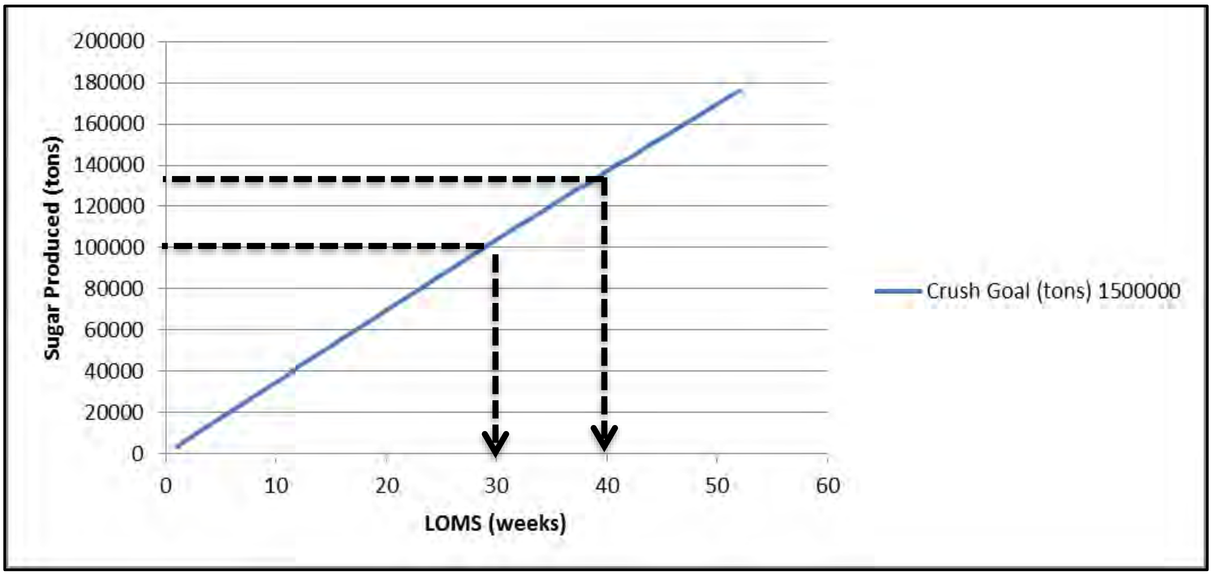

Figure 5.11	Graph illustrates the total sugar produced at a rate of 3 500 tons/week from a total of 1 500 000 tons of cane for Sezela mill

Figure 5.12 shows several scenarios of variable crush rates at a fixed crush goal to crush 800 000 tons of cane at Umzimkulu sugar mill. The various mill capacities are colour and indicated by the legend alongside to the graph. According to the plot, only crush rates lower than 26 500 tons have a 100% probability of achieving the goal. However, the 26 500 tons weekly crush rate only achieves the crush goal with a LOMS of 43 weeks, so this already means this rate is not favourable to the mill. Lowering the crush rate to 25 000 tons is resulting in an acceptable 36 week LOMS which can be the recommended operating crush rate for the 800 000 tons crush goal. As the crush rate increases the percentage of goal crushed decreases with the LOMS increasing up to 49 weeks. The lines in Figures 5.10 ad 5.12 were curved due to the use of constant crush rate and varying the probability to meet the goal based on matrix for the season as indicated by figure 5.2. Therefore, it is advisable for the mill to vary its weekly crush rate depending on availability of cane and this would be indicated by a straight line graph. The corresponding sugar produced from the recommended cane crushed in Figure 5.12 is shown in Figure 5.13.

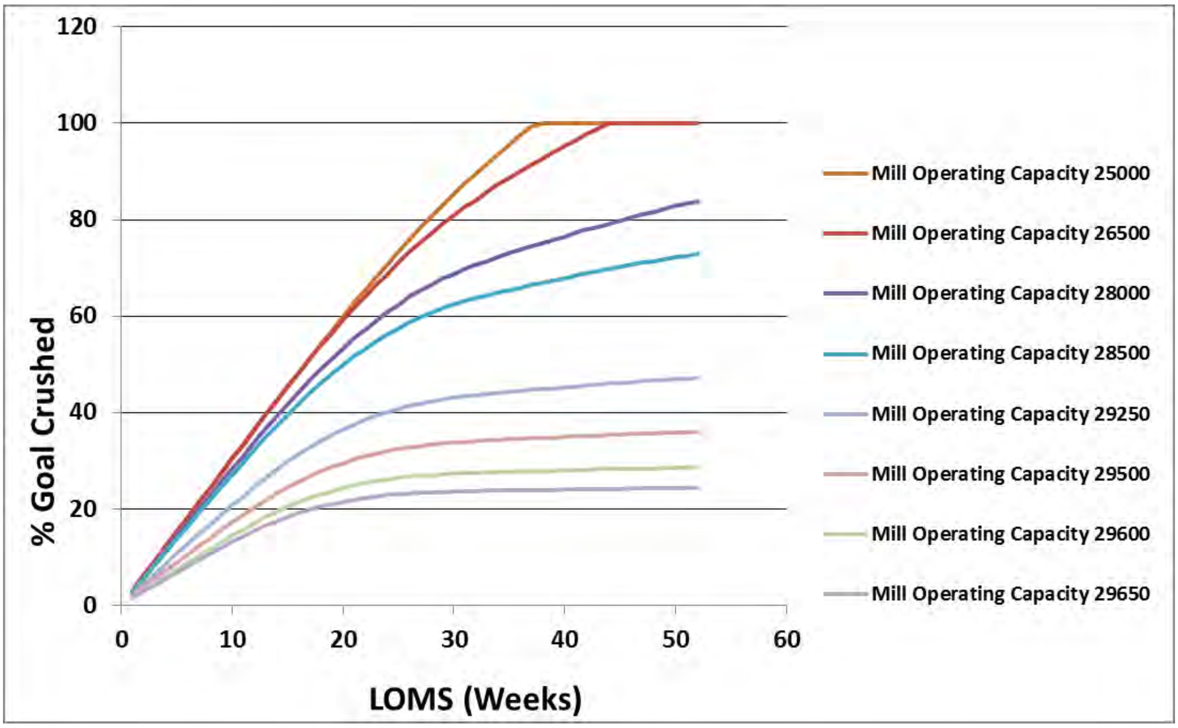

Figure 5.12 Graph indicating percentage of goal of 800 000tons of cane crushed at Umzimkulu with realistically variable weekly crush rates

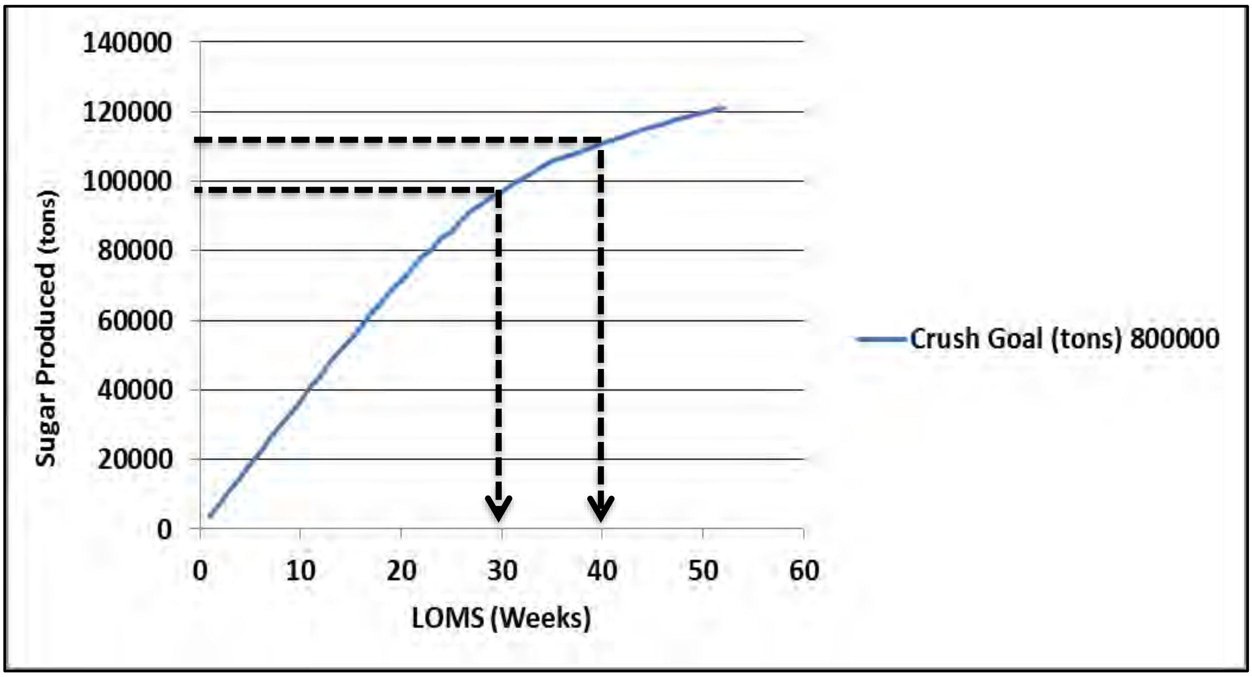

Figure 5.13 Graph of total sugar produced at a rate of 3 800 tons/week versus the LOMS from a total crush goal of 800 000 tons for Umzimkulu mill

Figure 5.13 is a plot of sugar produced based on the 800 000 tons of sugarcane crushed in Figure 5.12. According to the graph a crush goal of 800 000 tons resulted in production of 3800 tons of sugar per week. The graph also indicates that for a 30-40 weeks LOMS range, 96 000 to 110 000 tons of sugar are produced, respectively. In addition to the crush rate plots, the sugar produced plots aid by giving the MGB an indication of the actual amount of sugar they can expect during the season.

6. CONCLUSION AND FUTURE RESEARCH RECOMMENDATIONS

This section contains the concluding remarks of this project and suggestions for areas of further research.

6.1 Conclusion

The impacts of wet weather on the sugarcane supply chain and ultimately the LOMS were thoroughly reviewed at the beginning of the project. This was important since weather was one of the major components that made up the LOMZI model for the two areas of study Sezela and Umzimkulu. The review outlined that wet weather results in cane lodging, water logged fields and no cane-stops. Wet weather also has negative implications on cane quality, burning, harvesting, transportation and ultimately on the profits from sugar production.

Every mill area has its unique needs and therefore it requires its own customised solutions to the LOMS issue. To acquire a more realistic picture of the issues affecting the supply chain of sugarcane at the areas of study, a diagnostic study was performed. The study involved telephonically interviewing different stakeholders in the sugar industry. Some of the issues that were emphasised as affecting the LOMS included wet weather, labour absenteeism, harvest-crush delays, overestimation of cane by growers, and over fleeting of the system.

After identifying the issues affecting the LOMS, the LOMZI model was then used to simulate the LOMS. The purpose of the model was to investigate the impact of rainfall on sugarcane quality parameters (pol, brix and fibre) and ultimately on the LOMS of Sezela and Umzimkulu sugar milling areas. The LOMZI model consisted of three components, namely, quality, crush rate and ClimGen weather generator.

The quality model predicted the daily average Brix%, Pol% and Fibre% by utilizing available records of quality and weather data. The model's performance was verified using independent data for the two mills at Sezela and Umzimkulu. The R^2 values ranged between 0.78 and 0.90 and these were based on few years of data that were available. The correlation values were relatively high and this depicted that rainfall was significantly affecting the quality of sugarcane at the areas that supply the cane to the mill. Secondly, the crush model simulated the amount of cane crushed at a particular mill per day, and was based on recent rainfall events that the mills experienced. The performance of the crush model was verified, and the R^2 for the study areas ranged from 0.52 to 0.69 and it was averaged over a few seasons of data that were available. The quality and crush models used the GRG-non-linear approach with about 90 calibrating coefficients and 15 coefficients respectively. All the coefficients were determined by the Solver add-in. The aim of the Solver add-in was to maximise the correlation between the observed and simulated crush quantity and cane quality.

The LOMZI Model used weather data imported from a stochastic weather generator called ClimGen. ClimGen was used to generate a thousand years of weather data based on past weather patterns of the study areas. Twenty-five years of weather data was obtained from the SASRI Weather Web and used the ClimGen model to produce a thousand years of rainfall and temperature data. However, the efficiency of the model could be improved if all the homogenous zones had complete sets of weather data for the previous 25 years.

The LOMZI model used weather data generated by ClimGen and calibration coefficients from the quality and crush models to generate a thousand seasons of daily tons of cane crushed and sugar produced. The model performed satisfactorily in simulating the cane crushed and sugar produced. The high correlation values between the actual and simulated data indicated that rainfall significantly affects the LOMS at the areas of study. Sezela and Umzimkulu simulated data exhibited similar discrepancies in the results. This was due to the fact that the homogenous climatic zones for the two areas experience very different climatic conditions. The areas are separated into three zones namely, coastal, hinterland and inland. As a result, the cane in these areas matures at different times.

The simulated results of cane crushed and sugar produced were presented using exceedance profiles. The probability exceedance profiles contained weekly targets for the whole season, along with the corresponding chances of meeting those weekly targets. This is for both the crushing rate and sugar produced. The profiles exhibited an interesting interrelation between high weekly crush rate resulting in not meeting seasonal crush goal against a low weekly crush rate resulting in meeting the target but running the risk of extending the season into the wet summer months. 50%, 70% and 90% probability levels were plotted on three harvesting scenarios to investigate and find the recommended operating level which provides the highest chances of the mill meeting its seasonal crush target within an acceptable LOMS and a low risk level. The plot showed the 70% probability level to be advisable to use compared to the 50% and 90% scenarios.

To further represent the results in a more realistic way, decision support graphs were created to provide a simple diagrammatic picture that would provide more information to aid the MGB in the LOMS decisions. The graphs can also aid when deciding when in the season the chances of meeting the weekly target lies with minimum risks involved. Furthermore, the graphs provide the flexibility to be adjusted to set to any target. This can be useful in order to minimize risk, maximise mill utilisation, production and ultimately the profits for Sezela and Umzimkulu sugar mills. Hence, it is advisable that the mills should consider a variable crush rate with a maximum in the middle of the season when there is a higher probability of reaching their target as illustrated by the exceedance profiles.

6.2 Recommendations for future research

The project was an overall success and in the process of aligning the LOMZI model to the two mill areas, some areas to further improve the performance of the model were identified but could not all be incorporated into the model. Hence, this section lists the possible areas of further research and other areas where the model could be applied.

- For future research, performance of the quality model could be improved by using more seasons to build the model.
- During telephonic interviews, it was regularly mentioned that Eldana regularly affects sugarcane in the South Coast areas. Therefore, it would be ideal if the model considers the effects of pests and diseases such as, Eldana.
- The model performed satisfactorily, however it has not been thoroughly trained to pick up irregular crush and weather patterns, especially sharp dips and peaks in the data trends. Future research could aim at improving the model's performance to account for irregularities such as floods and drought and frost.

- At the mill, delays occur due to various reasons. During these delays the quality of sugarcane at the mill yard decreases. Hence, including a decrease in quality at the mill yard factor might improve the model results.
- Apart from rainfall and temperature there are other supply chain components that may influence quality and crush rate of cane at the mill. For future recommendations issues such as mill cane shortage, mill breakdowns, pay weekends and strikes need to be included in the LOMZI model.
- The crush rate model was calibrated using seven seasons. Calibrating and verifying the model using more past seasons as well as recent seasons could also help the results.
- The ClimGen weather generator was used in this project. However, for the future using two or more weather generators will allow for comparisons to be made.
- Due to the fact that some of the weather data was missing for some of the homogenous climatic zones, there is a chance that the performance of the model might improve if the missing weather data is included when training the model. Using more than 25 years of rainfall and 10 years of temperature might improve the weather data values.
- Reducing the number of simulations from a 1000 seasons to maybe 20 seasons could help reduce the volume of data to analyse and focus on irregular conditions such as floods and drought in the simulations.
- The South Coast homogenous climatic zones experience different weather conditions and due to this the cane matures at different times. Including a factor in the model that takes into account these differences is something that can be done in the future.
- Develop decision support graphs that display and quantify how other issues such as mill breakdowns, pay weekends and strikes are affecting the LOMS at the milling areas can be conducted.
- Including an economic analysis on sugar produced and crush rate results of the LOMZI model could help in further explaining the results.
- It would also be advisable to further verify the model performance against more recent data of 2014 and 2015 and perhaps to continue for the next few seasons to monitors exactly the models ability to predict the LOMS.
- Applying the modelling approach that was developed in this study to other areas of bio-resources production, for example in fruit and vegetable production is another

possible area of further research. In this case the mail changes in the model would be shortening the season and adding the other weather elements that affect fruits and vegetables.

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