A COMPREHENSIVE QUALITATIVE AND QUANTITATIVE ASSESSMENT OF HARVESTING AND OTHER SUGARCANE SUPPLY CHAIN DISRUPTIONS WITHIN THE ESTON MILL SUPPLY AREA

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ABSTRACT

The Eston Mill, which was established in 1994, is the newest in the KwaZulu-Natal sugar belt. Like for most other mills, it can be argued that there are inefficiencies in the supply chain due to systemic issues, which reduce optimum performance. The literature study involved a review of the factors which cause inconsistencies in sugarcane supply chains and the strategies implemented for improvement. This research study involved five main aims. First, a novice qualitative diagnostic analysis of the Eston sugarcane system, to identify a range of systemic issues and one pertinent problem, involving pay-weekends and subsequent labour absenteeism, was isolated for further investigation. This was conducted through explorative interviews and network analysis approaches. Secondly, based on the information from the diagnostic analysis, a model that predicts and quantifies the factors which influence daily crush rate disruptions at Eston, was developed, validated and verified. Thirdly, the extent of the pay-weekend problem area was systematically estimated in terms of frequency, variability and predictability. Fourthly, the cost of cutter absenteeism was conservatively quantified, based on two factors, namely, sugar recovery and mill operational costs. Lastly, a case study was carried out, which involved the feasibility of a mechanical harvesting system, to mitigate the impacts of labour absenteeism. The model involved the calibration of parameters for mill maintenance and operational stops, rainfall events and days in the week when slow crush rates occurred. The model captures approximately 64% of the variation observed in daily crush rates. Subsequent to the development of the model, additional cane supply disruptions, caused by cutter absenteeism, were also investigated. It was statistically verified that a significantly detectable degree of labour absenteeism occurs immediately after pay-weekends. There has been a general increased trend in cutter absenteeism from about 2007 until 2010. An economic analysis estimated the costs associated with cutter absenteeism to be approximately R1.3 million per season, for the Eston region. The alternative harvesting system case-study solution, was found to be risky. However, acquiring second-hand equipment, which was available on the market, is estimated to make the solution more feasible. Based on a literature search, this research is considered to be the most comprehensive analyses of sugarcane supply consistency at mill-scale worldwide. The model developed can be utilized to critically evaluate different sugarcane milling areas and could potentially make significant contributions to commercial sugarcane operations. The

effectiveness of the model is dependent on usage in other milling areas, as well as other industries. In addition, the specific labour absenteeism coefficients for each season can possibly be investigated using other industries as well.

PREFACE

I .... declare that

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G. F. Ortmann

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ABBREVIATIONS

BHTCD:	Burn-harvest-to-crush-delay
LOMS:	Length of milling season
DRD:	Daily rateable delivery
RV:	Recoverable value
ERC:	Estimated recoverable crystal
FIFO:	First-in-first-out
IPM:	Integrated Pest Management
SMS:	Short message service
MANOVA:	Multivariate Analysis of Variance
ADCR:	Actual daily crush rate
SASRI:	South African Sugarcane Research Institute
HCZ:	Homogeneous climatic zones
LTM:	Lower-trimmed mean
PDCR:	Potential daily crush rate
MDCR:	Modelled daily crush rate
BD:	Mill breakdowns and maintenance stops
OC:	The estimated economic losses associated with cutter absenteeism in the Eston area
S_{ERC}:	Estimated value of the additional sugar that would have been processed without cutter absenteeism
M_C:	Estimated sum of the additional daily mill operational costs, due to cutter absenteeism
TS:	Estimated total available funds to the Eston area, with the mitigation of cutter absenteeism,
R_B:	Conventional harvesting and haulage cost for sugarcane in the Eston area,
S_M:	Estimated total available funds to the Eston Sugar Mill, with the mitigation of cutter absenteeism
S_G:	Component of the available funds, with the mitigation of cutter absenteeism, allocated to growers in the Eston area
S_B:	Component of the total available funds, with the mitigation of cutter absenteeism, allocated to the Beaumont Estate

$S_{G'}$: Component of the total available funds, with the mitigation of cutter absenteeism, allocated to all the other growers (Beaumont Estate excluded)

S_{Illovo}: Estimated total funds available, with the mitigation of cutter absenteeism, allocated to the Illovo Group.

1. INTRODUCTION

1.1 Background to the Study

The South African sugar industry has existed since the middle of the 19th century (SACGA, 2012). The industry contributes significantly to employment, especially in rural areas. More than two percent of South Africa's population depend on this industry for a living (SASA, 2012a). The industry has created direct employment for approximately 79 000 people (SASA, 2012a). It is estimated that an annual average direct income of R8 billion is generated towards the national Gross Domestic Product, with sugarcane production contributing about R5.1 billion (SASA, 2012a).

Sugarcane farming in South Africa takes place mostly in the KwaZulu-Natal Province, but sugarcane is also grown in Mpumalanga and in the Eastern Cape. There are 14 sugar mills operating in these regions and sugar is produced by six milling companies. There are approximately 29 130 registered sugarcane growers (SASA, 2012a). The industry produces a season average of about 20 million tons of sugarcane, which results in an average of approximately 2.2 million tons of sugar per season. About 60% of the sugar produced is consumed domestically and the rest is exported (SASA, 2012a).

Lower commodity prices and increased international competitiveness have resulted in many agricultural industries investigating supply chain opportunities, which would increase profitability (Georgiadis *et al.*, 2005; Chiadamrong and Kawtummachai, 2008). The sugar industry is no exception. In order to remain internationally competitive, the South African sugar industry has been under growing pressure to increase overall sugar supply efficiencies and to reduce costs (Wynne, 2005; Le Gal *et al.*, 2008). This is mainly due to the deregulation of the agricultural sector (Gaucher *et al.*, 2003). In addition, there has been a decreased supply of sugarcane in South Africa, for various reasons (*cf*. Davis *et al.*, 2009; Smith *et al.*, 2010).

The sugar industry in South Africa is well-known and is regarded as relatively efficient (Le Gal *et al.*, 2008). However, optimal resource allocations could be hindered due to the presence of some inefficiencies in the system. Most of these inefficiencies are due to the various stakeholders having different overall objectives. Each stakeholder aims to fully optimize his/her individual processes, rather than the chain operation (Lejars *et al*., 2008; Le Gal *et al*., 2008; Piewthongngam *et al*., 2009). Gaucher *et al*. (2003) state that the focus must be kept on improving the coordination between the grower and the miller. This will improve productivity and reduce uncertainties in the supply of cane to the mill (Cassivi, 2006; Lejars *et al*., 2008).

Research has revealed that many opportunities exist in the overall supply chain, which could result in significant benefits to the sugar industry (Le Gal *et al*., 2008). Micro-optimizing approaches are often used, but they may lead to disagreements between stakeholders, because of the complex and integrated nature of the production system (Gaucher *et al*., 2004; Piewthongngam *et al*., 2009). Lejars *et al*. (2008) and Bezuidenhout and Baier (2011) found that much research in the sugar industry has not been implemented. Proposed solutions have excluded collaboration, innovation and information-sharing issues in the supply chain (Bezuidenhout *et al*., 2012b). In addition, Higgins *et al*. (2007) state that there have been limited studies on supply chain solutions for the sugar industry, compared to the manufacturing and automobile sectors. This is mainly because agricultural industries, including sugar, are generally more complex (Higgins *et al*., 2007; Chiadamrong and Kawtummachai, 2008; Bezuidenhout *et al*., 2012a).

The aim of sugarcane supply is to deliver the agreed amount of cane to the mill, when required, and to use resources optimally (Amu *et al*., 2013). The integration of the sugarcane supply chain can result in increased revenues, but the complexity of cane supply operations may create other vulnerabilities in the system (Boote *et al*., 2013). The numerous activities, from different resources, that form part of the sugar supply chain, require holistic management (Bezuidenhout and Baier, 2011; Thorburn *et al*., 2011). In addition, there are limited techniques available to quantify and predict the impacts of a decision. This can result in actions taken that do not always yield the expected results (Amu *et al*., 2013).

Before any significant improvements can be made, the sugarcane supply chain must, therefore, be researched more holistically than in the past, while considering various concurrent issues (Le Gal *et al*., 2004; Bezuidenhout and Baier, 2011). Furthermore, to unlock the potential for improving the supply of cane to the mill, methods are needed that will aim to capture the complexity of the system (Thorburn *et al*., 2011). Once this is created, the stakeholders are required to discuss and review the potential changes (Muchow *et al*., 2000; Piewthongngam *et al*., 2009). It has also been argued by Bezuidenhout *et al*. (2012a) that a "one-size-fits-all" approach to optimizing systems is unlikely to be a successful solution in the sugar industry. This is due to each mill being unique because of its history and the various biophysical issues on the ground, at different times. In addition, optimization approaches used alone may lead to solutions, but do not usually solve problems, because researchers may lack an understanding of the softer social issues (Gaucher *et al.*, 2004; Lejars *et al.,* 2008).

The Eston Mill, which was established in 1994 to replace the old mill at Illovo, is the newest in the KwaZulu-Natal sugar belt. The Eston Mill forms part of the Illovo sugar milling consortium. The average annual rainfall in the region ranges from 800 mm to 900 mm and the average temperature is about 18-19°C. The mill crushes an average of about 1.26 million tons of sugarcane annually, which results in approximately 125 000 tons of sugar and 51 000 tons of molasses (Lumsden *et al*., 2000; Department of Transport, 2011; Thompson, 2011). There have been previous studies conducted in the Eston region (Steindl, 1996; Lumsden *et al*. 1998; 2000; Lyne *et al*., 2005), however, to the author's knowledge, holistic integrated systems research has not yet been carried out in the Eston area.

1.2 Aims and Objectives

This study followed a different research approach, compared to conventional scientific investigations. Due to the complexity of the system, the specific issue to be investigated was not identified at the outset of the study. The aim of this study was therefore two-fold. Firstly, to identify a specific shortcoming in the complex integrated Eston system. This was conducted by analyzing the complexities in the area and is a relatively small component of the study, as discussed in Chapter 3 of this thesis. The issue that was identified involved cane supply consistency, especially due to cutter absenteeism. Having done this, the study then focused, in particular, on evaluating the impacts of harvesting and other disruption factors (Chapters 4 and 5), with an emphasis on finding a possible solution to mitigate cane cutter absenteeism in the Eston area (Chapters 6 and 7).

Specific aims and research road map:

1. A literature review is presented in Chapter 2, which discussed the causes of inconsistencies and the strategies used to improve sugarcane supply chains. Special attention is given to the literature that focused on sugarcane supply chains, from the field through to mill processing.

2. An exploratory diagnostics study is carried out in Chapter 3, to identify systematic issues that drive inefficiencies and reduce performance in the Eston sugarcane supply chain. The work is carried out through qualitative explanatory stakeholder interviews and network analysis approaches, which assists in determining a key opportunity for further research.

3. The investigation in (2) identified cutter absenteeism as a critical issue at Eston. Given this, a comprehensive daily cane supply analysis of past seasons is performed in Chapters 4 and 5. This is conducted using three statistically robust methods, in order to systematically estimate the impact of cutter absenteeism, as well as other disruption factors, in terms of frequency, variability and predictability.

4. The specific costs of cutter absenteeism, in terms of risk and profitability to the Eston region, is estimated in Chapter 6. The estimation is based on two quantifiable factors, namely, sugar recovery and mill operational costs.

5. Under a series of assumptions, a mechanical harvesting solution, to mitigate the impacts of cutter absenteeism, is proposed and evaluated in Chapter 7. The work considers various factors, including the cost and feasibility of the solution, the distribution of funds available among stakeholders, physical field constraints, as well as certain risks involved.

6. The conclusions are then synthesized in Chapter 8 and, in addition, future recommendations and issues that require further research are identified.

2. A REVIEW OF SUGARCANE SUPPLY CHAIN INCONSISTENCIES

In this document, a supply chain is defined as an integrated production network of people, organizations, activities, information, resources involved in the creation, distribution and sale of a product (Stevens, 1989; Thomas and Griffin, 1996; Maloni and Benton, 1997; Lambert and Cooper, 2000; Chen and Paulraj, 2004; Heng *et al.*, 2005). The system works together, with the aim of acquiring raw materials and converting them into a specific final higher-value product, which is then distributed to the consumer (Beamon, 1998; Pitty *et al.*, 2008). This can be achieved by using processing activities, such as transportation, storage and market mediation (Das and Abdel-Malek, 2003). It is usually characterised by a forward flow of materials and a backward flow of information and revenue (Gaucher *et al.*, 2004).

In this study, the sugarcane supply chain is defined as a generally inclusive agri-industrial system that aims to grow, harvest, transport and process sugarcane from the field to the mill (Gigler *et al.*, 2002; Gaucher *et al.*, 2004). The entire sugar supply chain is highly integrated and contains: (a) cane growing, (b) harvesting, (c) cane transport to the mill, (d) mill processing and refining, (e) sugar transported to the port or market, (f) storage, and (g) retailing to customers (Higgins and Muchow, 2003; Higgins *et al.*, 2006). Figure 2.1 illustrates the components of a sugar supply chain.

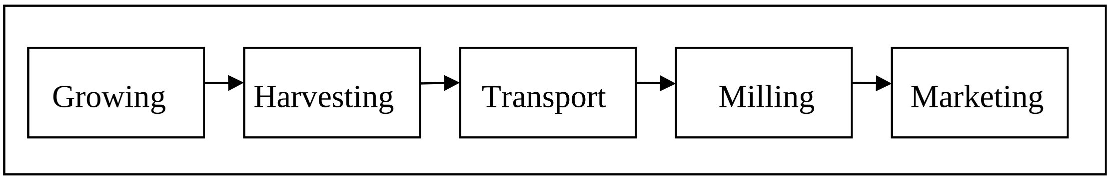

Figure 2.1 The sugar supply chain components (after Higgins *et al.*, 2004)

There are inconsistencies which occur in supply chains that make it difficult for the sugarcane industry to be optimally productive. Inconsistencies in the sugar industry occur due to many logistical, social, economic and physiological linkages across the chain. Most of these factors are inter-connected, such as the harvesting and transporting of cane, whilst many of the social and physiological aspects are difficult to quantify (Higgins and Lerado, 2006; Chiadamrong and Kawtummachai, 2008). Inconsistencies create risk and may decrease profitability for the parties involved in the supply chain. Therefore, decreasing inconsistencies in the sugarcane supply chain have the potential to increase profitability (Le Gal *et al.*, 2008). The impacts of supply chain inconsistencies can be mitigated by flexible strategies (Tachizawa and Thomsen, 2007; Pitty *et al.*, 2008). However, flexibility is difficult, due to the varying involvement of parties in the supply chain, their conflicting objectives, the geographical span of the system, logistical problems, as well as increased costs (Chen and Paulraj, 2004; Tachizawa and Thomsen, 2007).

This Chapter aims to provide a literature overview of: (a) the sugarcane supply chain and its processes (discussed in Section 2.1), (b) the properties which create inconsistencies (discussed in Section 2.2), and (b) the strategies which are used for the improvement of the sugarcane supply chain (discussed in Section 2.3). The focus will be on South African sugarcane supply chains, in particular, *i.e.* from the field to the production of raw sugar.

2.1 An Overview of Sugarcane Supply Chains

The refined product, sugar, is produced mainly from sugarcane (±75%) and sugar beet (±25%) (Higgins *et al*., 2006). Sugarcane products include table sugar, molasses, ethanol and electricity. Sugar is an important fuel for the body, because it is a carbohydrate (Deressa *et al*., 2005). Sugarcane is a tropical plant that is able to grow under various climates throughout the world, from sea level to 1500 metres. However, the ideal climate involves a long, warm growing season and a fairly dry, but frost-free harvest season (Everingham *et al*., 2002). Sugarcane is produced in over 110 countries in the world, with the majority produced in Brazil, Thailand, India, Australia, China, Pakistan, the United States and South Africa (Higgins *et al*., 2006).

2.1.1 Sugarcane supply chain

The sugarcane supply chain is highly integrated and involves the growing, harvesting, transporting and processing of sugarcane (Gigler *et al.*, 2002; Gaucher *et al.*, 2004). Climate and the ability of sugarcane to mitigate pests and diseases, result in the harvest age ranging from 12 to 24 months. Thereafter, sugarcane is either burnt or cut green, prior to harvesting. Burning usually takes place for a few hours each day, depending on the area of the fields to be harvested. The cane is then manually or mechanically harvested. In South Africa, manual or conventional harvesting involves employing labourers to cut and stack the cane on the field, before loading it onto a vehicle, which will then transport it to the mill. Growers either have their own vehicles or contract haulage enterprises to transport the cane. A mechanised harvesting system involves cutting and loading billeted cane onto a trailer. In South Africa, mechanical harvester contractors are usually employed to harvest the cane. The cane on the trailer is then usually offloaded onto the haulage vehicle, which will transport the cane to the mill. The time taken to transport cane depends on a number of factors, including the quantity of cane, the type of haulage vehicle, the weather and road conditions, as well as the distance to the mill (Thorburn *et al*., 2011). Once at the mill, vehicles are weighed and the cane is offloaded onto a stockpile or directly onto the spiller table and the empty vehicles weighed again. Finally, the cane is processed and refined at the mill, in order to produce sugar and molasses (Gigler *et al*., 2002; Higgins *et al*., 2006; Chiadamrong and Kawtummachai, 2008).

Collaboration between parties is an important constituent to support more efficient business operations and to lower inconsistencies in supply chains (Cassivi, 2006). In sugar production, the four stakeholder parties who are usually involved are the growers, the harvesters, the haulage contractors and the miller (Higgins and Muchow, 2003; Higgins *et al*., 2006; Bezuidenhout *et al*., 2012b). The ownership of mills is an important issue in sugarcane supply chains (Le Gal *et al*., 2008; Lejars *et al*., 2008) There are three possible scenarios which are generally used, in terms of farm and milling ownership in the industry. These are: (a) the miller owns some farms in the milling region, (b) the miller and growers are independent entities, and (c) the growers own the mill (Lejars *et al*., 2008). The miller controls the amount of sugar which may be recovered from each ton of cane that is crushed. The grower aims to reduce the costs of production. The haulier aims to load and transport cane and to sustain a constant supply to the mill at the least cost (Higgins *et al*., 2006; Chiadamrong and Kawtummachai, 2008). Although each party often operates independently, the supply chain is a single entity. Joint decisions can be made between many supply chain stakeholders, which have the potential to increase profits. These decisions also allow for important tactical planning and strategic problems to be addressed (Le Gal *et al*., 2008; Bezuidenhout *et al*., 2012b).

As with most agricultural supply chains, parties involved in the sugarcane supply chain compete and aim to minimise costs, in order to maximise net revenue (Lejars *et al*., 2010). Revenue is obtained from the sale of sugar and other sugarcane by-products, such as bagasse and molasses. An increase in revenue is likely to increase the quantity of cane grown and produced (Lejars *et al*., 2008). Increased revenue is only likely to be realised through an interconnected relationship between the growers, harvesters, hauliers and millers. In addition, profit maximization can be achieved by controlling three critical factors, namely, (a) throughput, (b) sugar recovery, and (c) quality. These factors are also generally interrelated (Higgins *et al*., 1998; Purchase and de Boer, 1999). The parties in the agricultural supply chain do not generally use strategies, such as product differentiation, for raw produce (Archer *et al.*, 2006).

One of the largest cost components in raw sugar production is logistics. It is estimated that the cost of transportation contributes approximately 20% and 25% of the total production costs in the sugarcane industries in South Africa and Australia, respectively (Milan *et al*., 2006; Amu *et al*., 2013). There is an increased emphasis on improving the integration of the harvesting and transport systems, because they are the more tangible components and can be quantified (Salassi and Champagne, 1998). Barnes *et al.* (2000) provide a detailed model of different harvesting and transporting techniques. Other components of the system, including agronomic, social, economic and physiological linkages across the chain, are difficult to quantify (Higgins and Lerado, 2006; Chiadamrong and Kawtummachai, 2008).

2.1.2 Sugarcane quality

Sugarcane is made up of different components, such as water, fibre, sucrose and non-sucrose content. The various typical percentages of components in the sugarcane plant are illustrated in Figure 2.2. These components are influenced by the type of soil, the variety of cane, the climate, the degree of maturity and the handling practices (Higgins *et al*., 1998). The most important factors, which contribute to high sugar recovery, are low fibre, low reducing sugars and high sucrose. Excessive fibre is undesirable in the production of raw sugar, because it reduces the volume of sucrose that may be extracted. However, fibre is required in the production of by-products, such as paper. Factors that affect the quality of sugar are, amongst others, its colour, ash content, crystal shape and filterability (Purchase and de Boer, 1999; Higgins, 2006).

Like many other agricultural products, sugarcane is a seasonal crop, which is influenced by weather and climatic conditions (Hassan and Gbetibouo, 2004; Thorburn *et al*., 2011). It displays a bell-shaped sucrose curve, which peaks once a year (Stray *et al*., 2012). Sucrose yields from cane are at their highest during dry and cool conditions, which makes certain times more ideal for milling, compared to others (Higgins *et al*., 1998; Higgins and Muchow, 2003). In South Africa, this is usually between July and September (Moor and Wynne, 2001). The subsequent rainy season reduces sucrose yields substantially (Kadwa and Bezuidenhout; 2013), which is undesirable. The rainy season also promotes disruption and mobility problems in the field. However, transport and mills are capital-intensive assets. These resources would, therefore, be underutilized, if designed to process the annual crop in a short period of time (Stray *et al*., 2012). For over-all economic purposes, this prolongs the milling season by a number of months and into the rainy season. In addition, the weather influences the number of days available for harvesting and is likely to impact on the composition of cane. For example, a long period of rainfall reduces the number of days for harvesting (Boote *et al*., 2011; Boote *et al*., 2013). Drought, on the other hand, will substantially decrease yields and hence profitability, because it creates fluctuating yield profiles (Higgins *et al*., 1998; Higgins and Muchow, 2003; Hassan and Gbetibouo, 2004; Thorburn *et al*., 2011).

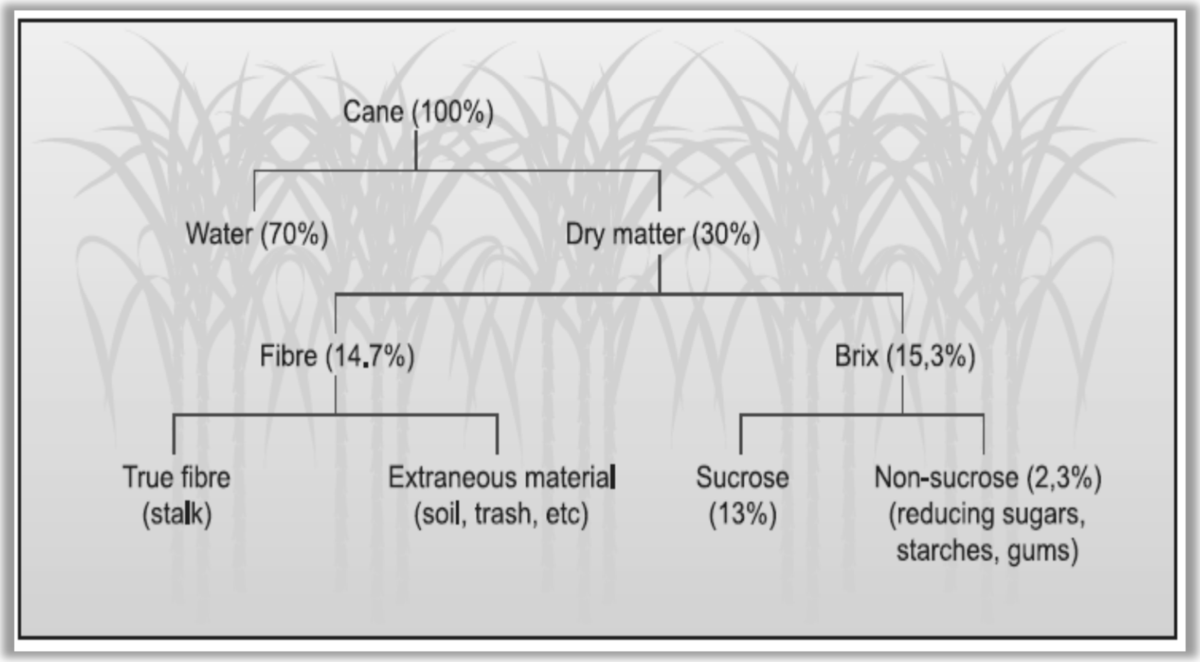

Figure 2.2 The typical composition of sugarcane (after SASRI, 2000)

The method of harvesting is a key determinant of sugarcane quality (Higgins *et al*., 1998; Higgins and Muchow, 2003). Sucrose levels are higher when there are minimal delays from the time of harvesting to the crushing of sugarcane. The burn-harvest-to-crush delay

(BHTCD) is defined by Higgins (2006) as the “time-elapsed between when the cane is harvested and processed by the mill.” The delay varies substantially in the South African industry, due to varying harvesting practices, and it is desirable to minimise the BHTCD (Beamon, 1998; Lionnet, 1998). For example, the burning of cane aims to improve harvest rates and reduce mill fibre levels. It may also improve cane quality and hence enhance the short-term profitability throughout the chain. However, burnt cane deteriorates faster and when large blocks are burnt, then dead cane could stand for some time before being harvested. Cutting green cane is a method used to reduce the harvest-to-crush delay (Lionnet, 1996; Meyer *et al*., 2005). Nonetheless, it is important to note that harvested cane is perishable (SASRI, 2000; Eggleston *et al*., 2001; Salassi and Champagne, 1998; Higgins *et al*., 2004; Eggleston *et al*, 2008).

2.2 Sources of Sugarcane Supply Chain Inconsistencies

As in other supply chains, there are various factors, each with different impacts, which create uncertainty and inconsistencies in sugarcane supply chains. These factors are inter-connected. The main properties in the supply chain are reviewed in this section, where inconsistencies have an impact on the system, from the field to the production of raw sugar. The two major properties reviewed are cane quality consistency and cane processing consistency in terms of flow rate (tons per hour). It is not always easy to differentiate these properties and some of these relationships fall beyond the scope of this study. Where possible, connectivity graphs (as in Figures 2.3 and 2.4) are used to depict the inter-connectivity between the different factors.

2.2.1 Cane quality inconsistency

There are various properties which are inter-connected in the sugarcane supply chain and that affect cane quality consistency. These are discussed below and summarized in Figure 2.3.

The milling season and variety of cane are important properties, which may cause quality inconsistencies. The prolonged milling season, as discussed in Section 2.1.2, causes inconsistencies in cane quality and yield (Higgins *et al*., 1998; Higgins and Muchow, 2003). Furthermore, Langton *et al*. (2005) found that the larger the number of cane varieties grown, the more cane quality consistency decreases. However, cane variety diversification is required, in order to reduce the impacts of pests and diseases.

In South Africa, about 90% of sugarcane tonnage is being manually harvested by cane cutters (Meyer and Farwick, 2003). Manual harvesting is unavoidable or favoured, because sugarcane is usually cultivated on steep slopes (Langton *et al*., 2006). Cane cutters normally start work early at 5am and they finish in the early afternoon, at around 2pm (Meyer and Farwick, 2003).

In the future, however, cutter availability is expected to decrease in South Africa (Langton *et al*., 2005). This is due to the effect of HIV/AIDS on the workforce, rising aspirations and growth in the industrial sector (Langton *et al*., 2006). In addition, the substantial increase in the minimum wage rate for farm labourers in South Africa from 2012, has dictated that improved cutter productivity is essential to the economic viability of the sugar industry. However, the increased real cost of labour will potentially cause farm owners to seek alternative methods for cane harvesting.

The amount of cane deterioration that takes place depends largely on the BHTCD, the prevailing temperature and humidity, as well as exposure of the cane to pests and diseases. Both the grower and the miller would gain significantly, through increased revenue, if cane could be processed immediately after it is harvested. However, this is seldom possible. There is often a BHTCD of three to four days, or even longer, between the harvesting and crushing of cane (Barnes *et al*., 2000; Diaz and Perez, 2000). Rangel *et al*. (2010) state that there are different distances between fields and the mill, which compromises cane quality consistency. There is likely to be a higher BTHCD for growers who are located further from the mill (Purchase and de Boer, 1999; Rangel *et al*., 2010). However, Barnes *et al*. (1998) and Amu *et al*. (2013) found that most of the waiting time is in-field and that transportation distances add minutes, compared to hours, in the field. Growers may also use different machines, equipment and methods for harvesting, which can lead to cane quality being inconsistent (Higgins, 2006). Unburnt cane deteriorates more rapidly than burnt cane during the week immediately after harvesting, due to plant respiratory activity. Thereafter, burnt cane deteriorates more rapidly due to microbial respiratory activity (Wood *et al*., 1972; Eggleston *et al*., 2001; Eggleston *et al*., 2008). Burning cane is usually the preferred harvesting method in South Africa, as it is generally possible to crush sugarcane within 48 hours. The rates of cane deterioration also vary significantly in different post-harvest conditions and according to the season. Sibomana *et al*. (2011) found that the cane qualities at the Felixton milling region in South Africa were significantly different after weekends, compared to the late-week. In addition, there is greater deterioration in the hot-humid summer months and the loss of sucrose value per day can be 2-3% (Lionnet, 1998). During winter, the loss averages one percent per day (Eggleston *et al*., 2008). The season also influences the development of pests and diseases, which restrict crop growth and also inflict damage to the cane, accelerating deterioration. The season, therefore, has an influence on the consistency of cane quality (Everingham *et al*., 2002; Grunow *et al*., 2007).

Figure 2.3 illustrates a summary of the relationships between the above-mentioned sources of cane quality inconsistency in the sugarcane supply chain. The network was developed, using the cause-and-effect map network technique utilized by Bezuidenhout *et al*. (2012a). The arrow from one point to another indicates the cause and effect relationship between the two factors. For example, the factor "*seasonality*" is a source of inconsistency because it has an effect on the factor "*cane deterioration*." Figure 2.4 can be read in the same way.

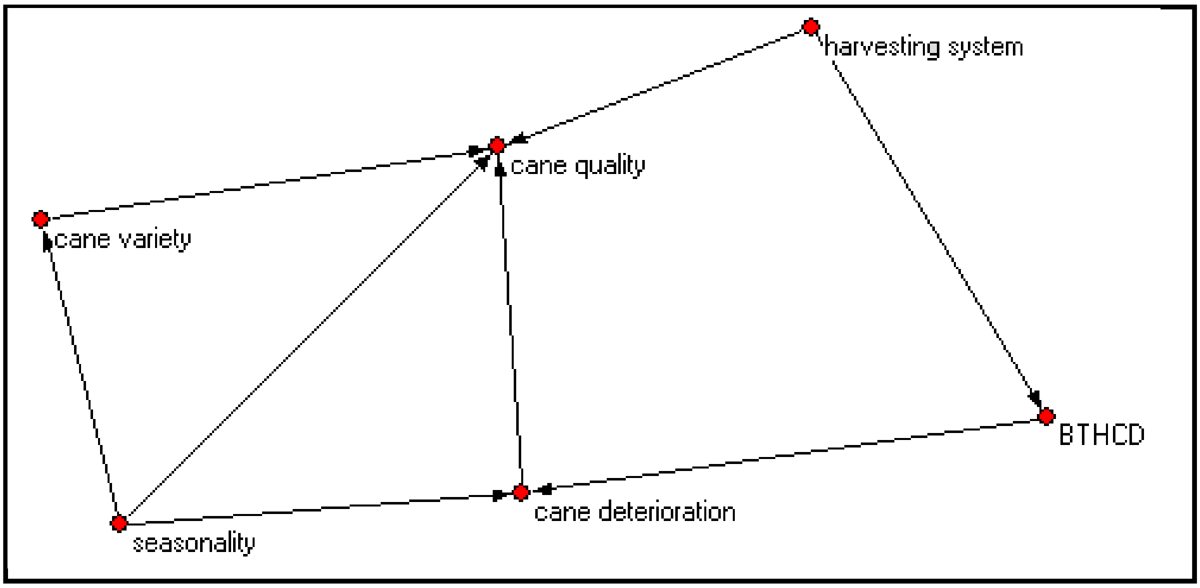

Figure 2.3 A cause-and-effect network of the properties in the sugarcane supply chain that affect cane quality consistency

2.2.2 Cane processing inconsistency

Sugarcane flow from the fields to the mill usually involves cutting or burning, loading, transporting and unloading at the mill (Diaz and Perez, 2000). There are various factors which affect the consistency of sugarcane flow through this process, in terms of tons per hour. These factors are discussed below and summarized in Figure 2.4.

Weather conditions are a major cause of cane processing inconsistencies, as discussed in Section 2.1.2. The uncertainty of future weather conditions increases the risk associated with the levels of sucrose produced, crop size, the time of harvesting, as well as in-field accessibility (Higgins *et al.*, 1998; Higgins and Muchow, 2003; Hassan and Gbetibouo, 2004; Boote *et al.*, 2011; Thorburn *et al.*, 2011; Kadwa and Bezuidenhout, 2013). For example, the supply system in Australia usually allows for expected weather disruptions in the harvest season; although excessive rainfall occurrences may have a significant impact and cause complications across the supply chain (Higgins, 2006).

The time and methods of harvesting are other major cause of cane processing inconsistencies. The ideal time to burn cane is at dawn. However, Crowe *et al*. (2009) found that when cane is manually harvested, the constant exposure to the late morning and early afternoon sun may result in decreased labour productivity. Furthermore, the BHTCD can be increased by a further 12 hours, or more, if enough cane is burnt to meet the allocation of a two-day demand, or more (Barnes *et al.*, 2000; SASRI, 2004; Higgins, 2006). Wet weather conditions after the burning of cane is undesirable, because it prevents cutters and hauliers from entering the fields. Kadwa *et al*. (2012) stated that this may result in an increase to over 100 hours in the BTHCD, with a substantially reduced sucrose content. In addition, Kadwa and Bezuidenhout (2013) studied the impacts of increased cutter absenteeism, especially after pay-weekends, at the Eston sugar milling region in South Africa. An estimate of the direct costs associated with cutter absenteeism, which results in decreased cane quality and an increase in the length of the milling season (LOMS), was found to be approximately R1.3 million per season. Other impacts of increased cutter absenteeism include reduced harvesting efficiency, increased field damage due to a longer LOMS (Boote *et al.*, 2013), an increased BHTCD, higher management costs, decreased transport efficiency and more mill breakdowns.

There are various factors that have an impact on mill operations, such as the seasonality of sugarcane, the composition of cane, the soil content in harvested cane, sugarcane trash and lodged cane. Mills are usually closed for maintenance and upgrades in the rainy and warmer seasons, also known as the growing season. The sugarcane supply chain is regarded as being effectively inactive during this period (Higgins and Muchow, 2003). Variable cane quality hampers different processes in the mill (Bezuidenhout, 2010). For example, fibre in the diffuser will have a negative impact on sugar output and will reduce milling efficiency. It is easier for the miller to process juices that need to be crystallised when the cane quality is high and when there are less impurities in the cane (Higgins, 2006). There are usually an increased number of mill stoppages at the end of the season, due to increased ash and soil in the cane (Kadwa and Bezuidenhout, 2013). Soil in harvested cane decreases the mill front-end capacity and it increases mill maintenance costs, with respect to the wear on chains and gear boxes. The quantity of soil in harvested cane is affected by the harvesting technique, the loading methods and weather conditions (Purchase and de Boer, 1999; SASRI, 2004; Rayno and Purchase; 2005). The quantity of soil in cane can be reduced, by avoiding harvesting in the rainy season.

Trash levels and lodging have an impact on mill operations, as well as cane bulk density. Lodging occurs when mature sugarcane falls over, usually due to high rainfall, wind, saturated soils or structural weaknesses (Singh *et al*., 2002). Larger crops, especially over 100 tons per hectare of cane yield, are typically susceptible to lodging, during windy and wet weather. Lodged cane is more difficult to harvest, which results in higher losses and costs. In addition, lodging reduces the amount of sugarcane that can be transported, because it reduces the bulk density. Furthermore, lodging increases the milling cost per unit of sugar produced (Singh *et al*., 2002). Trash is defined as the dry leaves, green leaves and some stalk material, which are left on the field after harvesting (Scott, 1977). Burning sugarcane before harvesting reduces brown leaf material by at least two-thirds, but some residue is still delivered and processed at the mill (Wynne and van Antwerpen, 2004). 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 mill operations, with shutdowns being more likely. Purchase and de Boer (1999) found that crushing sugarcane with trash has the potential of reducing sucrose throughput by 36% per hour.

A major supply chain problem in the sugar industry is that harvesting usually takes place only in daylight hours, whilst the mill operates continuously (Higgins *et al*., 2006). This problem usually results in times during the day when cane deliveries to the mill exceed the demand, whilst other times of the day the supply to the mill is inadequate. The time of delivery to the mill is also inconsistent over weekends and public holidays (Kadwa *et al*., 2012; Kadwa and Bezuidenhout, 2013). In addition, the location and number of collection points of harvested sugarcane vary each day (Stutterheim *et al*., 2008). The time required for loading and off-loading, the length of journeys and the type of vehicles and equipment used also differ.

Other factors that cause inconsistent deliveries include equipment maintenance, weather conditions, road conditions, accidents and vehicle breakdowns (Diaz and Perez, 2000; Higgins *et al*., 2004; Chiadamrong and Kawtummachai, 2008; Bezuidenhout, 2010; Boote *et al*., 2011). There is increased damage to roads when heavy vehicles travel on wet roads and there may be fewer accidents, by reducing the LOMS to avoid the rainy season (Boote *et al*., 2013; Kadwa and Bezuidenhout, 2013). There are also logistical and technical delays at the mill that can create queues, such as excess vehicle arrivals, weighing, as well as the inspecting and unloading of sugarcane (Rangel *et al*., 2010). Waiting queues create bottlenecks at the mill and usually take place as a result of mill breakdowns, driver shift changes and unscheduled deliveries (Giles *et al*., 2005; Boote *et al*., 2013). The above inconsistencies may result in over-sized fleets, low equipment utilization, increased costs, inconsistent throughput and possibly double-handling (Hahn and Ribeiro, 1999; Barnes *et al*., 2000; Kadwa and Bezuidenhout; 2013). For example, if trucks break down or queue for long periods of time during operations, the return time to the field or the mill will be compromised, hence it will slow down the overall supply chain (Rangel *et al*., 2010).

The above factors that affect cane processing consistency are summarized in Figure 2.4, which was developed, using the cause-and-effect map network technique, utilized by Bezuidenhout *et al*. (2012a). By carefully analyzing the network, three broadly classified groups that affect cane processing consistency are highlighted, namely, weather and harvesting time influences, transport issues and cane bulk density influences.

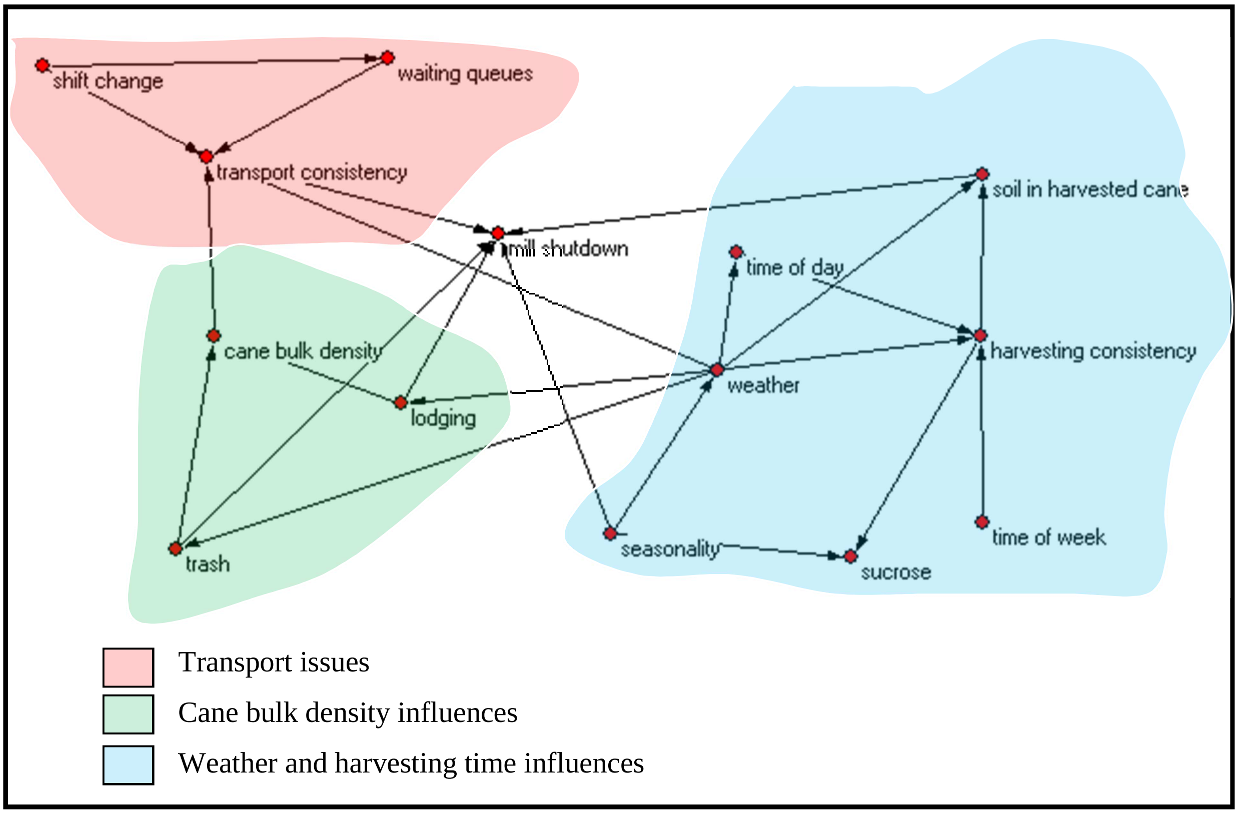

Figure 2.4 A cause-and-effect network of the factors that impact on cane processing consistency

2.3 Strategies to Improve Sugarcane Supply Chains

Due to the various inconsistencies, there are different strategies or methods, which have been proposed to improve sugarcane supply chains. These strategies have to be flexible, to allow for ever-changing uncertainties. The strategies that have been used include, amongst others, increasing communication and collaboration between the parties in the supply chain (Moor and Wynne, 2001; Wynne and Groom, 2003; Gaucher *et al*., 2004; Bezuidenhout *et al*., 2012b), introducing the correct sugar payment system (Todd and Forber, 2005), stockpiling (Bezuidenhout, 2010; Boote *et al*., 2013), rearranging harvest scheduling (Le Gal *et al*., 2008; Stray *et al*., 2010) and new co-ordinated delivery allocation rules (Higgins *et al*., 2006). The following subsections briefly describe each strategy. However, it is unlikely that one specific strategy would improve all sugarcane supply chains (Bezuidenhout *et al*., 2012a). These strategies may cause new problems in the supply chain (Giles *et al*., 2005). To be successfully implemented, therefore, each supply chain requires a detailed analysis of the improvement strategies.

2.3.1 Communication and collaboration

Gaucher *et al.* (2004) state that communication and trust between the various stakeholders is vital in the sugarcane supply chain, when farms and the mill are owned by independent entities. Increased feedback and communication, as well as more efficient administration reduces product quality variations, deterioration, the bullwhip effect (Wee and Wu, 2009), and hence, cane quality inconsistencies. To minimise conflict between entities in the chain, the stakeholders need to design collective growth strategies rather than to have individual viewpoints (Bezuidenhout *et al.*, 2012b). There will need to be increased training and participation between the entities. Outside assistance will be required for management to be changed and the development of systems. To encourage stakeholders to match their individual decisions with the collective interest, different economic tools, such as contracts, information and the appropriate payment systems, need to be implemented (Gaucher *et al.*, 2004; Higgins *et al.*, 2004; Piewthongngam *et al*., 2009).

Moor and Wynne (2001) developed an optimal milling season model, by assuming each mill area operates as a single entity. The model was designed to identify the point at which marginal losses are greater than the benefits of increased capacity utilization, due to decreasing cane quality. Wynne and Groom (2003) enhanced the milling season model of Moor and Wynne (2001), by identifying quantifiable parameters that cause the extensions of season length, for example, the adjustment of overall time efficiency included the effects of slow and fast mill crush rates. These factors were considered to reduce inefficiencies in the overall system. However, research carried out in seven milling areas in South Africa (Boote *et al*., 2011; Sibomana *et al.*, 2011; Bezuidenhout *et al*., 2012a, Kadwa *et al*., 2012; Sanjika *et al*., 2012; Boote *et al*., 2013; Bezuidenhout *et al*., 2013; Kadwa and Bezuidenhout; 2013; Sibomana and Bezuidenhout, 2013) have all highlighted the issue concerning what is perceived to be an inappropriate milling season.

It is difficult to reduce inefficiencies and to effectively determine the ideal milling season because of many physical and social factors. Wynne and Groom (2003) concluded that collaboration between growers, transporters and the miller would be required, to eliminate the cause of the inefficiency. Further research by Lejars *et al*. (2008), Bezuidenhout *et al*. (2012a), Bezuidenhout *et al*. (2012b), Bezuidenhout *et al*. (2013) emphasized this, by stating that large volumes of research in the sugar industry are not implemented, because the proposed solutions exclude issues in the supply chain, such as collaboration, innovation and information-sharing.

2.3.2 Cane payment systems

Cane payment systems are important in providing incentives for growers and millers to improve efficiency. The system incentivizes the improvement of cane yield and quality and also enhances milling performance, by increasing collaboration (Wynne, 2001; Todd and Forber, 2005). The sugar industry payment system usually aims at sharing the annual revenue, when millers and growers are separate entities. However, similar to most revenue-sharing agreements, the type of payment system is usually a contentious issue. The issue is complicated by the development of sugarcane co-products, such as ethanol, electricity, fibre-based products, including paper and packaging, as well as lactic acid (Lejars *et al*., 2010). There are various payment systems in sugarcane supply chains (Todd and Forber, 2005). For example, the growers and millers in the South Africa sugar industry receive revenue, based on a relative sugar recoverable value (RV) formula (Wynne, 2001; Murray, 2002; Wynne, 2005).

The RV formula payment system aims at growers improving quality, in terms of clean and mature cane, with the incentive of obtaining higher revenue (Wynne, 2001; Murray, 2002; Wynne, 2005). The RV formula is estimated, taking into account the sucrose, non-sucrose and fibre components of sugarcane, which all affect milling efficiency. The relative RV system removes the incentive for all growers to deliver when cane quality is at its highest in the season (Murray, 2002). This is an important consistency regulator. However, the RV payment primarily does not incentivise a consistent cane supply. In contrast, the daily rateable delivery (DRD) system is rule-based, with potential penalties in place, in order to identify and correct delivery inefficiencies (Wynne, 2001). However, these penalties are not always carried out. The systematic integration needed to improve cane consistency is, therefore, lacking between the DRD and RV payment systems (Murray, 2002; Mac Nicol *et al.*, 2007; Lejars *et al*., 2008).

2.3.3 Stockpiling

The methods used to allow consistent mill operations include stockpiling at the mill and storage in trailers in the field, before transportation to the mill (Higgins *et al*., 2006). A statistic that quantifies inconsistencies in stockpiles can be a key indicator of overall system inefficiency (Bezuidenhout, 2010). Stockpiling occurs when there are increased levels of inventory, which acts as a buffer to enable production to continue, especially when deliveries from suppliers are low (Heng *et al*., 2005; Germain *et al*., 2008). Wet weather is a major cause of low cane supply consistency (see Section 2.2.2). Boote *et al*. (2011, 2013) modelled the use of an enlarged cane stockpile outside the mill, in order to allow a consistent flow of cane to the mill, even when wet weather prevents further harvesting. The stockpile was estimated to shorten the LOMS and reduce the number of no-cane mill stops and slow crush rates. However, the results found that the stockpile would be a major disadvantage because of cane deterioration (Boote *et al*., 2011; 2013).

Sugarcane supply chain stockpiles can be divided into two groups, namely, deliberate and unexpected (Bezuidenhout, 2010). Bezuidenhout (2010) explains three reasons why deliberate stockpiles are maintained: (a) to mitigate risk, such as building up a stock before approaching rain, (b) synchronization, to reduce inconsistencies, for example, the differences that exist in operating times between harvesting and milling, such as over weekends, when growers are reluctant to deliver cane, and (c) cane maturing, when some growers deliberately allow cane to age, to artificially increase its RV percentage. Unexpected stockpiles occur due to saturated and unsaturated conditions. Saturated conditions involve capacity bottlenecks. Unsaturated conditions refer to manageable changes in cane flow rates, such as widespread and simultaneous driver shift changes.

Bezuidenhout (2010) tabulated the above groups and the appropriateness of each stockpile to reduce inconsistencies, in order to allow for continuous and consistent mill production. It is not useful to have an in-field stockpile, because it is difficult to predict inventory levels, it does not allow for an efficient night transport operation and is generally vulnerable to wet weather. It is beneficial to have loading zone stockpiles, although it is difficult to estimate stock levels. It is not advisable to use a vehicle stockpile because it is highly inefficient use of expensive equipment, is a major cause of the bullwhip effect and is expensive. It is logical to have a mill yard stockpile, however, the mill yard may become congested, it can be difficult to maintain the first-in-first-out (FIFO) principle and it could promote under-utilization in the transport fleet (Bezuidenhout, 2010).

2.3.4 Harvest and transport scheduling

In this thesis, harvest and transport scheduling refers broadly to any harvesting and logistic techniques or methods that aim to improve efficiency in the sugarcane supply chain. These include a daily rateable delivery system (Higgins *et al*., 2004), night transportation (Higgins *et al*., 2006), an improvement in vehicle scheduling (Giles *et al*., 2005; Higgins, 2006) and the rearrangement of harvest scheduling (Le Gal *et al*., 2008; Stray *et al*., 2012).

A daily rateable delivery (DRD) system aims for a constant daily supply of sugarcane to the mill. This can improve cane processing consistency, but it does not have any regard for cane quality consistency (Barnes *et al*., 2000; Higgins *et al*., 2004). Bezuidenhout (2010) states that this system can usually only apply when mill processes run below capacity, due to variability in cane quality that would constrain certain parts of the mill. In addition, Bezuidenhout (2010) states that using the DRD system generally results in deliveries to the mill varying during the day, which negatively affects the mill processing operations (as discussed in Section 2.2.2).

The transportation of sugarcane to the mill during the night is likely to increase processing consistency. It allows for a more continuous supply of sugarcane to the mill, which probably will decrease the BHTCD and hence improve quality consistency. However, weather patterns, grower operational hours and communication systems can negatively affect the success of night transportation (Higgins *et al*., 2006).

An improvement in vehicle scheduling, in terms of arrival time at the mill, would result in a shorter queue at the mill, because less vehicles would be required to get the crop to the mill and there would be a reduction in the risk of mill shutdowns (Higgins *et al*., 2006). Higgins (2006) states that if there was an equally-spaced arrival time of vehicles at the mill, which is aligned with the mill throughput rate, then there would not be any queues and, hence, waiting time at the mill. This will minimise the BHTCD and improve profitability. However, weather conditions, as well as the varying locations of the farms and the mill, can compromise this idea (Hahn and Ribeiro, 1999). The millers may prefer to have a queue of trailers or vehicles in the mill-yard, rather than run the risk of idle time, because there is a substantial cost to the miller if the mill has to shut down, or slow down, operations (Higgins *et al*., 2006). Furthermore, Giles *et al*. (2005) concluded that due to the sugarcane supply chain being highly integrated, improvements to the transport system may only be effective if several other system properties, such as driver shift changes, contractual agreements, multiple collection points and loading times, are simultaneously adopted.

Le Gal *et al*. (2008) used the MAGI decision support tool (Le Gal *et al*., 2003) to maximise RV yield and increase delivery throughout, by comparing different supply chain scenarios. The aim is to improve profitability and reduce apparent inconsistencies in the chain. The study included investigations into exploiting geographical and temporal RV production variation opportunities, by modifying the cane supply scheduling during a season. Le Gal *et al*. (2008) concluded that an improvement of the supply chain can occur, by taking advantage of quality differences within the mill supply region. This can be achieved by rearranging harvest scheduling on a different basis, with the effect of changing the cane delivery structure from the fields to the mill. The changes may result in the harvesting season being reduced, to maximise cane quality and hence profitability. However, this is dependent on the milling and transportation capacity.

2.4 Discussion and Conclusions

A well-managed supply chain is usually important in any industry, especially in raw sugar production. There are various causes and impacts of supply chain inconsistencies, which can clearly be witnessed in the sugarcane supply chain as well. Even though the growers, hauliers and the miller are parties that operate independently, the sugarcane supply chain can be regarded as a single entity. There is limited peer-reviewed literature on the link between properties in the sugarcane supply chain, from the field to the production of raw sugar, where inconsistencies have an impact on the system. Research has been conducted on various properties which affect harvesting and transport issues in sugarcane supply chains, but the link between processing consistency requires further research. Sugarcane quality and processing consistency are the two properties that have been developed and reviewed as sources of supply chain inconsistencies. These properties significantly decrease consistency across the supply chain, as well as a decrease in the sugar supply. However, it is not always easy to differentiate between properties and some of these relationships can be further researched.

Cane quality consistency is influenced by the season, harvesting system, deterioration and variety. The date and method of harvesting have an important impact on the composition of cane, its deterioration and therefore the profitability of the industry. Sugarcane displays a bell-shaped sucrose curve, which peaks once a year in August. Sucrose yields from cane are at their highest during dry and cool conditions, which makes this the ideal time for harvesting. However, due to limited transport and milling capacity in most countries, the harvest season is prolonged over a number of months, which results in increased exposure to seasonal cane quality fluctuations. The amount of cane deterioration that takes place depends largely on the burn-harvest-to-crush delay (BHTCD), as well as the prevailing temperature and humidity. Rainfall events generally lead to significant BHTCDs. In South Africa, the BHTCD is often three to four days, whilst hot and humid conditions result in greater deterioration, compared to cooler conditions.

Cane processing consistency in terms of flow rate (tons per hour) is impacted by various properties which have been broadly classified into three factors, namely, weather and harvesting time influences, transport issues and cane bulk density influences. The uncertainty of weather conditions increases the risk associated with the levels of sucrose produced, crop size, the time of harvesting, as well as in-field accessibility. The time of day, as well as day of the week, affects harvesting consistency. Cutter productivity decreases during the day, when exposed to extreme heat, as well as after pay-weekends. There are various factors that have an impact on mill operations, such as the seasonality of sugarcane, the composition of cane, the soil content in harvested cane, sugarcane trash and lodged cane. Lodging and trash affect sugarcane transport and production, by reducing the cane bulk density and the mill capacity, respectively. A major supply chain problem in the sugar industry is that harvesting usually takes place only in daylight hours, whilst the mill operates continuously. This problem usually results in times during the day when cane deliveries to the mill exceed the demand, whilst at other times of the day the supply to the mill is inadequate. Other factors that cause inconsistent deliveries include equipment maintenance, weather conditions, road conditions, accidents and vehicle breakdowns.

Many strategies have been developed to improve the supply chain and mitigate the above-mentioned inconsistencies. An optimal milling season model was developed to try to reduce cane quality and processing inconsistencies. The model was designed to identify the point at which marginal losses, due to decreasing cane quality, are greater than the benefits of increased capacity utilization. However, several studies have highlighted issues concerning what are perceived to be the ideal milling season. This is because the model does not consider issues in the supply chain, such as collaboration, innovation and information-sharing, which is the same in much of the research in the sugar industry. Sugar payment systems incentivize the improvement of cane yield and quality, as well as enhancing milling performance by increasing collaboration. However, the sugar recoverable value (RV) formula used in South Africa, for example, does not directly incentivise for a consistent cane supply. Consistent mill operations can take place by using a stockpile, but this causes double-handling and further cane deterioration, which substantially reduces profitability. The emphasis of research has been to improve the integration of the harvesting and transport system. A daily rateable delivery system can be implemented to allow for constant daily cane flow rates. On the other hand, it does not consider cane quality, there are fluctuations in delivery times within the day and over weekends and it can only be applied when mill processes run below capacity, due to cane qualities constraining different parts in the mill. Vehicle scheduling can reduce the number of vehicles required, although it will only be effective if several system properties, such as driver shift changes and contractual agreements, are changed simultaneously. Taking advantage of quality fluctuations within the supply region, by rearranging the harvest schedule in the harvest system has also been researched, to improve the supply chain. However, the effectiveness of this strategy is influenced by mill and transportation capacity. Further research is required for improvement.

These strategies need to be flexible and it is unlikely that one strategy would improve all sugarcane supply chains simultaneously. It is, therefore, important to ascertain the most appropriate approximation, within a specific mill area. In Chapter 3, a survey was carried out at Eston, to determine this.

3. A SUPPLY CHAIN DIAGNOSTIC STUDY AT ESTON

3.1 An Overview of the Eston Mill Region

The Eston Mill forms part of the Illovo sugar milling consortium, with the Sezela and Umzimkulu Mills on the south coast and the Noodsberg Mill north of Pietermaritzburg (see Figure 3.1). The reason for this move was the close proximity of the former Illovo Mill to the Sezela Mill. Eston was centrally-situated and millers would benefit by moving the mill, rather than to compensate growers for long-haul deliveries. The centrally-situated location also helped to improve cane quality by reducing the burn-harvest-to-crush delay (BHTCD). Eston is conveniently situated between the Sezela and Noodsberg Mills (see Figure 3.1). Growers also agreed to sign a 20-year contract to produce and deliver cane to the mill, which they were unlikely to do at the old Illovo Mill. This agreement will be reviewed in 2014 (Lumsden *et al*., 2000; Department of Transport, 2011; Thompson, 2011).

There are a total of 1140 active sugarcane growers in the Eston region. This encompasses approximately 950 small-scale and 190 large-scale growers. However, small-scale growers only contribute an average total sugarcane supply of 1.75% of the annual total crush. Large-scale growers contribute on average 93.75% of the total sugarcane supply to the mill. The remaining 4.5% of total crush is provided by the Beaumont Sugar Estate, which is owned by the miller. An average of 34 600 hectares of land in the Eston region is utilized for the growing of sugarcane (Lumsden *et al*., 2000; Department of Transport, 2011; Bezuidenhout *et al*., 2013). Average annual rainfall in the region ranges between 800 mm to 900 mm and the average temperature is about 18-19°C. The cooler temperatures inhibit and accommodate different pests and diseases, compared to those along the coast (Cronje, 2011; Bezuidenhout *et al*., 2013).

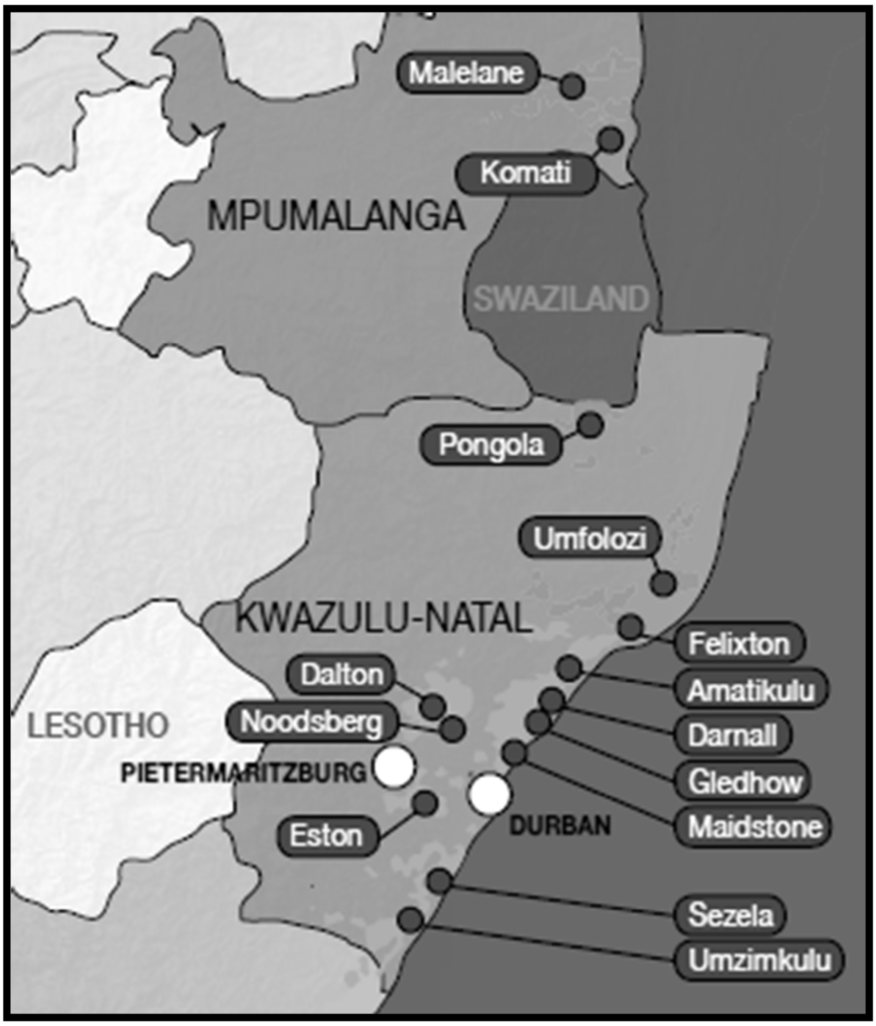

Figure 3.1 Map of the sugar mills in South Africa (after SASA, 2012b)

The Eston Mill operates 7 days a week, 24 hours a day and is usually open for approximately 34 weeks in the year from March or April until November or December. The mill crushes an average of 1.26 million tons of sugarcane annually, which results in 125 000 tons of sugar and 51 000 tons of molasses. All cane deliveries are transported by road and cane growers are located up to 58 kilometres from the mill. A large amount of cane at Eston is delivered by haulage tractors (Lumsden *et al*., 2000; Department of Transport, 2011; Bezuidenhout *et al*., 2013). Processed sugar is normally transported by road to the export terminal in Durban. Both Noodsberg and Sezela have additional processing plants and sugarcane from the Eston region is often diverted at a high cost to these mills, in order to optimize the company's overall profitability. Sugarcane in the Eston region grows relatively slowly, but yields and especially purity are high once the 24 months growing cycle is completed (Lumsden *et al*., 2000; Department of Transport, 2011; Thompson, 2011).

This Chapter aims to identify a pertinent problem in the Eston integrated sugarcane supply chain. The methodology used to establish the key problem area is explained in Section 3.2. Section 3.3 explains the results, whilst Section 3.6 provides a narrative of the issues that are experienced in the above-mentioned supply chain.

3.2 Methods

This diagnostic study involved three tasks. Firstly, an inquiry was carried out into the Eston integrated sugarcane supply chain, to establish a list of pertinent issues that hampered operations. Secondly, network analyses were employed to structure and analyse the acquired knowledge. Thirdly, a feedback session helped to establish a key problem area for further research. These tasks are described in more detail below. The study was conducted during July 2011. Some of the research conducted in this Chapter has been published by Bezuidenhout *et al*. (2013).

3.2.1 Inquiry

The aim of the inquiry phase was to establish the systemic issues that reduce performance and drive inefficiencies in the Eston milling area. Information gathering during this phase was based on qualitative exploratory stakeholder interviews. Irvine and Gaffikin (2006) state that qualitative approaches enable researchers to explore and explain vital issues of concern.

It is, however, also recognized that different realities exist, depending on the individual’s perspective (Irvine and Gaffikin, 2006). Therefore, 13 diverse stakeholders, who had been part of the Eston milling area for at least two years, were interviewed. According to the researchers’ knowledge, the stakeholders who were selected for interviews were highly involved in the systemic issues of the process and were considered to provide representative viewpoints from their specific profile. The stakeholders represented a wide spectrum of different profiles that were present in the area (see Table 3.1). A stakeholder’s interests often overlapped with more than one of the profiles listed in Table 3.1. The interviewers remained flexible and sometimes had to make additional appointments with new individuals whose names surfaced as prominent role players during other interviews. A maximum of one hour for each interview was allowed.

The sample chosen was guided by the adequacy, accessibility and availability of stakeholders, rather than size. A purposive (rather than random) sampling technique was utilized for the identification of interviewees. Redundancy and saturation of issues would have occurred with a greater sample size. Therefore, the sample size was less meaningful than its adequacy, which was determined when theoretical saturation was reached.

Table 3.1 Stakeholder profiles that were interviewed during the inquiry phase of the Eston milling area diagnostic study

Stakeholder profile	**Number of persons interviewed**
Cane supply manager*	2
Extension specialist	1
Local agricultural economist	1
Mill group board chairman	1
Large-scale growers	2
Small-scale grower	1
Grower who often disagrees with the system	1
Harvesting contractors	2
Large haulier in the area	1
Grower-cum-haulier	1
The cane quality testing manager	1
The mill manager	1

*Cane supply manager was interviewed first and more time was allowed for the interview

The interview process allowed for a rich exploration of complex issues and their causalities, outperforming any survey questionnaire (Luna-Reyes *et al*., 2005). The interview format was semi-structured and exploratory, which enabled detailed descriptions, with the interviewees elaborating without interruption. The following four open-ended questions were asked of each interviewee, which helped prompt further discussion:

- Can you identify some major problems in the current supply chain operation?
- On what issue/s do you focus most of your time on?
- What do you think can be done to improve the system efficiency?
- Did we miss out on any other important issues in this discussion?

The information gathered from the interviews were synthesized, into two networks and a narrative, using the methodology discussed in Sections 3.3.2 and 3.3.3.

There are, however, possible limitations to the above-mentioned methodology. The researchers attempted to choose a representative sample, but there could have been the risk of bias in mill area representation, because only 13 stakeholders were interviewed (*cf.* Martinez-Lopez *et al*., 2009). Borgatti *et al*. (2006) state that the information gathered would only be unbiased if the sampling method, which was used to select individuals to interview, did not insert any systematic error. In addition, the time constraints may have prevented further questions and deeper discussion, which also could have altered the conclusions of the study. Furthermore, the interviews were all conducted at one particular time, which could potentially result in the risk of a bias towards problems experienced at that specific period of time. Therefore, the magnitude of these problems could have been exaggerated.

3.2.2 Data analyses and network development

Network analyses employs techniques from algebra, graph theory and statistics. It can be used to depict a multitude of entities and relationships, within a single cohesive structure (Cross *et al*, 2002; Bezuidenhout *et al*, 2012a). Such an approach assists in system visualization and is especially powerful in systems of which researchers have limited knowledge (Borgatti and Xun, 2009). In addition, graph theory approaches in network analysis provide powerful tools for a network to be systemically assessed and can help identify key points where opportunities for improvement exist (Bezuidenhout *et al*, 2012a).

The Pajek software package was utilized to facilitate the network analyses in this study. Pajek is specifically designed to handle large, complex networks and is available free of charge (Huisman and van Duijn, 2003; De Nooy *et al*., 2005; Xu *et al*., 2010). Pajek has been compared with other network packages and was found to provide an appropriate application in supply-networks research (Mueller *et al*., 2007).

From the diverse spectrum of the interviewee responses, a triangulation process was used to identify systemic problems in the Eston milling area and to determine the major domains that seem to regulate the system. This helped to develop two networks for the Eston area, namely, an overall system domains network and a more detailed theme network (Bezuidenhout *et al*., 2013). These networks were developed and illustrate the issues that were identified in July 2011. In addition, the triangulation process assisted in compiling a narrative concerning all the issues in the mill area.

Bezuidenhout and Baier (2011) confirm that many research recommendations in the sugar industry worldwide have not been successfully implemented. This is due to many of the proposed solutions excluding issues in the integrated system, such as the nature of stakeholder collaboration, innovation and information sharing. The ten system domains, which could potentially override (or *veto*) the adoption of a scientific innovation, are illustrated in Figure 3.2.

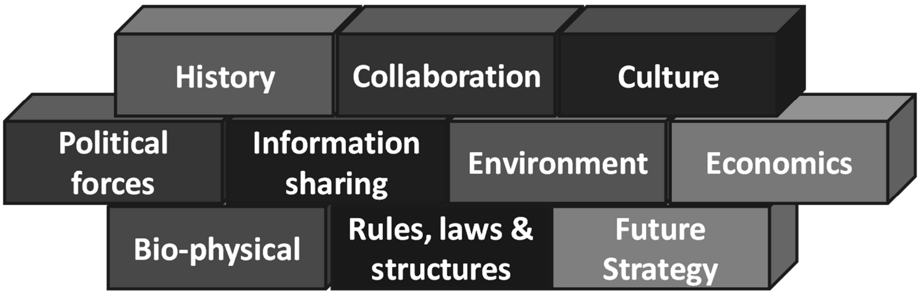

Figure 3.2 Ten important domains in an integrated agri-industrial system that could potentially *veto* the implementation of a scientific innovation (after Bezuidenhout and Baier, 2011)

Each statement raised during the interviews was carefully allocated to either one of the ten domains, or was placed on the interface between any two domains. For example, if a stakeholder mentioned that "*more efficient equipment is not purchased because of insufficient funds*", then the statement would be assigned to the intercept between the bio-physical domain (efficient equipment) and the economics domain (insufficient funds). Once all the stakeholders' statements had been categorized, the domains that dominated the conversations, were highlighted. Therefore, the relationships between each domain and the strengths of each domain are generally different. The size of each domain illustrates the number of times an issue was characterized into that specific domain. The connectors illustrate the number of times that an issue was characterized on the interface between two domains (as demonstrated in Figure 3.3).

A more detailed theme network complemented the system domains network and was extracted from the same interview data. The theme network was aimed at identifying pertinent issues in the supply chain by representing the connectivity between the issues in the system. Identifying the centrally located issues in the system unlocks potential opportunities for improvement. Based on the interviews, an inventory of the issues that were raised was compiled. For example, if a stakeholder noted that "*the mill is running out of cane because cane cutters do not come to work after pay weekends*", then "*No-cane stops*", "*Cane cutters*" and "*Pay-weekends*" were added to the inventory of issues. A concerted effort was made to keep the list of issues to a minimum by combining related topics, whilst not losing sight of the fine detail.

The theme network was developed according to the following steps. First, a vertex for each issue identified became a separate vertex in the network. Secondly, the researchers' connected vertices that were directly related to each other, based on first principles. For example, in the Eston theme network (Figure 3.4), the vertex "*Drought*" is directly related to "*Yields*" and "*Cane cutters*" is directly related to "*No-cane stops*". Thirdly, the network was projected, using Pajek, with the Kamada-Kawaii (1989) energizing transformation. This technique considers the connectivity between vertexes and positions each vertex in close proximity to other related ones. Fourthly, Freeman's (1977) technique of centrality, based on betweenness, was used with Pajek to determine the sizes of vertexes. Betweenness centrality is essentially a measure of the number of paths that travel through each vertex. For example, the vertex "*Yield*" was connected to many other vertexes, which resulted in a large vertex size or large betweenness centrality. Finally, this revealed a theme network, as demonstrated in Figure 3.4, which was then studied and larger overall themes were allocated to groups of vertexes that were closely related. For example, "*Yield*", "*Eldana*" and "*Field damage*" could all be grouped under the general theme of agronomy.

3.2.3 Further analyses and validation

The theme network created an appropriate platform, from where a detailed narrative was compiled, to explain the different issues in the system. The narrative was exclusively based on the problematic issues raised during the inquiry phase (see Section 3.2.1). The narrative also discusses the linkages between different issues.

The results of the inquiry and network development phases were presented to a wide range of stakeholders at a feedback session. This consultation assisted to confirm that the results were indeed representative of the Eston milling area and that the study did not suffer from undue bias (as discussed in Section 3.2.1). A few potential system opportunities that could be further researched were presented to the stakeholders at this session. The stakeholders then discussed and assisted to establish the specific area to be further researched.

3.3 Results

Figure 3.3 illustrates the system domains network for the Eston sugarcane milling area. The network could be depicted in many other ways and is based on the information gathered from the interview process (as discussed in Section 3.2.1). Figure 3.4 can be read in the same way. The size of each vertex reflects the number of times a particular issue was raised. It is clear that bio-physical issues were often related to the environment, economics and the culture of other people in the area (depicted by dark lines between dots). In contrast, issues pertaining to committees and structures, collaboration, information flows, future issues, politics and the history of the area were seldom voiced. The Kamada-Kawai (1989) energising transformation automatically positioned closely related and important issues towards the centre of the graph. It can be argued that any research conducted at Eston should include aspects of, at least, the centrally located domains. The network could be depicted in many other ways and is based on the information gathered from the interview process (as discussed in Section 3.2.1). Figure 3.4 can be read in the same way.

The stakeholders generally understood and agreed with the system domains network, during a feedback session, even though they were unaware of these broad domains during the interview process. The system domains network appears to be a powerful technique to surface subtle, but strong, forces within the milling area and could be utilized in other industries. It is, therefore, important that further research using this technique is undertaken to demonstrate the effectiveness of this network.

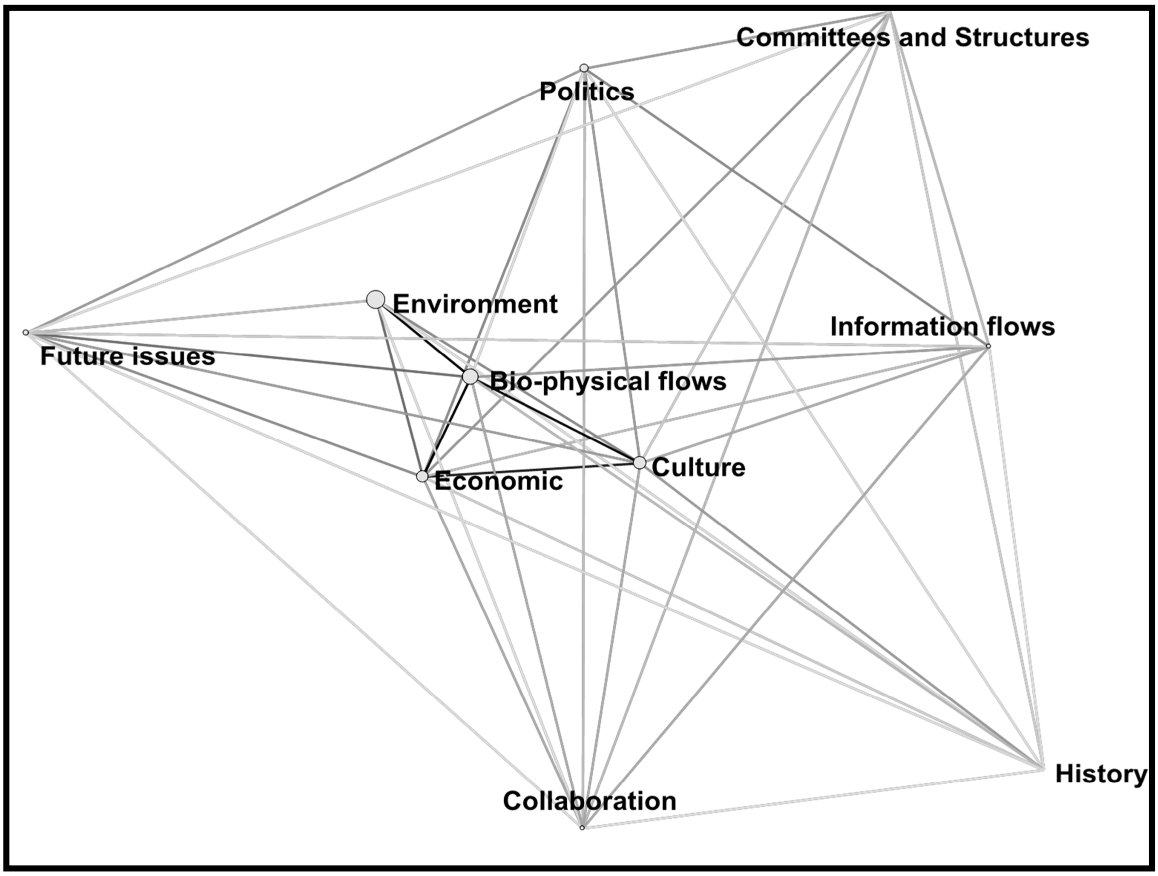

Figure 3.3 An energized system domains network of the Eston sugarcane supply chain, July 2011 (Bezuidenhout *et al*., 2013)

The Eston theme network (Figure 3.4), illustrates the pertinent issues raised during the inquiry phase, in relation to their influence on the overall sugarcane supply chain. The explanation of each issue, according to the interviewees, can be found in the narrative (Section 3.4). The issues were broadly characterised, by the researcher, into four larger issues that are related to each other, *viz*. (a) milling, (b) cane supply logistics, (c) agronomic, and (d) long-term sustainability. There are clear overlaps between (a) long-term sustainability and agronomic issues, as well as between (b) cane supply logistics and milling issues. The larger vertices in this grouping are the "*Length of season*," "*Wet weather*," "*Slow crush rate*," "*Below rateable delivery (DRD)*," "*Cane cutters*," and "*No-cane stops*." The problems raised under the agronomic and long-term sustainability issues of the theme network (Figure 3.4) were considered to be beyond the scope of this research. Therefore, it was appropriate to select a research focus from an area within the milling and cane supply logistics issues of the network.

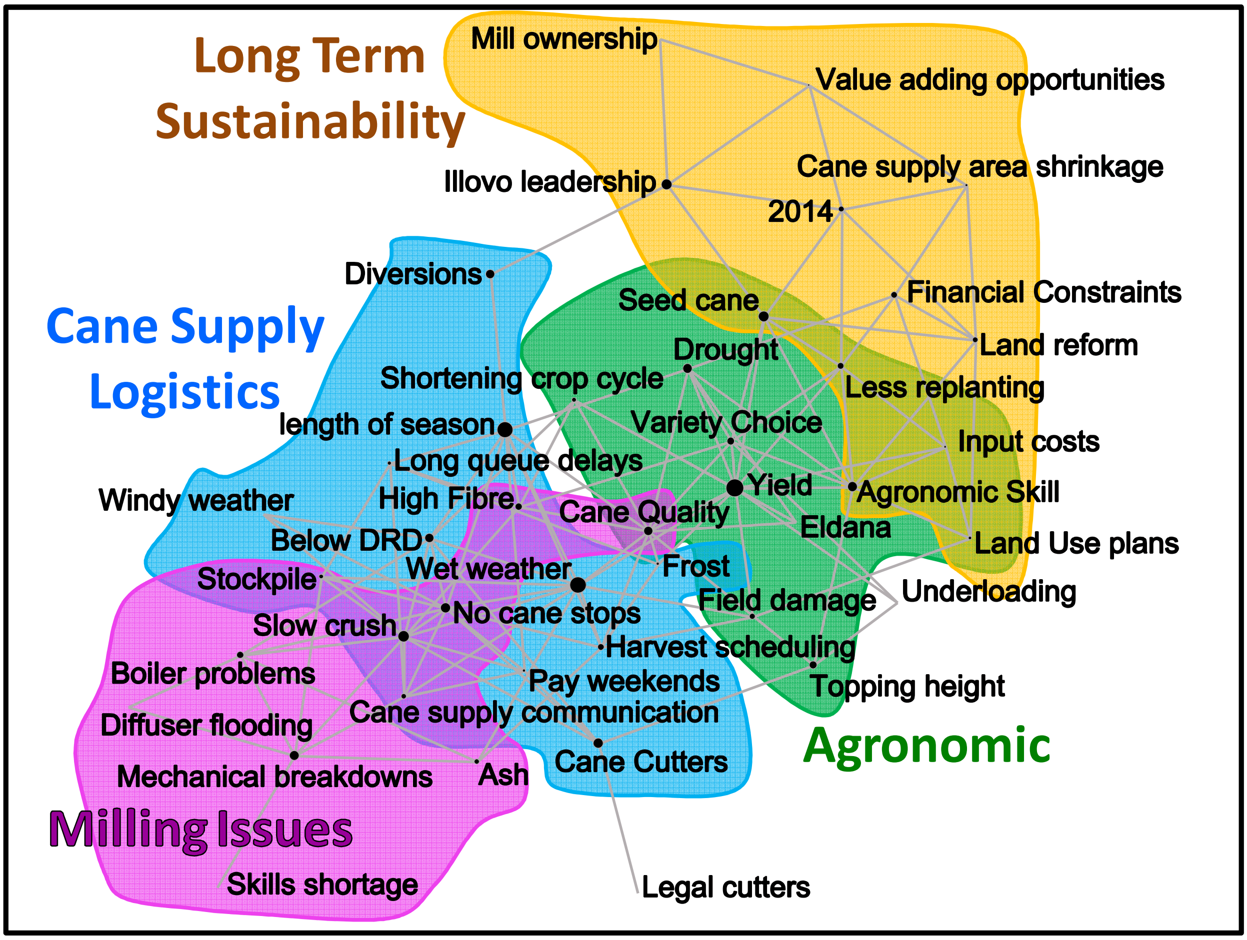

Figure 3.4 An energized theme network of the pertinent problems in the Eston sugarcane supply chain, July 2011

The results of the theme network (Figure 3.4), which were initially complex, were ultimately illustrated in a relatively easily understandable image. The technique used helped to develop the different clusters and linked various issues into one holistic network. The final results were depicted in a way that the stakeholders could easily relate to and understand. The theme network approach has potential applications in other industries to represent connectivity between components, which then increases understanding of the system. However, it should be noted that the theme networks present a particular projection of the Eston milling region at a specific point in time. It is important to remain neutral and not to jump to conclusions about the most pertinent problems in the milling area. The final conclusions could only be validated through report-back meetings with the stakeholders.

3.4 Narrative

The growers, hauliers and the millers stated that communication and information flows were generally pleasing in the Eston region. However, most growers considered communication not to be fully transparent. Growers believed that there is a lack of feedback from the mill when breakdowns occur. They indicated that they are penalised, not only when the mill has an insufficient quantity of sugarcane, but also when the mill has a shutdown or experiences a slow crush rate.

Many growers also believed that they are being incorrectly compensated because they only receive an income for sugar recovered and not for by-products, such as bagasse. The payment of cane is regulated by the Sugar Act. The uncertainty about the changes to the Sugar Act, which is currently under review, has been a major cause of reduced farm investments. There has been minimal improvement to the infrastructure on farms and reduced farm maintenance, for example, the lack of alien plant removal.

It has been perceived that there was a lack of information flow between the Eston Mill and the Illovo head office, especially with respect to sugarcane diversions to and from the mill. The Eston Mill diverts cane to and from the Noodsberg and Sezela Mills. There is uncertainty in the system as to the length of the milling season because of regular changes in the amount of cane diverted. An increase in diversions to the Eston Mill in the 2011/12 season, mainly due to the temporary closure of the Umzimkulu Mill, extended mill operations into the rainy season, which was undesirable. It was felt by some individuals that the Illovo head office focuses primarily on the Sezela and Noodsberg Mills, where value adding downstream plants exist, compared to the Eston Mill.

There has generally been a lack of land use plans on farms in the Eston Mill region, which have the potential to improve farm productivity. It is easier to implement farm plans on a new or abandoned farm than to establish land use plans whilst farming practices are underway. Land use plans on sugarcane farms involve many different aspects, including the placement of extraction routes, as well as the position and number of loading zones. This is a complex process and requires detailed analysis linking physical farm features, such as soil types and the economic aspects of farms. An example of a problem in the Eston region, which could be addressed by land use plans, is that some sugarcane varieties, such as N31, are perceived to be grown in incorrect locations. Land use plans can also be used to reduce the impacts of Eldana on fields.

Eldana, a stalk borer (see Figure 3.5), has a large-scale impact on sugarcane by potentially reducing the crop cycle, quality and sucrose levels. Eldana have recently invaded the Eston area (Singels *et al*., 2010). The impact of Eldana can be reduced by using Integrated Pest Management (IPM) techniques (Ramgareeb *et al*., 2010). This involves farm diversification, such as the growing of timber, water or natural vegetation. The impacts of Eldana can also be reduced by the usage of treated seed cane. Seed cane has become a topic of much debate, especially with the over-use of current sugarcane varieties in the region. Over reliance on the N31, N29 and N12 sugarcane varieties were being exploited, due to the lack of diversification. Large areas under homogeneous genotypes expose the milling area to pest and disease outbreaks.

Seed cane varieties can also be used to reduce lodging. The adoption of seed cane schemes was low and there were no nurseries in the Eston region. Some growers believed that the mill did not regard seed cane to be a serious issue. The mill trade agreement stipulates that a grower must produce a certain amount of sugarcane each season. Investment in seed cane was restricted, due to these agreements. The area has since learnt to appreciate the importance of seed cane, but, as of June 2011, the mill did not offer to subsidize or assist growers and alter the trade agreements. As of June 2011, 40 growers agreed to the adoption of seed cane. However, other growers believed that conducting their own experiments on varieties would be the best method to determine the most suitable variety for their farms. Study groups have assisted in this method and have proved to be beneficial. Some growers also believed that scientific plant breeding is required in the Eston Mill region.

Figure 3.5 Eldana stalk borers feeding on a sugarcane stalk (Courtesy of G Leslie)

The weather is a fundamental factor that affects yield and, hence, also the RV or profits in the Eston sugarcane supply chain. The weather is the main driver of supply chain inefficiencies and is a significant indirect cause of mill shutdowns. The Eston Mill region can be broadly characterised into two climate regions, namely Richmond and Eston. Some growers thought that harvesting scheduling could be done to take advantage of the different climates, which will benefit the region by maximising RVs.

The 2010/2011 drought in the Eston region was the worst ever recorded. The drought reduced sugarcane supply and cutter productivity, by about 15%. This led to many growers not meeting their Daily Rateable Delivery (DRD). Some growers resorted to cut immature cane to meet their DRD, but this reduced their RV and had an impact on the subsequent seasons.

As in most sugarcane regions in South Africa, the summer months, from November to March, are wet and rainy. Rain is one of the major drivers of the length of the milling season. After October, rain drastically reduces the supply of sugarcane and the mill may run out of cane on numerous occasions. The most ideal milling season is probably from April to October. Harvesting in wet weather causes field damage and excessive rain reduces the time available to harvest cane, which slows down cane supply and can increase the BHTCD. An increase in the BHTCD results in cane deterioration, which reduces sucrose levels, and hence, the RV.

Wind, fire, hail and frost are other extreme environmental conditions, which have negatively affected the sugarcane supply chain at Eston. Windy conditions during the milling season have prevented cane burning. This has led to a lower cane supply to the mill and increased the pressure on growers to meet their DRD. Runaway fires have also affected some growers, because they may shorten crop cycles and cause growers to harvest and supply cane to the mill ahead of schedule. The RV is reduced when immature cane is harvested. Hail has the ability to reduce sucrose and yields for more than one milling season and can occur at any time of the year, although normally only over small areas. Hail also shortens the crop cycle and causes field damage. Frost causes shortened crop cycles, damages crops, may reduce sucrose content and hence RVs. Frost, along with cold winter conditions, is common in the Eston region and can reduce cutter availability, as well as productivity.

Cane is currently cut manually in the Eston region (see Figure 3.6). The theme network (Figure 3.4) domain named ‘Cane Supply Logistics’ presents pay-weekends, cane cutters, slow crush and no-cane stops as centrally-located issues in the system. In addition, the economics, culture and bio-physical flows in the system domains network (Figure 3.3) also encompass these issues. This was due to the availability and productivity of farm workers being a fundamental problem in the Eston Mill region. The major problem, which impacts most growers, is absenteeism, especially amongst cutters after pay-weekends. There was a high proportion of cutter absenteeism, often greater than 50%, after a pay-weekend. The problem usually impacts the mill after the first weekend of each month because cutters are generally paid on the first Friday or Saturday. Many growers have indicated that the majority of cutters do not return to the farms on the subsequent Sunday or Monday after a pay-weekend. The cutter workforce may only fully return to the farms on a Wednesday or Thursday after the weekend. It is important to note that the milling season last on average for nine to ten months and labour absenteeism has significantly affected the mill. The lack of cutters reduces harvesting rates, which results in lower sugarcane supply to the mill. It causes no-cane stops, prolongs the season and indirectly decreases RVs considerably, by moving the harvest window out of the high quality period. It was perceived that the length of the milling season (LOMS) can be reduced if this problem was alleviated.

A few growers have also made reference to the poor mind-set of some farm employees. These workers, especially cutters, are perceived to be not interested in earning a higher income. After the introduction of a minimum wage policy, some farm workers have reduced the number of days on which they work, because they can earn the same amount of wages for fewer working days. It was perceived that this problem is compounded by an increase in social grant allocations and has worsened the problem of pay-weekends, because absenteeism rates have increased. Absenteeism and the late arrival of farm workers are also generally higher on cold days, which reduces harvesting rates. This is another reason why growers are unable to meet their DRD.

The number of cutters available was also a problem for some growers. Labour regulations in South Africa have stipulated that growers should employ South African citizens or legal immigrants. There were contradicting reports from growers in terms of employment. Some growers said that there was an excess supply of South Africans, whilst others have stated that they were unable to attract an adequate number of local employees. These growers have resorted to employing cutters from Lesotho, some of whom are illegal. These growers felt that the government should assist them by re-evaluating employment requirements and aid them to find and employ South Africans, or provide more work permits for foreigners.

Figure 3.6 A sugarcane cutter at work (Courtesy of CN Bezuidenhout)

A few growers also raised concerns about the tax requirements for their employees. The government requires all employees to have a tax number, regardless whether they are eligible to pay tax or not. The problem is that many employees do not have birth certificates or identity documents. To acquire these documents is a long and complicated process. To avoid heavy penalties, growers sometimes were forced to dismiss employees without documentation, some of whom have been working for long periods of time and who were highly productive. This may compound the problem of illegal cutters, if government does not review their farm labour employment policies. Another perceived labour problem, which is difficult to quantify, is the effect of HIV/AIDS on the entire Eston sugarcane supply chain.

HIV/AIDS and nutrition are alleged to have a substantial impact on cutter and driver availability, as well as productivity.

In recent years, there has been an increase in input costs, which is mainly attributed to the increase in the fuel price. In-field haulage costs have increased substantially with the large increases in the diesel price. The cost to replenish and maintain equipment has also increased. The increased fuel price also increases other input costs, such as fertiliser and haulage to the mill. All these additional costs have reduced the profitability and supply of cane and some growers have phased out sugarcane production. For example, some growers have changed from sugarcane production to the growing of vegetables. This, along with other urban developments, has led to a reduction in the land area utilized for growing sugarcane in the Eston region.

Most new, small- and some large-scale growers have stated that they experience severe cash flow constraints, due to substantial fixed and operating costs. A key fixed cost is servicing the land debt. Labour and other farm inputs, such as fertilizer and pesticides, are the main variable or operating costs incurred by these growers. Many small-scale and some large-scale growers also hire contractors for the harvesting and haulage of sugarcane, which enhances their cash flow problem. The growers also suffer from lack of skilled labour for growing and harvesting of cane. Financial constraints have prevented the training of labourers, the improvement of farm conditions, and hence, the yield per hectare. In addition, the financial constraints have resulted in less replanting. Lack of replanting has been a fundamental issue, which has many impacts. It reduces future yields and resulting profits, as well as the ability to re-establish farms for the new growing season. Small-scale growers believed that the government should assist them in reducing their cash flow problems, for example, by providing grants for farm ownership and establishment.

Many individuals in the Eston supply chain believed that there is a problem of vehicle over-fleeting. The number of vehicles has grown from 38 in 1995 to approximately 70 in 2011. Vehicles range from small tractors to large trucks. The increased number of vehicles has led to an increase in waiting queues at the mill (see Figure 3.7). However, some growers argued that there is logic in having so many vehicles. Many of the smaller vehicles move in-field, which reduces double-handling and haulage expenses.

Figure 3.7 Sugarcane vehicles at the Eston Mill waiting area (Courtesy of CN Bezuidenhout)

Furthermore, there are policies with regards to the size of vehicles and the distance within which they were allowed to operate in the Eston Mill region. These policies were implemented by the cane procurement division at the Eston Mill. Growers located within a radius of 10 km from the mill are authorized to transport sugarcane on 15 ton payload haulage tractors. Growers within a 20 km radius of the mill are permitted to deliver cane in vehicles with payloads of no less than 20 tons, while payloads in excess of 26 tons are required for farms located more than 20 km from the mill. Growers are penalized and could be banned from delivering sugarcane to the mill, if they fail to comply with these regulations. Some growers perceived these regulations as unfair, because they provide certain advantages to growers located in close proximity to the mill.

In Eston, the mill yard and weighbridge (see Figure 3.8), which form part of the mill front-end, is controlled by the factory. The miller uses a vehicle calling system to instruct vehicles to move from the waiting area to the weighbridge. The calling system has reduced waiting queues, which had previously been a problem at the mill. Once they have been called, it takes, on average, between 24-30 minutes for vehicles to offload and leave the mill area. The calling system has received extensive positive comments from all entities in the supply chain and is regarded as being highly effective. In 2007, the mill also successfully introduced a Short Message Service (SMS) system, whereby growers are informed when they have submitted an overloaded vehicle to the mill. Growers are penalized for overloading. The SMS system has improved the average payload and reduced overloading. However, as of June 2011, there was no penalty implemented for vehicle underloading.

The mill experiences an inconsistent supply of sugarcane throughout the day. This is due to many grower operations being reliant on daylight hours, whilst the mill requires sugarcane to be supplied continuously for 24 hours. This normally results in a shortage of cane supply from 5am to 9am, whilst from 10am to 6pm, there is generally an excess supply. In an effort to combat this problem, the mill separated the day into four shifts, each six hours long, with growers being allocated a time and amount of cane allowed for delivery during each shift. However, the effects of rain and wind reduced the success rate of the shift schedules.

It appeared that there are potentially numerous areas for improvement in the Eston Mill. The sugar to RV % ratio was about 93% in the 2010 season, which is deemed to be low and has resulted in economic losses. The mill also suffered from substantial undetermined losses, which could not be attributed to chemical or physical causes. Some mill personnel believed that there was a lack of skilled-labour at the mill, which reduces the mill’s throughput efficiency and increases mill breakdowns. The lack of nearby accommodation and transport to the mill, as well as lower wages, compared to other industries, such as manufacturing and construction, were perceived as reasons for the mill not being able to adequately attract skilled employees.

Other reasons for mill breakdowns included diffuser flooding and boiler capacity constraints. There are two boilers at the mill (Figure 3.8). One of the two is unable to burn a large amount of coal, due to its design. This becomes a problem when the supply of bagasse is low. A new storage shed for bagasse has been proposed. At the Eston Mill, diffuser flooding is mainly caused by the presence of impenetrable fibre in the cane. In addition, personnel at the mill have stated that the ash content in cane is high, due to the incombustible soil components in the Eston region being more erosive and abrasive, compared to coastal regions. Ash in cane has increased the wear on hammers and shredders, which causes mechanical downtimes. A sand-and-rock-remover has been proposed to reduce the problem of sand in cane, but has not been installed to date.

After the relocation of the mill from the Illovo site to Eston, it was proposed that the Eston Mill may eventually expand. An additional boiler is required for the mill capacity to expand. The mill crush rate will have the potential to increase, from an average of 250 tons to 375 tons of sugarcane per hour. This can also reduce the milling season, which has the potential to improve the RV. However, an additional boiler is estimated to cost R350 million.

It was appropriate to select a research focus from an area within the milling and cane supply logistics issues of the network (see Section 3.3). A large proportion of these issues were related to pay-weekends. For example, the growers stated that they are unable to meet their DRD, which appears to be largely due to pay-weekends. This leads to no-cane stops and slow crush and a large emphasis on cane supply communication. Pay-weekends have also led to a longer LOMS, which pushes production into the rainy season, with an increased incidence of wet weather and field damage. This results in an increased quantity of fibre in cane. The problematic issue of pay-weekends was emphasized by the vast majority of stakeholders, highlighting this issue as the most pertinent problem in the Eston sugarcane supply chain.

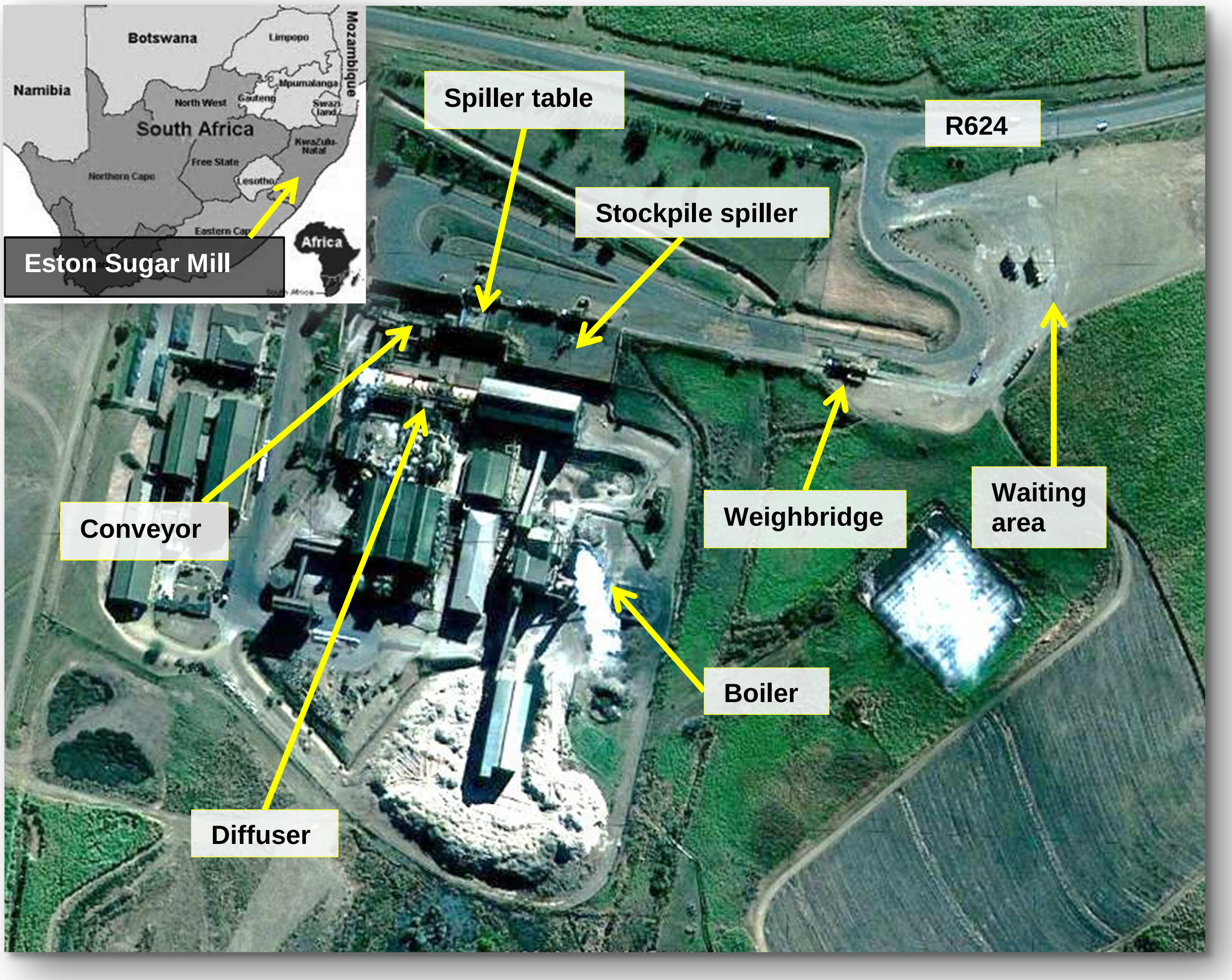

Figure 3.8 An overview of the Eston Sugar Mill

3.5 Conclusion

The theme and system domains network used in this investigation, proved to be valuable, in order to identify a pertinent problem (pay-weekend related cutter absenteeism) in the Eston sugarcane supply chain. However, further research can be conducted using these techniques, in order to determine if they are scientifically valuable. The system domains network established ten domains, which could potentially override the adoption of a scientific innovation. It can be argued that any systems-based research should consider these domains, when changes are being made to the system. The theme network creates a platform from where a detailed narrative could be written, to explain the different issues in the system. The narrative also discusses the linkages between the different issues. This created a knowledge-rich platform from where specific issues can be further explored. Pay-weekends were highlighted as a problematic issue in the Eston region, which called for further research. A detailed study of this problem is discussed in subsequent Chapters. There are other prominent issues, which fell outside the scope of this study, which include, among others, upgrading the mill and introducing harvest scheduling to the region based on the different climatic zones.

4. METHODOLOGY: MODEL DEVELOPMENT, DATA ANALYSIS AND ASSUMPTIONS

The Literature Review (Chapter 2) outlined the need for cane processing and quality consistency. The careful management of the different sectors in the supply area is required to ensure that growers harvest at a uniform rate, which enables the mill to consistently process cane (Le Gal *et al*., 2004). The diagnostic exploratory study (Chapter 3) identified various factors that cause inconsistencies in the sugarcane supply chain at Eston. This Chapter proposes three methods to quantify the impact of the factors that influence disruptions to the sugarcane supply chain at Eston. The results are reported in Chapter 5.

4.1 Introduction

This Chapter proposes three methods to establish the impacts of factors that influence disruptions at the Eston Mill. Firstly, a simple Multivariate Analysis of Variance (MANOVA) was conducted, to depict the impacts of pay-weekends on daily crush rates for five recent milling seasons (2006 – 2010). This is discussed in Section 4.2. Secondly, a conservative, yet simple and well-structured data analysis process, using a novice lower-trimmed mean approach, was employed to analyze a typical sugarcane season. Five recent seasons (2006 – 2010) were analysed, using this process. This approach is discussed in Section 4.4. Thirdly, a more complex mechanistic model was developed, calibrated and verified, in order to identify the impacts of disruptions to the mill crushing operations. Four milling seasons (2004, 2005, 2011, and 2012) were utilized for the development and calibration of the model, whilst five other seasons (2006 – 2010) were reserved for verification purposes. The methodology used for the model development, calibration and verification is discussed in Section 4.5. Figure 4.1 compares the type of analysis considered for the lower-trimmed mean approach (in orange) and the mechanistic model (in purple). These techniques are discussed in more detail in Sections 4.4 and 4.5. Based on a literature search, this research is considered to be the most comprehensive analyses of sugarcane supply consistency at mill-scale worldwide.

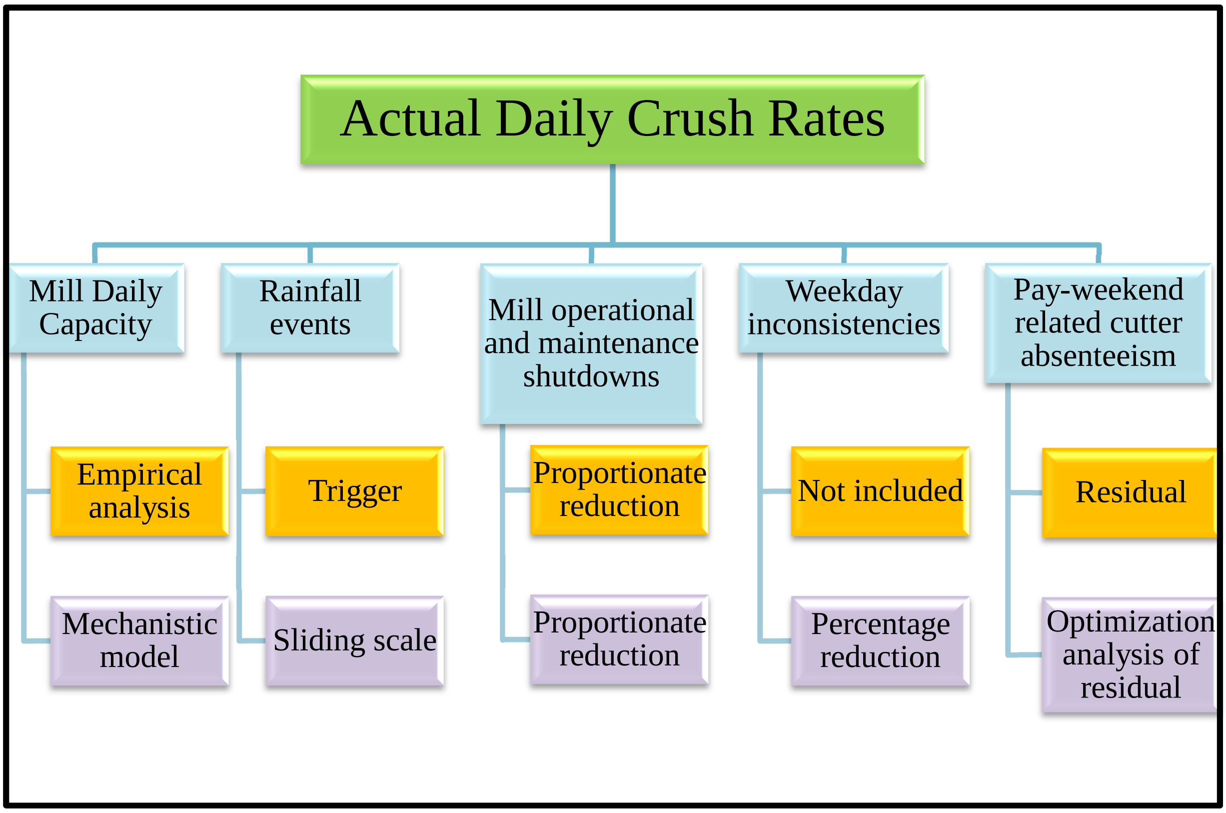

Figure 4.1 A comparison of the lower-trimmed mean (in orange) and mechanistic modelling approach to analyse cane flow consistencies at the Eston Mill (in purple)

The type of data used for the analyses are discussed in Section 4.2. A certain number of assumptions were made in this study because of insufficient information, or ambiguous data. In all cases, conservative assumptions were maintained, to avoid unrealistic outcomes. These assumptions are also discussed in Section 4.2.

4.2 Data and Assumptions

In this research, a milling season is defined as the number of days that the mill is operational in a year. The analyses were based on various types of data, for nine milling seasons, from 2004 to 2012. The analyses were based on a daily time step, which included sugarcane crush records, in tons per day ($t.d^{-1}$); mill stops and breakdowns, in minutes per day ($min.d^{-1}$); and rainfall events, in millimetres per day ($mm.d^{-1}$). This Section discusses the type of assumptions made for the above-mentioned data.

4.2.1 Daily crush rates

The daily crush rate can be defined as the total tons of sugarcane that the mill processes over the course of a 24-hour period, from 6:00 am on one day to 5:59 am on the next day. The actual daily crush rate (ADCR) data for the nine seasons were obtained from Cane Testing Services at the Eston Mill (Govender, 2011; Naidoo, 2013). Ideally, hourly crush rates would have been more appropriate, to establish the times during the day when cane flow inconsistencies impacted on mill processing. However, these data were unavailable.

Table 4.1 summarizes the total annual cane crushed at the Eston Mill (t.d^{-1}), the length of the milling season (LOMS) (tons per season), the average ADCR and the number of days of rainfall (> 1mm per day) for each of the seasons analysed. The LOMS and size of the crop varies from one season to another, mainly due to rainfall variations. An increased number of rainy days generally results in a longer LOMS. Table 4.1 also depicts how the ADCR varies. Graphs of the ADCRs for different seasons are presented in Appendix B (which are similar to Figure 5.2). The Eston Mill aspires to crush sugarcane at an average rate of 250 t.hr^{-1}, *i.e.* 6 000 t.d^{-1} (Pillay, 2011). However, it is estimated that the average crush rate is significantly lower, which could mainly be due to rainfall, mill stops and breakdowns, as well as cutter absenteeism.

Table 4.1 Cane processing and annual length of the milling season (LOMS) at the Eston Mill (Govender, 2011; Naidoo, 2013; SASRI, 2013)

Mill Season	Total actual annual cane crushed (t.s^{-1})	Average ADCR (t.d^{-1})	LOMS (d.s^{-1})	No. of rainfall days (> 1mm)
2004	1 074 963	4 594	234	57
2005	1 306 058	4 947	264	86
2006	1 267 501	4 592	276	109
2007	1 409 281	5 015	281	108
2008	1 342 575	5 204	258	97
2009	1 207 697	4 774	253	81
2010	1 008 379	5 093	198	38
2011	1 141 931	4 514	253	121
2012	1 252 853	4 523	277	114

4.2.2 Rainfall

As discussed in Chapter 2, rainfall negatively impacts cane processing and quality consistency significantly. This has resulted in the need to quantify the impact of rainfall. The Eston region contains approximately six homogeneous climatic zones (HCZs) (Bezuidenhout and Gers, 2002; Bezuidenhout and Singels, 2007), namely, Umlaas Road, Bainsfield, Tala Valley, Eston, Mid Illovo and Umkomaas. The daily rainfall data for each HCZ, for the period 2002 to 2012, were obtained from the SASRI Weather Website (SASRI, 2011; 2013). The rainfall data from each HCZ are recorded over a 24-hour period, from 8:00 am on one day to 7:59 am on the next day. This compares reasonably well with the daily crush rate, which is captured from 6:00 am to 5.59 am.

Table 4.2 summarizes information for the HCZs in the Eston region, with specific production data for the 2012 season. The majority of cane is dryland, with only 7.8% of total cane in the region being irrigated. The dryland cane growth cycle of 23 months is consistent throughout the region. The Eston and Mid Illovo HCZs contribute about 61% of the cane in the region. It can, therefore, be argued that rainfall events in these HCZs have the potential to significantly affect mill operations. The specific impacts of each HCZ are, however, beyond the scope of this research.

Table 4.2 Summary of information for the six homogeneous climatic zones in the Eston region for the 2012 season (SASRI, 2011; 2013; Singels, 2013)

HCZ name	**Growing cycle (mo)**	**Irrigation (I) vs Dryland (D)**	**Area under cane (ha)**	**Average cane yield (t.ha^{-1})**	**Estimated sugarcane production (t)**	**Percentage of total mill area**
Umlaas Road	23	D	1930	125.1	241421.8	10.8%
Bainsfield	23	D	3130	138.5	433573.9	19.4%
Tala valley	18	I	1067	137.8	147020.9	6.6%
Eston	23	D	6939	108.8	754810.5	33.8%
Mid Illovo	23	D	4591	137.2	629655.7	28.2%
Umkomaas	12	I	300	96	28790.1	1.2%

Rainfall data for the nine seasons were obtained for each HCZ (SASRI; 2013). However, the Bainsfield HCZ does not have a suitable rainfall gauge. Rainfall events for the Tala Valley HCZ have only been recorded from 2008 onwards. These two HCZs contribute about 26% of the total cane production for Eston. The Eston-Hayfields weather station data were used as indicators for Bainsfield and Tala Valley (SASRI, 2013; Singels, 2013).

4.2.3 Mill breakdown and slow crush rate data

The Eston Mill can shutdown, be stopped or slowed down for various reasons, such as mechanical faults, maintenance and a shortage of cane supply (Meyer and van Antwerpen, 2001). All of these lead to a lower crush rate and an increase in the LOMS, or more diversions to other mills. A mill can be stopped for either maintenance, which could be due to the replacement of hammers and shredders, or due to no-cane. A no-cane stop or a slow crush rate, which is recorded when the mill crush rate is less than 200 $t.hr^{-1}$, normally occurs when there is insufficient sugarcane supply to the mill. The shortage in cane supply can normally be attributed to rainfall and/or a shortfall in farm labour. An unexpected mill mechanical fault, such as flooding in the diffuser, results in a mill breakdown. The effect of a mill breakdown is generally more severe than a no-cane stop, because of its unpredictability (Boote *et al.*, 2013).

Daily data on mill breakdowns, stops and slow crush rates for the nine seasons, in minutes, were obtained from records at the Eston Mill (Clarence, 2011; Le Roux, 2013). The detailed daily data provided the start-time, end-time, duration, reasons for the slow crush, stops and breakdowns, as well as the department responsible for the disruption. These included, amongst others, the front-end mechanical, back-end operational and power generation mechanical departments, a scheduled maintenance stop, foreign matter, electrical faults and a lack of cane supply. It was assumed that a lack of cane supply was normally due to rain or a shortage in farm labour and an emphasis was placed on these breakdowns. An analysis of the other causes of breakdowns, such as back-end mechanical, was beyond the scope of this research. On days when more than one breakdown occurred, the summation of durations were calculated. On some days, the breakdown lasted more than 24 hours, or spanned across two days. The allocation for each day was proportionately allocated, based on the start- and end-times.

Personnel at the mill (Cronje, 2011; Govender, 2011; Pillay, 2011; Thompson; 2011) have stated that in an attempt to reduce the impacts of pay-weekends, long maintenance stops are usually scheduled to commence late on Sundays and encompass a large proportion of Mondays. These long maintenance stops usually take place every three weeks and are approximately 18 hours long. Evidence of this was found in the analysis of mill shutdown data.

4.3 Multivariate Analysis of Variance (MANOVA)

As mentioned in Chapter 3, pay-weekends are believed by many stakeholders at Eston to have a negative impact on the consistency of mill processing. Farm workers, including cutters, are usually paid on the first Friday or Saturday of each month. It is alleged that mill processes are slowed down, or stopped, on Sundays, Mondays, as well as some Tuesdays and Wednesdays, due to these payments and their subsequent absenteeism.

In order to determine the impacts and predictability of pay-weekends on mill processes, the ADCR data were analyzed, which combine the 2006 – 2010 seasons. A Multivariate Analysis of Variance (MANOVA), with a 95% confidence level, was conducted to determine whether the daily crush rates are significantly different after the first weekend of each month, compared to the daily crush rates after all the other weekends of each month. By combining all five seasons, the impacts of rainfall and breakdowns are negligible. However, the specific impacts of cutter absenteeism for each season cannot be estimated, using this method. In addition, a considerable variance in the impacts of pay-weekends is likely to be estimated, when using this method.

4.4 The Lower-Trimmed Mean Approach

In comparison with the MANOVA, the lower-trimmed mean (LTM) approach is more sophisticated. The LTM approach analysed ADCR for the 2006 – 2010 milling seasons. The analysis involved the development of a conservative, yet simple and well-structured, statistical process to analyze a typical sugarcane season. Each season was analysed independently. The first step was to analyse the ADCR data and identify days when the mill processes were below potential. These were used to identify the potential factors that caused a reduction in the crush rate. The LTM approach was developed for this purpose.

4.4.1 The lower-trimmed mean

The LTM, in t.d^{-1}, was used to estimate the potential milling capacity on any particular day, in the absence of rainfall, mill breakdowns, stops and other slowdowns, as well as cutter absenteeism. The LTM is novice and was designed for this study, but is based on the principles of the trimmed mean (Stigler, 1973). The LTM was calculated by assuming that any day (*i*) should be able to crush as much cane as during any other four productive days, in the week that surrounds *i*. This was done by calculating the mean crush rate for the four most productive days around *i*, as depicted in Equation 4.1:

$$LTM_i = \frac{1}{4}\left(\sum_{j=i-3}^{j=i+3} ADCR_i - \sum_{p=1}^{3} ADCR_p\right) \tag{4.1}$$

where:

LTM_i is the lower-trimmed mean for day *i*,

$ADCR_i$ is the actual daily crush rate for day *i*, and

p represents the days with the three least productive crush rates in the period [i – 3,…,i + 3].

In other words, the LTM estimates the running average of the four highest values within a seven-day period, as demonstrated in Table 4.3. The daily crush deficit ($\Delta ADCR_i$ in t.d^{-1}), which was calculated when the ADCR was less than 10% of the LTM_i, was estimated according to Equation 4.2 and is also demonstrated in Table 4.3. Such a crush deficit could then be attributed to rainfall, mill maintenance or mechanical breakdowns, as well as cutter absenteeism.

$$\Delta ADCR_i = LTM_i - ADCR_i \qquad | \; ADCR_i < 0.9 LTM_i \tag{4.2}$$

Table 4.3 An illustration of how the lower-trimmed mean was calculated for Friday the 10th of April 2009

Date (2009)	**Day**	**ADCR (t.d^{-1})**	**LTM_i (t.d^{-1})**	**$\Delta\, ADCR_i$ (t.d^{-1})**
07 April	Tuesday	5828		
08 April	Wednesday	5848		
09 April	Thursday	6040		
10 April	Friday	4394	5842	5842 – 4394 = 1448
11 April	Saturday	5430		
12 April	Sunday	5652		
13 April	Monday	3667		

The LTM is relatively conservative. It could be argued that an average crush rate, based on the highest two or three days, would provide an even higher, yet realistic, potential milling capacity. In addition, the LTM estimates a daily crush rate deficit, when the actual crush rate is less than 10% of the LTM. It could, for example, also be argued that a daily crush rate deficit could occur when the actual crush rate was less than 5% of the LTM.

4.4.2 Identification of potential daily crush rates (PDCR)

It was assumed that a pay-weekend related problem day can only be quantified, if each subsequent day is affected. For example, if a cutter absenteeism day occurs on a Monday, Tuesday and Wednesday, then the potential losses for all three days are assumed to be due to cutter absenteeism. Conversely, if mill processes are not hampered on a Tuesday, but are lower on the subsequent Wednesday, then cutter absenteeism is most likely not the reason for the lower crush rate.

In this research, the potential or achievable daily crush rate (PDCR) was defined as the quantity of sugarcane that possibly would have been crushed for the day, if there were no disruptions in the system due to cutter absenteeism. The achievable daily crush is calculated by subtracting crush reduction from the LTM, which result from mill operational and maintenance stops, as well as rainfall.

It was assumed that there are specific predetermined thresholds of rainfall events that put a halt to harvesting for a certain number of days (Table 4.4). Boote *et al*. (2013) used a Receiver Operating Characteristics Analysis (Fawcett, 2006) in the Umfolozi sugarcane area, to determine the depth of rainfall that leads to wet field conditions and, hence no-cane stops. However, a Receiver Operating Characteristics Analysis was considered beyond the scope of this research.

A simple and conservative method was adopted, to determine the impacts of rainfall on ADCR, using the LTM approach. This was based on qualitative threshold information provided by key stakeholders in the Eston region (Clarence, 2011; Cronje, 2011; Thompson, 2011). Any shortfall in daily crush rates ($\Delta ADCR_i > 0$) were conservatively attributed to rainfall, when more than 5 mm fell anywhere in the milling area, as per Table 4.4. The highest rainfall occurrence, from the HCZs, was calculated for each day of the milling season. For example, if rainfall of between 5 mm and 10 mm on a given day was recorded in any of the HCZs (as per Table 4.4), it was assumed that harvesting could have been inhibited for the given day, as well as for the following day. These estimates are regarded as conservative, because rainfall could have occurred in one HCZ, while cane supply from other areas could have allowed the mill to continue operations. The mechanistic modelling approach, discussed in Section 4.5, addresses this shortcoming, by analysing the average rainfall in the Eston region in more detail.

Table 4.4 Rainfall thresholds that were assumed to inhibit sugarcane harvesting at Eston for the LTM approach (Clarence, 2011; Cronje, 2011; Thompson, 2011)

Rainfall depth (per day)	Number of harvesting days inhibited
> 5 mm	2 days
> 10 mm	3 days
> 30 mm	4 days
> 50 mm	5 days

Shortages of cane supply ($\Delta ADCR_i > 0$) that were not attributed to rainfall, were then investigated to determine whether mill breakdowns and stops could have been the cause. The mill breakdown data, as discussed in Section 4.2.3, were used for this purpose. There were many days when a breakdown, or a maintenance stop, was partly responsible for the crush deficit. In these cases, the pro-rata proportion of daily crush deficit, which was not related to mill maintenance and breakdowns, was estimated and allocated to the PDCR.

Shortages of cane supply ($\Delta ADCR_i > 0$), after a pay-weekend, which were not attributed to rainfall or mill breakdowns and maintenance stops, were assumed to be caused by cutter absenteeism. Therefore, pay-weekend related problems, were identifiable. The total amount lost, due to cutter absenteeism, was estimated and summed across the entire season. The quantifiable factors of pay-weekend related cutter absenteeism are presented and discussed in Chapter 6.

4.5 Model Development, Calibration and Verification

An alternative and more sophisticated method compared to the MANOVA (Section 4.3) and LTM approaches (Section 4.4), involved the development, calibration and verification of a predictive mechanistic multivariate model. The proposed model was used to optimally predict and quantify the factors that influence daily crush rate fluctuations in the Eston sugarcane supply chain. To the author's knowledge, the model is the first of its kind for predicting sugarcane supply consistency at a mill-scale.

Four milling seasons (2004, 2005, 2011, 2012) were utilized to calibrate, refine and validate the model, while five other seasons (2006 – 2010) were reserved for verification purposes. Fibre was assumed to be the limiting factor for maximum daily mill crushing capacity and was used to predict the PDCR, before the consideration of mill disruptions. The model involved the estimation of disruptions from mill maintenance stops and breakdowns, rainfall events and days in the week when slow crush rates occurred. The residual between the estimated modelled daily crush rates (MDCR) and the ADCR was then analysed, to estimate the impacts of cutter absenteeism for five seasons.

4.5.1 Model development and calibration

The first step of model development involved the quantification of the mill's capacity for a given day. Fibre loading at the mill was used as the capacity limiter. Fibre % cane is a key limiting factor, at the Eston Sugar Mill (see Chapter 3.3). The diffuser tends to flood when cane with high levels of fibre is processed. Fibre loading was used to constrain the maximum PDCR, before the consideration of mill disruptions. Daily fibre % cane data, for all nine seasons, were provided by Naidoo (2013). Figure 4.2 illustrates the historic relationship between fibre % cane values and the daily crush rates, for the 2004, 2005, 2011 and 2012 seasons. 98% of all data points are situated below the solid line. The solid line indicates a strong negative trend between fibre % cane and the maximum attainable crush rate.

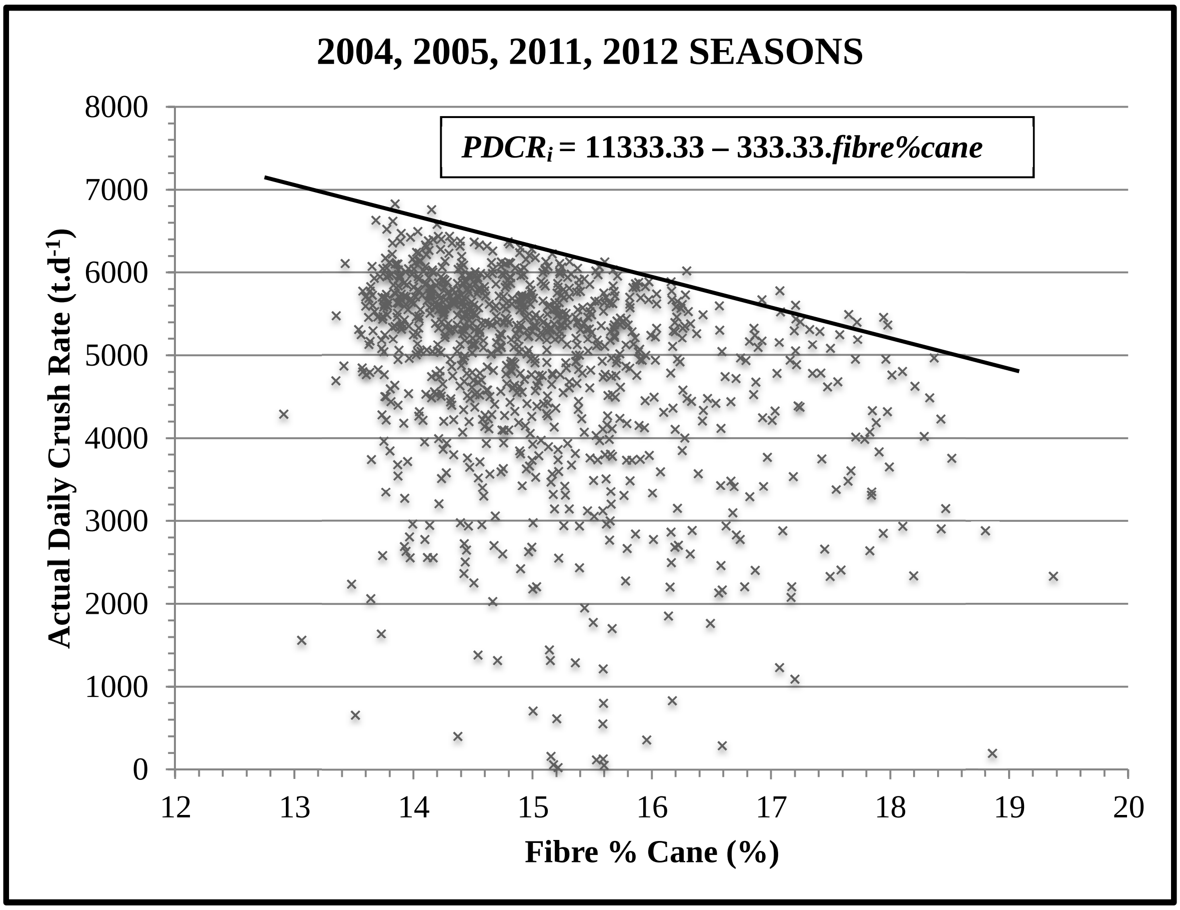

Figure 4.2 Fibre % cane as a daily crush rate capacity limiter at the Eston Mill

A crush gap was determined by subtracting the ADCR from the PDCR. The crush gap could be due to numerous factors, such as rainfall, mechanical breakdowns, maintenance stops, as well as pay-weekend related cutter absenteeism. Mill breakdowns and maintenance stops were the first disruption factor to be considered in the model.

The mill breakdown and maintenance stops data were used, as discussed in Section 4.2.3. Mill stops that were due to rain and cutter absenteeism-related cane supply shortages were excluded from this part of the model. It was assumed that stops and breakdowns have a pro rata impact on daily crush rates. In other words, for each breakdown hour, a 4.17% reduction in daily crush rate would occur. This assumption was tested by regression analysis against the actual crush rate and was found to fit the data. Figure 4.3 illustrates the relationship between the total duration of breakdowns and maintenance stops for a day and the corresponding total daily crush rate for the day. The trendline confirms a negative relationship between breakdowns and crush rates. The slope of the curve suggests that about 3.49 tons are lost per minute, due to breakdowns.

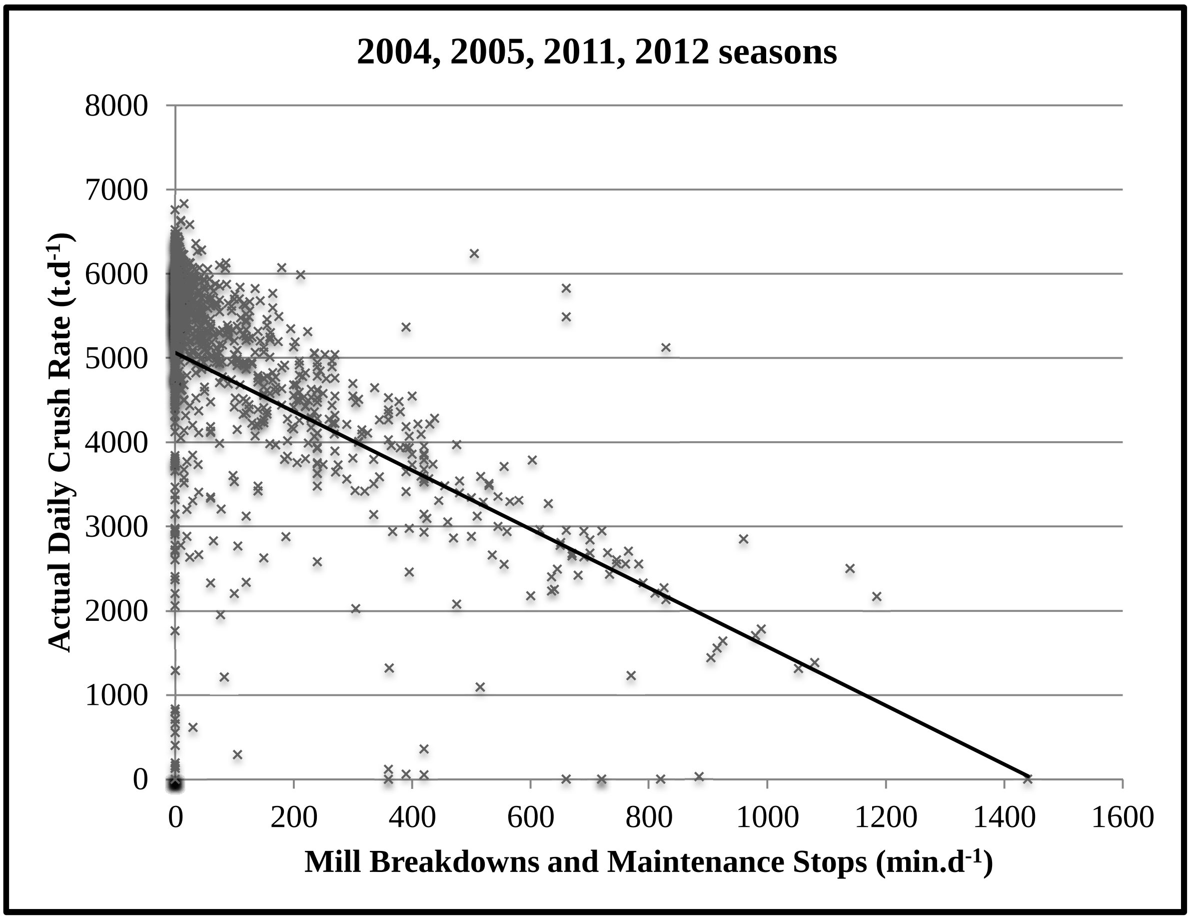

Figure 4.3 Daily crush rates, mill breakdowns and maintenance stops, Eston Mill

Equation 4.3 was used to calculate the impacts of breakdowns and maintenance stops on daily crush rates.

$$BD_i = BD_m \div (60 \times 24) \times PDCR_i \tag{4.3}$$

where:

BD_i is the reduction of daily crush rate in tons, due to breakdowns and maintenance stops,

BD_m is the total duration of breakdowns and maintenance stops for day i (in minutes), and

$PDCR_i$ is the fibre loading estimated achievable daily crush capacity rate for day i, (see Figure 4.2)

Rainfall was the next crush rate disruption factor considered to reduce the crush gap. Rainfall usually results in an increased level of fibre in cane. It is, therefore, likely that some of the impacts of rainfall may already have been considered by the fibre loading factor, but this may require further research. During initial analyses, it was found that the most reasonable correlation existed between the ADCR and the average rainfall (across different HCZs) for each day. The impacts of rainfall were assumed to last for a period of five days. The impacts for each day were given a different weight and calculated as per Equation 4.4.

$$R_i = \sum_{i=0}^{-4} w_i \, (c_r + d_r \overline{P_\iota}) \qquad | \sum w_i = 1 \tag{4.4}$$

where:

R_i is the fraction of the achievable crush reduced by rainfall for day i,

w_i is the weight for each of the five days after rain falls [$i = 0,\ldots,i - 4$],

c_r is the offset fraction (%)

d_r is is the slope of the function (%.mm^{-1})

$\overline{P_\iota}$ is the mean rainfall, in mm, that occurred in the six HCZs in the Eston region.

The last variable considered for the model involved the estimation of the impacts of weekday inconsistencies. Each day of the week may have a different tendency towards slow crush rates. Sibomana *et al*. (2011; 2013) found, for example, that cane qualities were significantly different after weekends, compared to the late-week, in the Felixton milling region. This resulted in the inclusion of a weekday correction coefficient for the Eston Mill, for each day of the week (DOW_i).

4.5.2 Model calibration

Microsoft Excel Solver was used for calibration. This was conducted by changing the coefficients to allow the model data to fit optimally on a 1:1 line with the observed or ADCRs. Solver is ideally suited to fit linear, non-linear and integer functions, via an iterative algorithm (Walsh and Diamond, 1995; Fylstra *et al.*, 1998; Kemmer and Keller, 2010). Solver has become the most widely used general purpose optimization modelling tool, since its inception in 1991 (Fylstra *et al.*, 1998; Brown, 2001; Kemmer and Keller, 2010). Solver is simple, intuitive, relatively quick and can be implemented successfully without extensive programming experience (Brown, 2001). Solver was used to concurrently determine the parameter coefficients for each day of week and the rainfall coefficients (Equation 4.4). Fibre loading, mill maintenance stops and breakdowns did not require Solver for calibration.

4.5.3 Model verification and residual

The model was verified using five independent seasons (2006 – 2010). These seasons were used for both the LTM and MANOVA approaches. The R-square (R^2), or coefficient of determination (Cameron *et al*., 1997; Gujarati and Porter, 2009), was used to estimate the goodness of fit of the model to the ADCR data.

After the model was developed, calibrated and verified, a residual remained. The residual can be defined as the variation in daily crush rates that is not explained by the model (discussed in Section 4.5.1). A histrogram depicting the distribution of residuals was constructed.

4.5.4 Estimation of cutter absenteeism

A positive residual indicates that the model over-predicted the crush rate for day *i*. Some positive residuals could be due to cutter absenteeism. Only the positive residuals were subsequently analysed, to estimate the impacts of pay-weekend related cutter absenteeism on the daily crush rates. The 2006 to 2010 seasons were used to compare the results with the MANOVA (see Section 4.3) and LTM approaches (see Section 4.4).

Cutter absenteeism coefficients were estimated for each of the five seasons, according to Equation 4.5, using Solver. Pay-days were assumed to occur on the first Saturday of each month (as discussed in Chapter 3 and Section 4.3). During the week after pay, days were analysed to determine any possible impacts of cutter absenteeism. A single restoration coefficient (c) was calibrated, over the entire data set, with a value of 0.38. A coefficient for cutter absenteeism (a_s), with a correction offset (b_s), were calibrated for each of the five seasons (2006 – 2010). A high value of a, after correction, for a given season, would indicate large reductions in daily crush rates, due to cutter absenteeism. Due to the LOMS in the South African sugar industry, only eight or nine weeks were analysed for each season. This is considered to be a limitation, because coinciding rainfall and mill maintenance stops may significantly influence the estimated impacts for each season.

$$\mathrm{CA}_{is} = \mathrm{MDCR}_i - \frac{a_s}{x^c} + b_s \qquad | \, \mathrm{MDCR}_i > \mathrm{ADCR}_i \, | \, \mathrm{MDCR}_\mathrm{i} > 0 \tag{4.5}$$

where:

CA_s is the estimated daily crush rate, after cutter absenteeism, for day i in each season [s= 2006, 2007…, 2010],
MDCR_i is the modelled estimated daily crush rate for day i,
a_s is a calibrated coefficient for cutter absenteeism for the season, in tons,
x is the number of days after the pay day for each month [x = 1, 2, …, 7] (Sunday = 1, Monday = 2, …, 7 = Saturday),
c is a restoration coefficient, calibrated to be 0.38, and
b_s is a correction offset for each season, in tons.

5. RESULTS AND DISCUSSION

This Chapter reports and compares the results of the Multivariate Analysis of Variance (MANOVA), the lower-trimmed mean (LTM) approach and the mechanistic model that was developed in Chapter 4.

5.1 Multivariate Analysis of Variance

A detailed analysis of the actual daily crush rate (ADCR) data indicated that pay-weekend related problems most likely occurred after the first weekend of each month. Growers generally stated that farm workers are paid on the first Friday or Saturday of each month (see Chapter 3.4).

Figure 5.1, which illustrates the results of the MANOVA, compares the average weekday crush rate of the first week after a pay-weekend, with the average weekday crush rate of the other weeks in the month. More details of the MANOVA are displayed in Appendix A. The MANOVA concludes that crush rates on Sundays and Mondays after the first weekend of each month, are significantly different, with a 95% confidence level, compared to the Sundays and Mondays, which fall in the remaining three or four weeks of each month. It is evident in Figure 5.1 that most Sundays, and especially Mondays, have lower crush rates for all weeks. This is probably due to long maintenance stops, which are usually scheduled to take place every third Sunday and Monday (see Chapter 4.2.3). However, after a pay-weekend, Sundays and Mondays experienced an even more significantly reduced crush rate (Figure 5.1(a). No other factors, including rainfall and other mill breakdowns, could be found to explain this trend. It can, therefore, be concluded that pay-weekends, followed by excessive cutter absenteeism, are the reason for a significant reduction in crush rates on these days.

MANOVA is a relatively simple technique, yet easy to understand. It can only be utilized on historical data. It provides a broad indication of the impacts of cutter absenteeism, but fails to identify the specific impacts for each season.

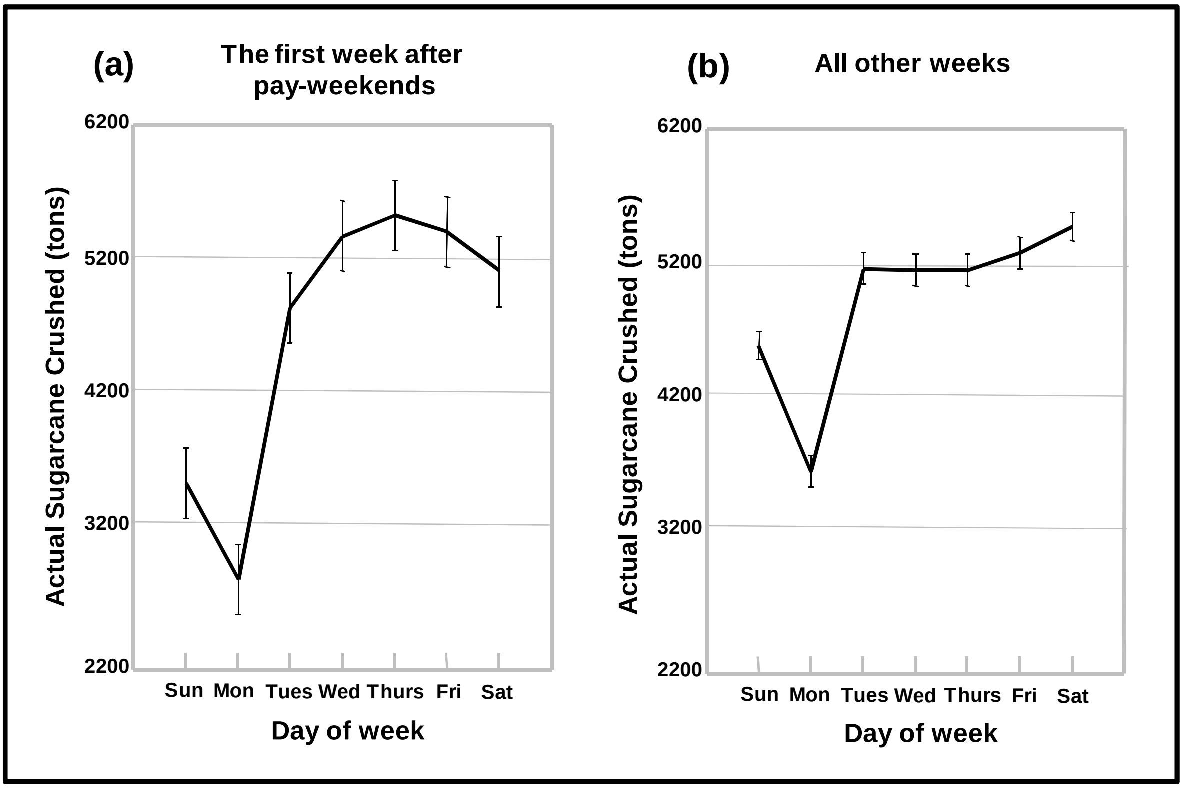

Figure 5.1 A comparison of (a) the actual daily crush rates after the first weekend and (b) after the other weekends of every month, at the Eston Mill, 2006 – 2010

5.2 The Lower-Trimmed Mean Approach

Figure 5.2 illustrates the cutter absenteeism-related reductions in crush rate (in red) for the 2009 season, based on the LTM approach. The estimated increase in daily crush rates would have resulted in a shorter length of the milling season (LOMS), with a higher average estimated recoverable crystal (ERC) %, value and, hence, higher sugar recovery. The other disruptions in production were not due to cutter absenteeism and were attributed to rainfall and mill breakdowns. The impact of rainfall has a more severe effect during the latter part of the season, as illustrated in Figure 5.3. Similar graphs were generated for the other seasons and are displayed in Appendix B.

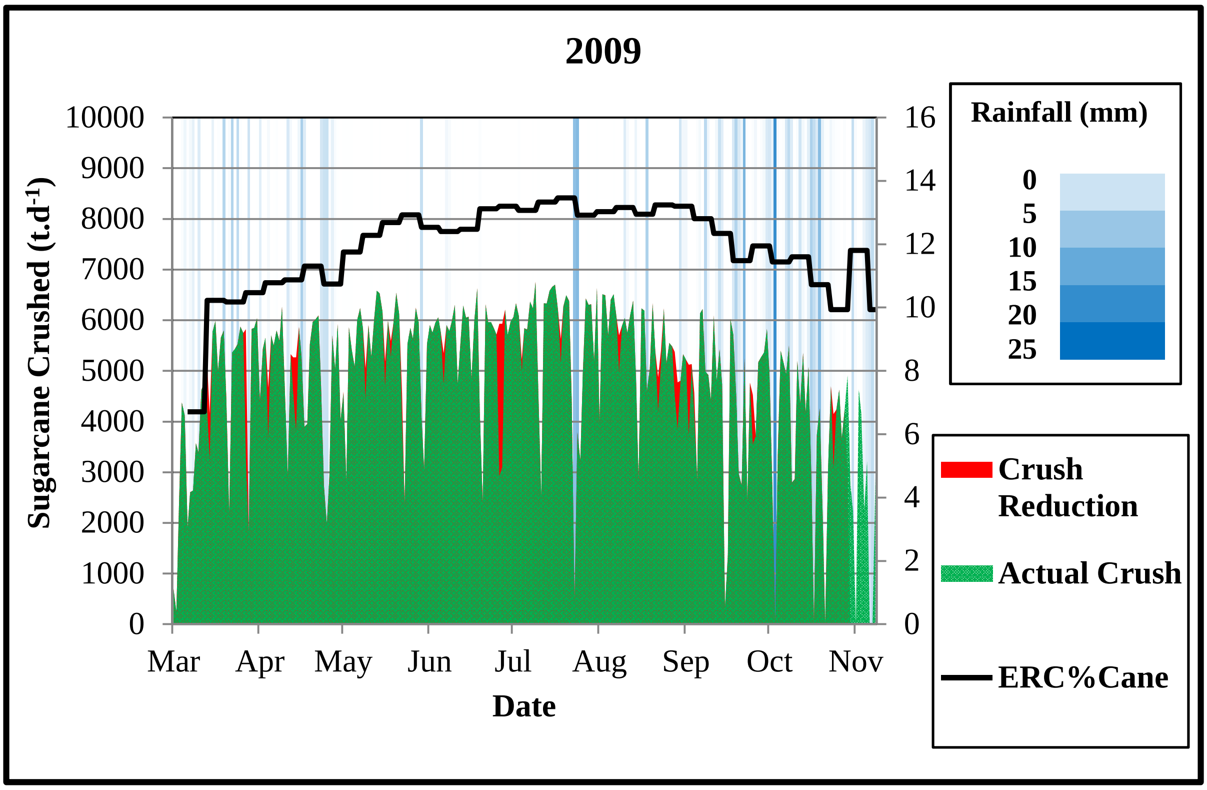

Figure 5.2 The potential reduction in daily crush rates (in red) associated with cutter absenteeism for the 2009 milling season, Eston Mill

Figure 5.3 focuses specifically on the days during the 2009 season, when the achievable or potential daily crush rate (PDCR) is greater than the ADCR. Similar graphs were created for the other seasons and are displayed in Appendix C. The days are sorted in order from the largest shortfall (ΔADCR) to the smallest. It is evident that cutter absenteeism have not completely curtailed mill production for an entire day. The average impacts of cutter absenteeism on these days are estimated at 20% of achievable crush. It is also apparent that the impact of cutter absenteeism varies on different days. For example, 3 400 t.d^{-1} on 5 July 2009 was estimated to be the largest crush deficit during the 2009 season. Furthermore, it was conservatively estimated that there were a total of 27 days, for this particular season, when shortfalls were due to cutter absenteeism. The 13th of November 2009 had a lower crush rate, compared to the other days. This was due to a five-hour mechanical breakdown at the mill, as well as the occurrence of rain on days before and after the 13th of November, which reduced the LTM. This illustrates a limitation of the LTM approach (see Chapter 4.4) and emphasizes the conservative stance that was adopted. It was found that the largest crush deficit, due to cutter absenteeism, for a single day, throughout the five seasons, was 3 500 tons, on the 2nd of May 2010. The total number of days when cutter absenteeism impacted on mill processes, range from 25 to 29 days per season, which is approximately 10% of the length of the milling season.

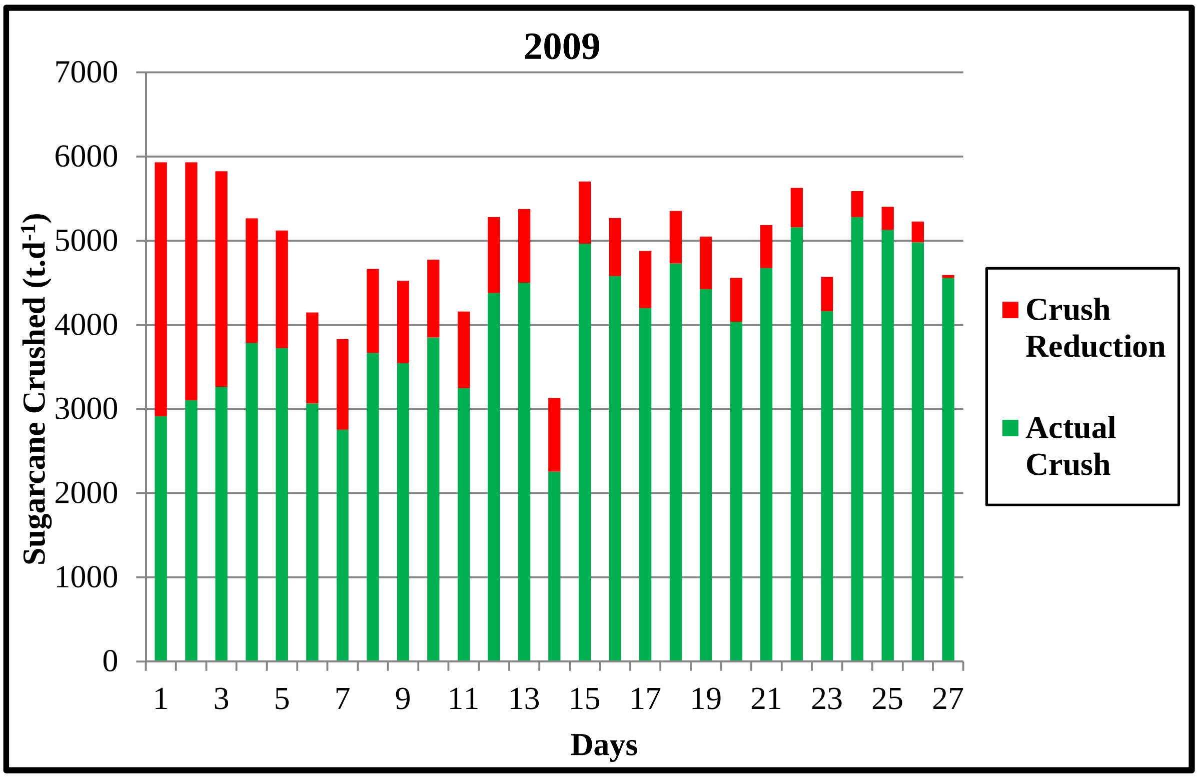

Figure 5.3 The potential reduction in daily crush rates on cutter-affected days, due to cutter absenteeism, for the 2009 season, Eston Mill

It can be argued that the LTM is a conservative, yet simple and well-structured, analytical process to analyze a typical sugarcane season at a mill-scale. The approach appears useful when analysing historical data. It can form the foundation of various studies to help identify the best-suited, most cost-effective and efficient solutions in a mill area. This method can, therefore, be utilized to quantify the economic impacts of cutter absenteeism on the Eston sugarcane supply chain. The LTM approach was used effectively in a later case study, in Chapter 7. However, the LTM approach is considered a weak predictor for future seasons, because of its dependence on actual data.

5.3 Model Results

This section provides the results for the mechanistic multivariate calibration model. Firstly, the estimated calibration coefficients, which were based on the 2004, 2005, 2011 and 2012 seasons, are discussed. Secondly, the verification results, based on the five independent seasons (2006 – 2010 seasons), are discussed.

5.3.1 Model calibration coefficients

Table 5.1 provides the coefficients calibrated by Microsoft Excel Solver, for the period of five days, as well as for the slope and the offset, which converts mm to a fraction (as per Equation 4.4). About 19% of the impacts of a rainfall event on crush rates are experienced on the same day (w_0), with 49% of the impacts being experienced on the subsequent day (w_1). This is probably due to rainfall occurring in the late afternoon or evening, which inhibits harvesting on the next day. In addition, the lagged impact could be due to the extended BHTCD (see Chapter 2.2.1). Approximately 29% of the impacts of a rainfall event are experienced two days after the downpour (w_2). It can, therefore, be concluded that the impacts of rainfall are most significant on the subsequent day, with a diminishing effect occurring over the next two days. The impact of rainfall usually persists for a period of four days. This corresponds with local stakeholder opinions used in the LTM approach, which assumed that rainfall could have impacts for a period of up to five days.

Table 5.1 The calibration coefficients for rainfall, based on Equation 4.4

Rainfall Variable*	**Coefficient**
c_r (%)	0.03
d_r (%.mm^{-1})	0.03
w_0 (%)	0.19
w_1 (%)	0.49
w_2 (%)	0.29
w_3 (%)	0.03
w_4 (%)	0.00

* w_i: the weight for each of the five days after rain falls
* c_r: the offset fraction (%),
* d_r: is is the slope of the function (%.mm^{-1})

Figure 5.4 illustrates an estimation of the magnitude of a downpour, to a reduction in daily crush rates. It is estimated that rainfall of less than 2 mm, over a 24-hour period, does not reduce crush rates. In addition, it is statistically estimated that there is a linear increase in the impacts of rainfall, where approximately every 5 mm of rainfall reduces the crush rate by an additional 1 000 tons. However, as displayed in Table 5.1, these impacts are spread over a period of four days ($w_4 = 0.00$).

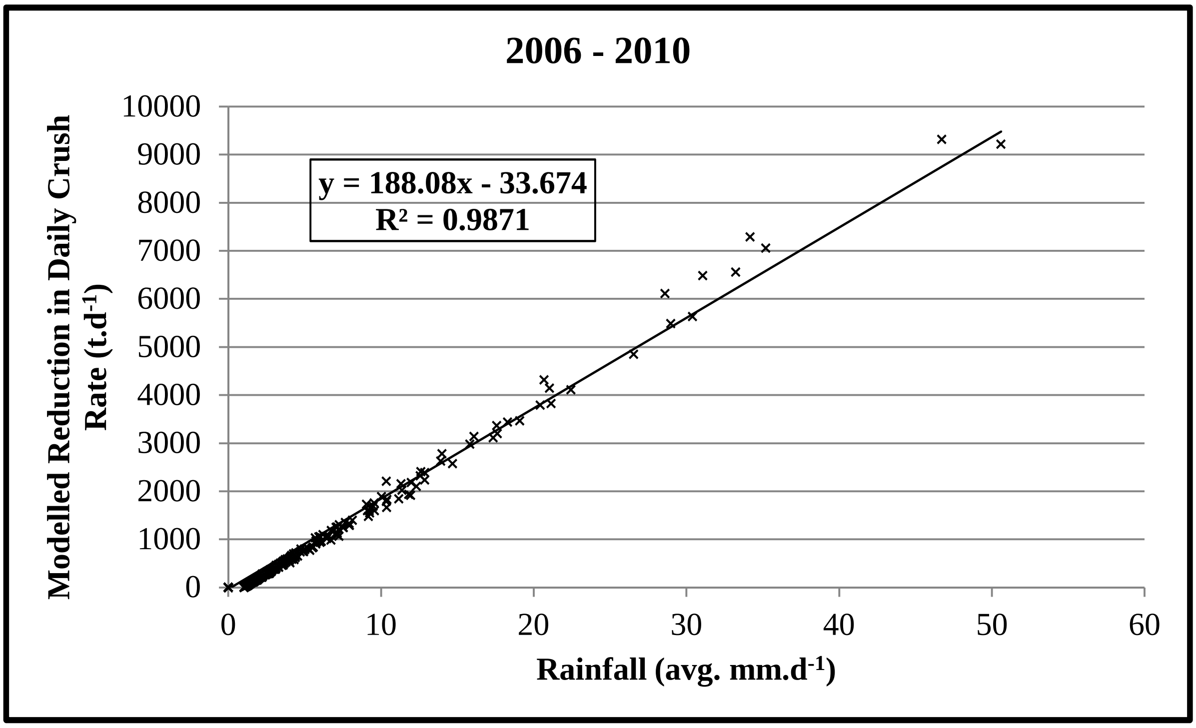

Figure 5.4 The reduction in daily crush rates due to rainfall, Eston Mill

Figure 5.5 provides the estimated impacts of weekday inconsistencies to the mill, expressed relative to the mean. The range of crush rates is only about 4%. However, Sundays, and especially Mondays, usually experienced a greater proportion of slow cane crush rates. This could be due to more shutdown occurrences on these days, which have slow startup times.

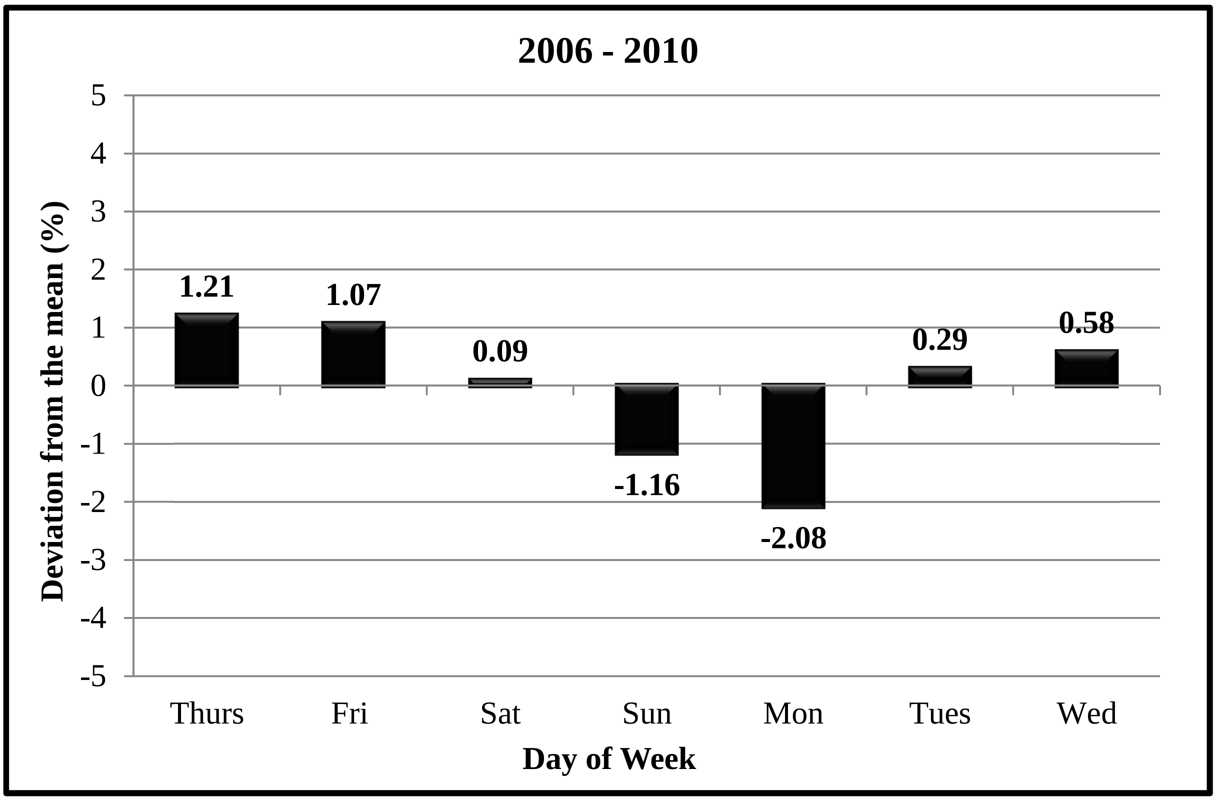

Figure 5.5 Calibrated coefficients for slow crush rate inconsistencies during the week, Eston Mill

5.3.2 Model verification

Figures 5.6 and 5.7 illustrate the comparison of the modelled daily crush rates (MDCR) and the ADCR. Figure 5.6 illustrates the MDCR and ADCR for the 2009 season. Similar graphs were generated for the other seasons and are displayed in Appendix D. Figure 5.7 illustrates the goodness of fit for the MDCR and the ADCR, fitted on a 1:1 line, for the five independent seasons (2006 – 2010). The trendline produces an R^2 of 64%. This is considered to be a moderately good fit. It is lower than the LTM approach, because the calibration coefficients were calculated independently of the data for these seasons.

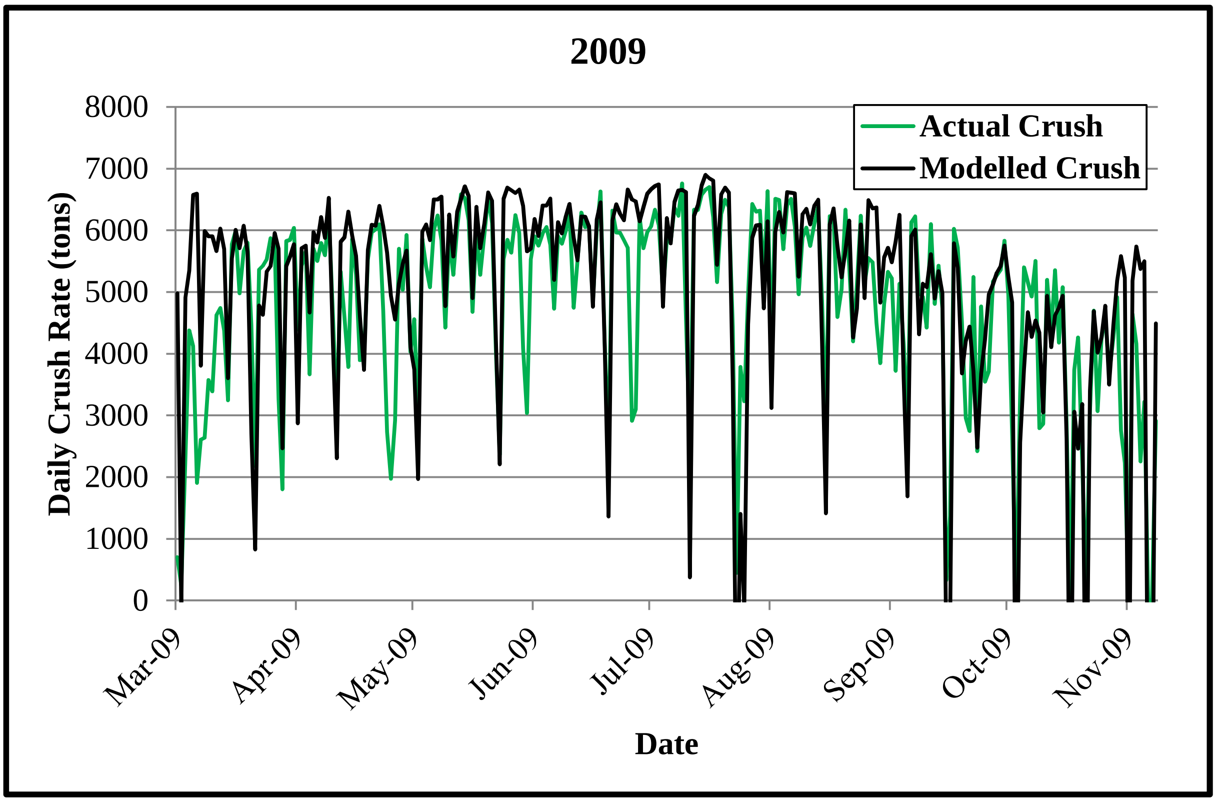

Figure 5.6 Comparison between the ADCR and the MDCR, for the 2009 milling season, Eston Mill

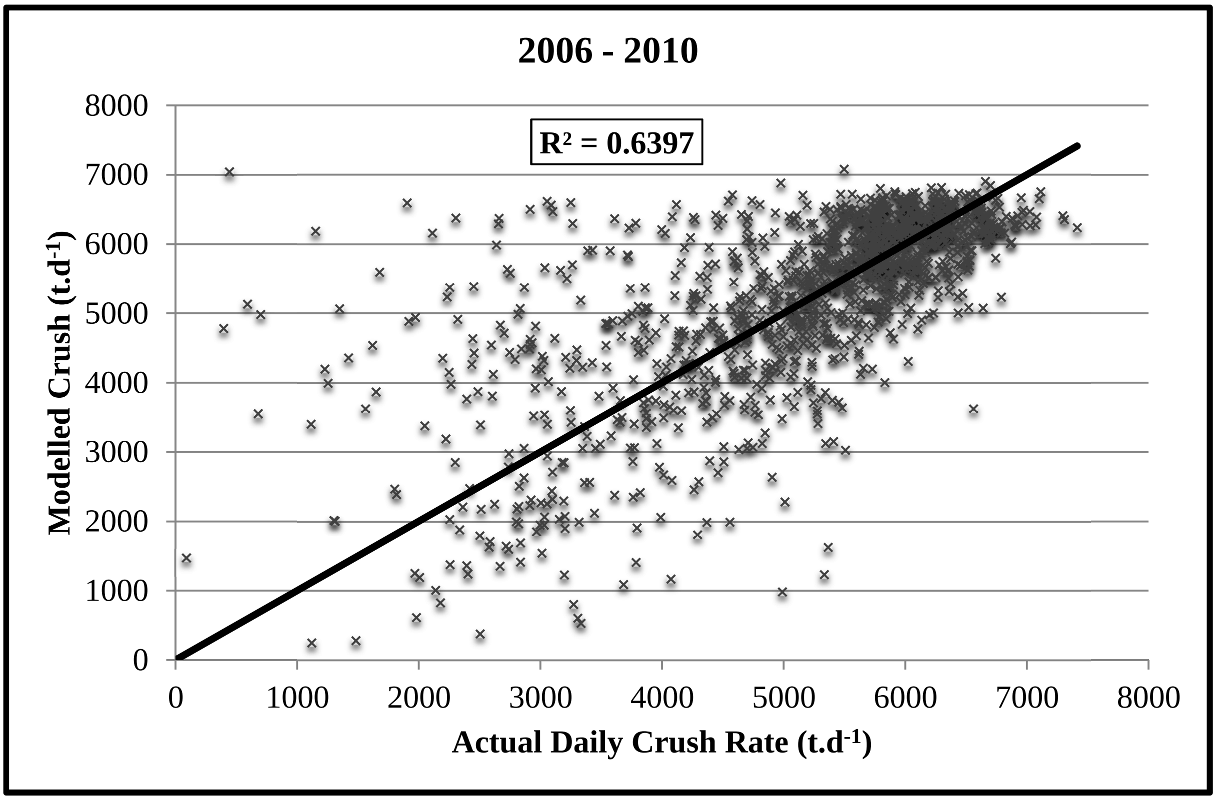

Figure 5.7 Goodness of fit for the MDCR and the ADCR, for the 2006 – 2010 milling seasons, Eston Mill

Table 5.2 summarises the total variation in crush rates, for the 2006 – 2010 seasons, as per the different components of the model (expressed in terms of R^2). Fibre % cane and mill breakdowns together are estimated to capture 59% of the variation in daily crush rates. Thereafter, rainfall and weekday inconsistencies capture an additional 6% of the daily crush rate variation. However, fibre loading could have accounted for some of the impacts of rainfall (as discussed in Chapter 4.5.1). About 36% of the overall variation in daily crush rates remains unexplained. This could be due to various factors, including cutter absenteeism. Overall, the model captures 64% of the total variation in crush rates.

Table 5.2 Summary of the R^2 for the factors that capture the variability in daily crush rates at Eston

Disruption Factor	$\mathbf{R^2}$
Fibre loading	0.34
Fibre loading, maintenance stops and breakdowns	0.59
Fibre loading, mill maintenance stops, mill breakdowns and rainfall	0.63
Fibre loading, mill maintenance stops, mill breakdowns, rainfall and weekday inconsistencies	0.64
Remainder	0.36

The mechanistic modelling is useful to help predict future seasons. The model can be utilized to critically evaluate the different sugarcane milling areas and could potentially make significant contributions to cane supply management and milling operations. By using stochastic weather generators (Lumsden *et al.*, 2000; Diaz-Nieto and Wilby, 2005; Boote *et al.*, 2013), the model allows for the daily crush rates, mill breakdowns and rainfall events to be simulated for hypothetical seasons, whilst using the same calibration coefficients. This is, however, beyond the scope of this study.

5.3.3 Model residual and cutter absenteeism

Figure 5.8 illustrates the frequency distribution of the model residuals, before and after the consideration of cutter absenteeism. The estimation of cutter absenteeism was calculated according to Equation 4.5. Cutter absenteeism reduced the residual, on average, from 800 $t.d^-$

[1] to 680 t.d^{-1}. The inclusion of cutter absenteeism, therefore, reduces the positive residuals by about 15%.

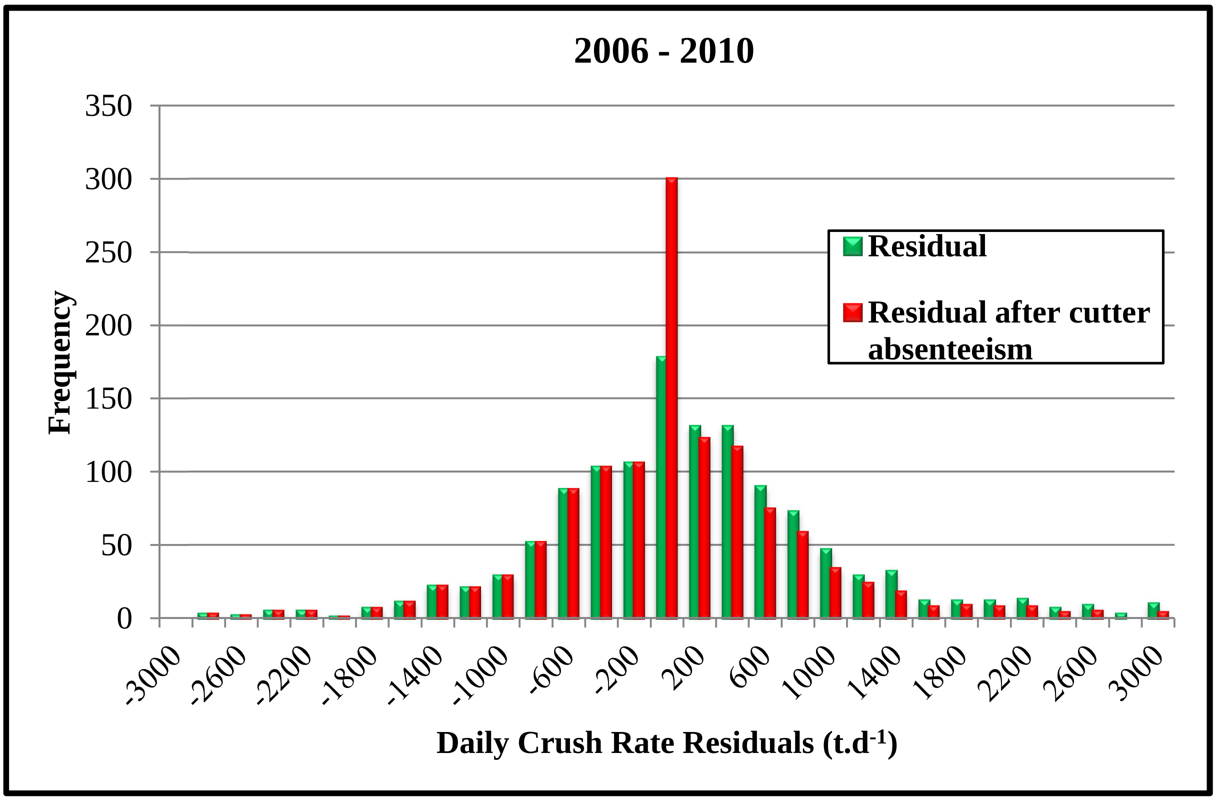

Figure 5.8 A histogram comparing the model residuals before and after cutter absenteeism, for the 2006 – 2010 milling seasons, Eston Mill

Table 5.3 and Figure 5.9 display the statistically optimal estimates of cutter absenteeism for each of the five seasons analysed. Table 5.3 provides the calibrated coefficient for cutter absenteeism (a_s) and the offset for each season (b_s), according to Equation 4.5. Subtracting b_s from a_s represents the crush reduction for the first Sunday of each month, due to cutter absenteeism. For example, if a MDCR of 5 000 tons was calculated for the first Sunday of a month, then the crush rate after consideration of cutter absenteeism, in 2009, is estimated to be 5000 - (5606.75 - 1958.69) = 1 352 tons. Figure 5.9 illustrates the estimated impacts of cutter absenteeism for the first Sunday, Monday and Tuesday of the month for each season. Cutter absenteeism appears to be different for each season. It appears that there was an increasing trend from 2007 onwards, especially on Sundays. This confirms the reasons behind the majority of stakeholders (interviewed in July 2011) highlighting cutter absenteeism as a key problem in the Eston area (see Chapter 3). In 2010, Mondays and Tuesdays had a reduction in cutter absenteeism. However, these estimations are only based on eight or nine weeks per season, which has statistical limitations, as discussed in Chapter 4.5.4. The reason for the seasonal differences in cutter absenteeism is beyond the scope of this research, but probably is related to the overall labour market in South Africa. For example, prior to 2010, the country had a significant rise in the construction industry, which anecdotally draws in labourers who previously may have been harvesting cane.

Table 5.3 The estimated impact of cutter absenteeism, based on the modelled residual, for the 2006 – 2010 milling seasons, Eston Mill

Season	a_s **(t.d^{-1})***	b_s **(t.d^{-1})****	$a_s - b_s$ **(t.d^{-1})**
2006	4 099.28	1 427.28	2 672.00
2007	2 011.64	0.00	2 011.64
2008	3 894.04	1 593.67	2 300.37
2009	5 606.75	1 958.69	3 648.06
2010	8 179.56	3 963.02	4 216.54

* a_s: calibrated coefficient for cutter absenteeism for the season, in tons
** b_s: correction offset for each season, in tons.

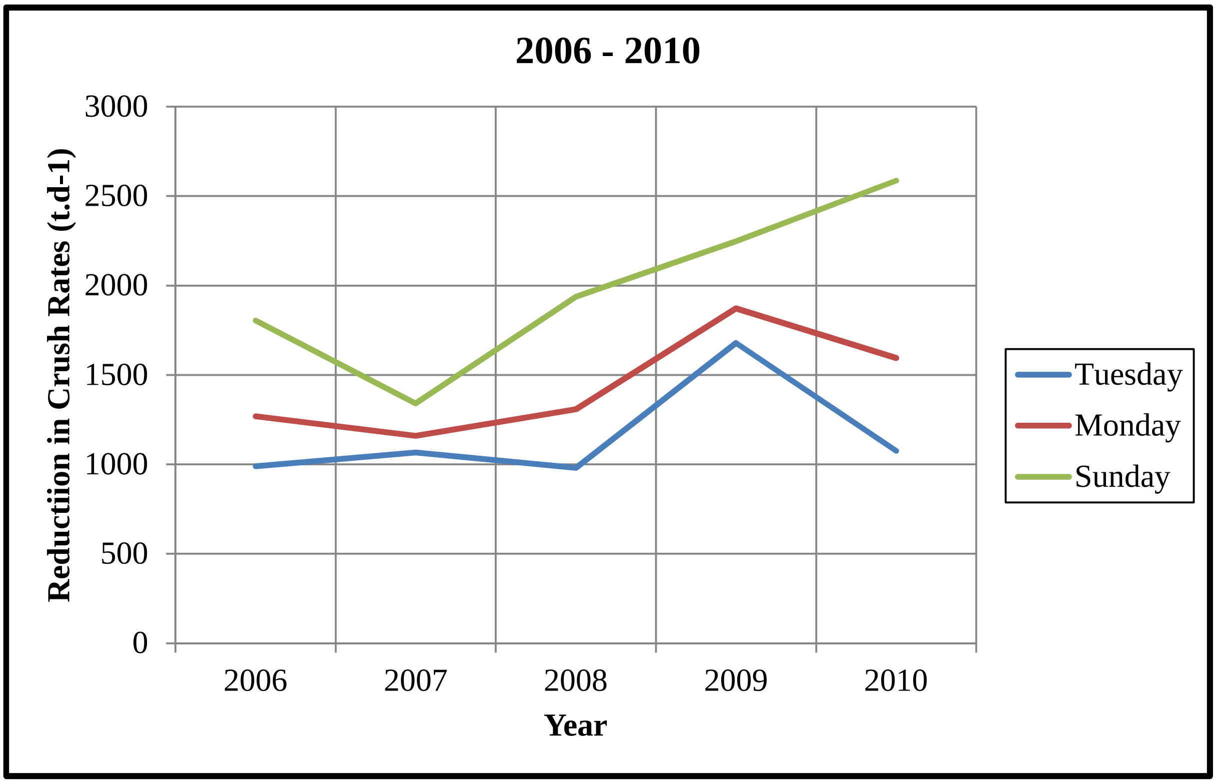

Figure 5.9 The estimated impact of cutter absenteeism on the first Sunday, Monday and Tuesday of each month, for the 2004 – 2010 milling seasons, Eston Mill

This application of the model allows for the fabrication of an independent labour productivity index based on cutter absenteeism for each season. This may be a significant advance forward towards an independent quantification of labour issues in the sugar industry, but perhaps also in other industries. According to the author’s knowledge, this is the first labour index of this nature in the sugar industry worldwide.

5.4 Conclusion

Three methods were used to predict the impacts of the disruptions to daily crush rates at the Eston Mill. Firstly, the MANOVA was found to be an easily-understood technique, but can only be utilized on historical data. It provided a broad indication of the impacts of cutter absenteeism, but failed to identify specific trends in each season. Secondly, it can be concluded that the novice lower-trimmed mean (LTM) approach is a conservative, yet simple and well-structured analytical process, but it also relies on historical data. The LTM approach can form the foundation of various studies to help identify the best-suited, most cost-effective and efficient solutions in a mill area. Finally, a model that was developed was found to be a moderately good predictor. The model can be utilized to critically evaluate different sugarcane milling areas and could potentially make significant contributions to cane supply management and milling operations. The model could also be used to quantify the magnitude of different disruption factors in a milling area. The model allowed for the development of a labour index, which predicts cutter absenteeism, for each season. The specific labour absenteeism coefficients for each season can possibly be investigated using other industries as well.

The three methods analysed cane delivery data to the Eston Mill over a period of five seasons and estimated that the incidences of cutter absenteeism were closely correlated with pay-weekends. In addition, pay-weekends have been found to reduce the supply of cane to the Eston Mill, particularly on the first Sunday and Monday of each month. Furthermore, the LTM approach conservatively estimated that there are between 25 and 29 days per season, when cutter absenteeism occurs.

The modelling approach confirmed that fibre loading, mill maintenance stops and breakdowns, as well as rainfall and weekday inconsistencies all have an impact on daily crush rates at the Eston Mill. It was estimated that every 5 mm of rainfall, reduces the crush rate of approximately 1 000 tons, spread over four days, with 49% of the impacts experienced on the subsequent day. However, the impacts of rainfall are relatively small compared to fibre loading, mill breakdowns and maintenance stops. Fibre loading, mill breakdowns and maintenance stops, as well as rainfall events, capture about 63% of the variability in daily crush rates at Eston. Slow crush rates are more prevalent on Sundays and especially, on Mondays.

The labour index confirms that cutter absenteeism occurs after the first weekend of each month. Daily crush rates are reduced on Sundays, Mondays and Tuesdays, but at a diminishing rate. There seems to be a general increasing trend in cutter absenteeism from about 2007 onwards.

The next chapter quantifies specific costs of cutter absenteeism, in terms of risk and profitability, for the 2006 – 2010 seasons.

6. A COSTING OF CUTTER ABSENTEEISM TO THE ESTON SUGARCANE SUPPLY CHAIN

The diagnostic exploratory study (Chapter 3) found that an inconsistent cutter workforce is a major factor that affects the consistency of cane supply to the Eston Mill. Furthermore, the statistical analysis (Chapters 4 and 5) conclude that pay-weekend related cutter absenteeism impacts on cane supply after the first weekend of each month. The remainder of this study involvs two aims: (a) to estimate the cost of cutter absenteeism to the Eston sugarcane supply chain, due to pay-weekends (Chapter 6), and (b) to conduct an economic and bio-physical analysis, based on a specific case study analysis, in order to determine the feasibility of a mechanical harvesting system, to mitigate the impacts of cutter absenteeism (Chapter 7).

6.1 Methodology – an Estimation of the Severity and Losses Associated with Cutter Absenteeism to the Eston Sugarcane Supply Chain (*OC*)

6.1.1 Introduction

The estimated economic losses associated with cutter absenteeism, also referred to as *OC* in subsequent sections of this document, were quantified by adding the losses associated with sugar recovery (S_{ERC}) and the additional mill operational costs (M_C). These were the only two factors that could be quantified with relative ease. Initially, the researcher attempted to estimate the typical cost of a mill no-cane stop associated with cutter absenteeism. However, upon further investigation, it was found that the majority of no-cane stops are due to rainfall. Cutter absenteeism usually resulted in a slow crush, which did not result in any direct mill start-up or breakdown costs. There are potentially many other losses that could be associated with cutter absenteeism, such as management costs and transport efficiency, but these could only be discussed in a qualitative manner. The economic impacts of cutter absenteeism were conservatively estimated for the 2006 to 2010 seasons, using the results from the lower-trimmed mean (LTM) approach (see Chapters 4 and 5). The research carried out in this Chapter has been published by Kadwa and Bezuidenhout (2013).

6.1.2 Additional mill operational costs (M_C)

Operationally, the mill experiences additional costs due to an extended LOMS (Boote *et al.*, 2013). An accountant at the Eston Mill estimated that the average daily cost of mill operations in 2011 was R50 000 (Applesamy, 2011). This value incorporates various costs, such as diesel, coal, firewood, chemicals, service contracts, general and contractual-based maintenance, as well as salaries and wages. Therefore, the additional costs to the mill (M_C) for the season can be estimated by multiplying the additional number of days in the LOMS, due to cutter absenteeism, by R50 000 (Applesamy, 2011).

6.1.3 Sugar recovery losses (S_{ERC})

The estimated recoverable crystal, or ERC %, is defined by Peacock and Schorn (2002) as "the estimated quantity of crystal, which can be recovered from the incoming cane supply (expressed in terms of crystal % cane)." The ERC % encompasses the estimated earnings from raw sugar production for the entire sugarcane supply chain. The ERC % weekly data for the five seasons was obtained from the Eston Mill Factory Manager (Pillay, 2011). From 2006 to 2010, the average ERC % at Eston was 12.45% (Pillay, 2011). The average actual recoverable crystal (ARC %) and the estimated ERC % cane is not always exactly the same, because of specific conditions at the particular mill. In this case, the average sugar to ERC ratio was relatively consistent across seasons at 99.25% (Pillay, 2011).

As mentioned in Chapter 2, the ideal time to harvest and process sugarcane in South Africa is during late winter and early spring. Figure 6.1 depicts the average ERC % at Eston derived from the five seasons studied. At the mill area level, the ERC % peaks around August and September. If the mill has the capacity, it is desirable for sugarcane deliveries to be concentrated in the middle of the season and for the LOMS to be reduced. This is likely to result in increased profitability, especially since the late season experiences a relatively rapid decline in ERC %.

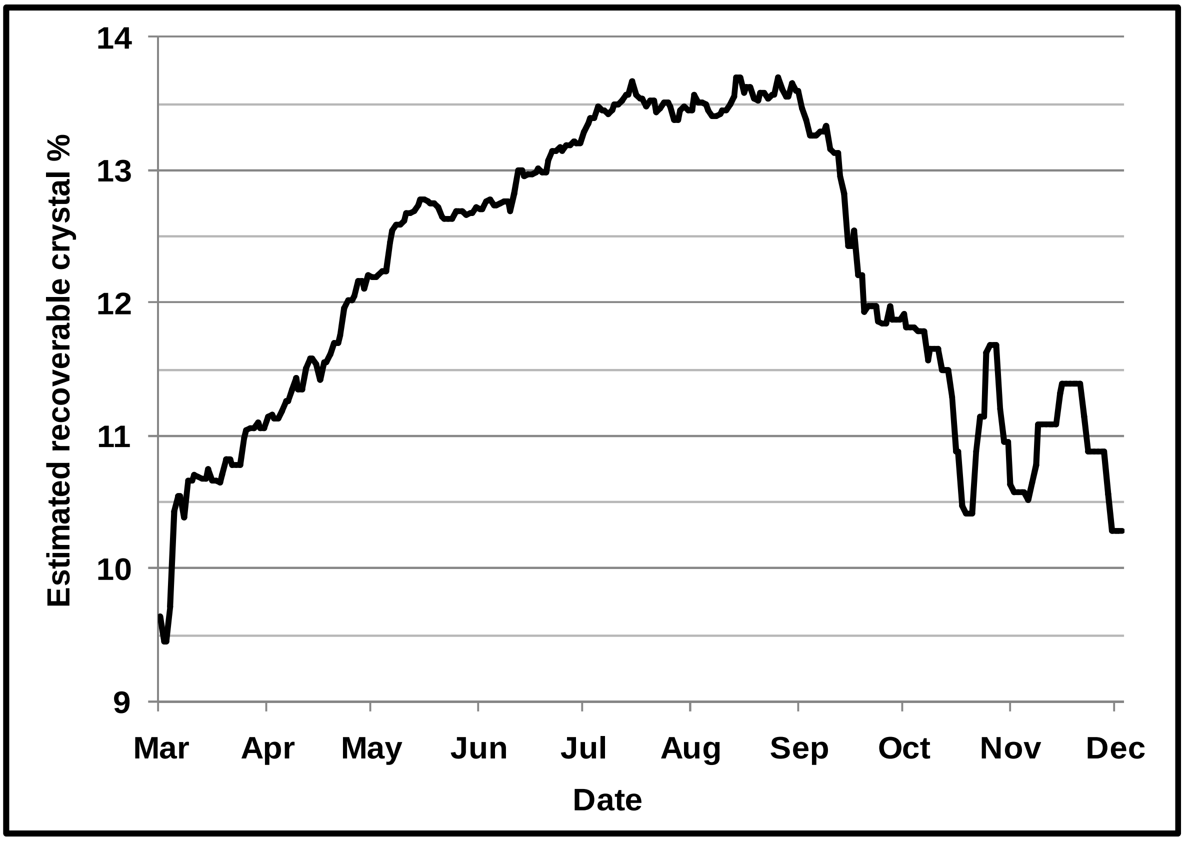

Figure 6.1 The average estimated recoverable crystal % during the milling season for the Eston sugar area over the 2006 – 2010 seasons

The weekly ERC % curve for the specific season was used to determine the sugar losses associated with cutter absenteeism. The weekly averaged ERC % data, obtained from Pillay (2011), were interpolated into daily averages, in order to suit the daily crush data. The extractable sugar was estimated according to Equation 6.1. The sugar to ERC % ratio appeared stable during the season, with a high degree of predictability (R^2=0.9925).

$$Sug_i = ADCR_i \times ERC_i \times 0.9925 \tag{6.1}$$

where:

Sug_i is the estimated sugar produced on day i,

$ADCR_i$ is the actual daily crush rate for day i, and

ERC_i is a daily ERC % value, which was interpolated from available weekly ERC % data for the season.

The 2011 price of R4 500 t.$^{-1}$ for raw sugar in South Africa was assumed. This estimate was used for all the seasons, rather than real values for each season, in order for the total values to be comparable. The difference between the estimated total actual sugar produced and the potential sugar produced, presents an approximation of the loss that each season experienced (S_{ERC}). It should be remembered that these values are conservative, due to the assumptions discussed in Section 4.4.

In addition to the above calculations, a simple sensitivity analysis was conducted to determine the increase in losses, which would result from an additional 5% increase in cutter absenteeism. This was calculated using only the days when cutter absenteeism occurred.

6.2 Results and Discussion

6.2.1 The quantified losses associated with cutter absenteeism (*OC*)

Table 6.1 summarizes the estimated potential decrease in the LOMS and the total associated available funds (*OC*) that could have been materialised, by mitigating cutter absenteeism for the five seasons studied. As discussed in Chapters 2, 3, 4 and 5, rainfall negatively impacts on the LOMS and is variable for each season. For example, the drought experienced during the 2010 season was partly the cause of the shortened season (see Table 4.2). With the alleviation of cutter absenteeism, the LOMS is estimated to have been decreased by an average of eight days. This would have resulted, on average, in daily operational funds available (M_C) of R400 000, to the mill. There also would have been an increase in sugar processing (S_{ERC}) in all the seasons, except 2010. The reason for this is further explained in the next paragraph. There are substantial, yet varying, estimated available funds, which could have been realised. This emphasises high risk and a need to be aware of the various sensitivities in the system. However, on average, S_{ERC} is estimated to have increased by 200 tons per season, which is valued at an estimated R900 000 to the Eston sugarcane supply chain. Additional sugar recovery is estimated to contribute about 70% of the total associated funds available. Therefore, it appears that there are considerable available funds to alleviate cutter absenteeism.

Table 6.1 General information and the estimated available funds associated with the elimination of cutter absenteeism for the Eston sugarcane supply chain, 2006 - 2010

	Mill Season					
	2006	**2007**	**2008**	**2009**	**2010**	**Average**
Total rainfall (mm)[1]	532	635	398	305	78	390
Actual LOMS[2] ($d.s^{-1}$)	276	281	258	253	198	253
Estimated achievable LOMS ($d.s^{-1}$)	269	275	249	243	189	245
Decrease in the LOMS ($d.s^{-1}$)	7	6	9	10	9	8
M_C[3] ($R.s^{-1}$)	350 000	300 000	450 000	500 000	450 000	400 000
Actual ERC[4] % average (%)	11.47	12.4	12.57	11.89	13.43	12.35
Total crush ($t.s^{-1}$)	1267501	1409281	1342575	1207697	1008379	1247087
Estimated actual sugar production ($t.s^{-1}$)	144 800	173 314	166 089	143 403	132 654	152 050
Estimated achievable sugar production ($t.s^{-1}$)	144 945	173 788	166 532	143 565	132 422	152 250
S_{ERC}[5] ($t.s^{-1}$)	145	474	443	162	-233	200
S_{ERC} ($R.s^{-1}$)	650 000	2.13 mil	2.00 mil	730 000	-1.05 mil	900 000
OC[6] ($R.s^{-1}$)	1.00 mil	2.43 mil	2.45 mil	1.23 mil	-590 000	1.3 mil

[1] Only rainfall during the milling season was accumulated
[2] LOMS: Length of the milling season
[3] M_C: Estimated sum of the additional daily mill operational costs, due to cutter absenteeism
[4] ERC: Estimated recoverable crystal
[5] S_{ERC}: Estimated value of the additional sugar that would have been processed without cutter absenteeism
[6] OC: The estimated economic losses associated with cutter absenteeism in the Eston area

The unexpected loss in 2010, can be explained by the unusual ERC % curve in Figure 6.2. It is clear that ERC % increased from July 2010 through to September 2010. Therefore, crushing cane earlier in the season, for example, in April or May instead of July, would have resulted in a lower sugar recovery, and hence, a decrease in profitability. This season experienced a severe drought, which created anomalies in the ERC % curve, rainfall patterns and interruptions, as well as total cane crushed. Although further research is warranted, it is believed that these exceptional conditions occur infrequently.

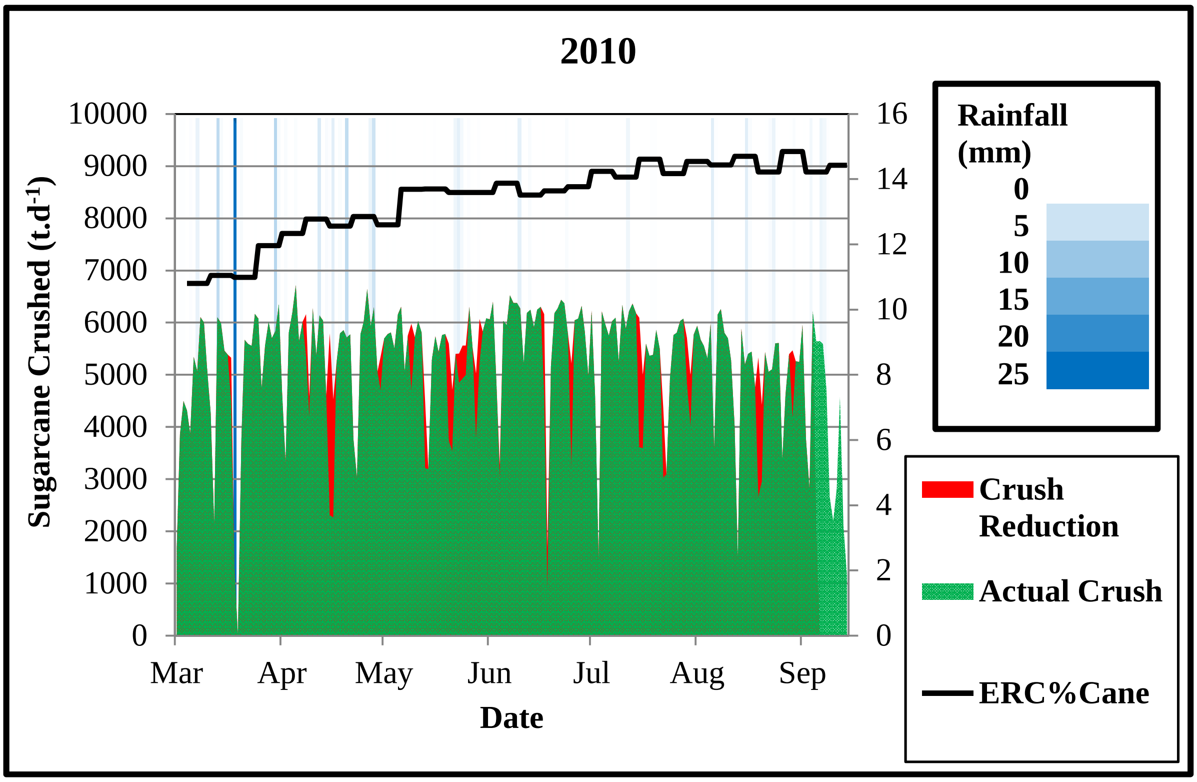

Figure 6.2 The potential reduction in daily crush rates (in red) associated with cutter absenteeism, for the 2010 milling season, Eston Mill

The results of the simple sensitivity analysis, which assesses the impacts of an increase in cutter absenteeism by 5%, are summarized in Table 6.2. On average, the LOMS is extended by two days and sugar recovery is reduced considerably, when cutter absenteeism increases by 5%. However, the 2010 season is once again an exception, because sugar recovery is estimated to increase, with an extended LOMS. It can be deduced that investing in reducing cutter absenteeism may have a high return.

Table 6.2 The estimated impacts of a 5% increase in cutter absenteeism, for the period 2006 – 2010, Eston Mill

	5% higher cutter absenteeism		
Mill Season	**Increase in the LOMS (d)**	**Decrease in Sugar Recovery (t)**	**Associated total losses (R)**
2006	2	50	320 000
2007	3	170	930 000
2008	2	150	775 000
2009	2	290	1 405 000
2010	2	- 40	- 80 000
Average	**2**	**125**	**6700**

6.2.2 Other benefits and losses associated with a reduction in the LOMS

In addition to the estimated available funds, as calculated in Section 6.2.1, there are several other benefits that could have been realised, if the occurrences of cutter absenteeism were mitigated. The associated available funds from these benefits are difficult to quantify. Further consultation with the Beaumont Estate Manager helped to qualitatively identify these factors (Padayachee, 2012).

The most significant problem of an extended LOMS is rain. Wet weather conditions result in various issues, which include the following:

- The rainy season forces some growers to enter wet fields with tractors. This results in field damage and soil compaction problems, which could reduce yields and the quality of cane in subsequent years. In addition, some growers may have to burn immature cane, due to the mill closing date being set. With the LOMS being reduced, the sugarcane crop is given more time to grow for the next harvest period. This is likely to result in a better crop in the future, with increased sucrose levels and higher profitability (Padayachee, 2012; Boote *et al*., 2013).

- Rainfall can cause burn-harvest-to-crush delays (BHTCD) for a period ranging from two days up to a week. For example, the Beaumont Estate aims to have a BHTCD of approximately 50 hours (Padayachee, 2012). Wet weather conditions after burning of cane is undesirable, because it prevents cutters and hauliers from entering the fields to harvest and load cane. This may result in an increase in the BTHCD to over 100 hours, with substantial levels of cane deterioration.

- Some growers pay cutters on a daily basis, whilst others pay per ton. Growers who pay cutters per day are likely to suffer substantial unwanted losses when rainfall extends the LOMS. In addition, both payment systems are likely to pay more for housing, insurance and management costs under an extended LOMS (Padayachee, 2012).

- The hauliers are also likely to benefit from a reduced LOMS because they may save on payments to their employees, such as drivers. There is increased damage to roads when heavy vehicles travel on wet roads and there may be fewer accidents, when the LOMS is shorter. By reducing the LOMS will reduce the wear and tear of vehicle tyres and roads and, therefore, maintenance costs (Padayachee, 2012). However, hauliers will operate on fewer days per season and, therefore, may be negatively impacted by a shortened LOMS.

The mill could also benefit significantly from a reduction in the LOMS. Besides the benefits associated with sugar recovery and mill operational days, there are likely to be fewer maintenance stops and breakdowns. There are usually an increased number of mill stoppages at the end of the season, due to increased ash and sand in the cane. This results in the hammers and shredders at the mill wearing off more quickly, as well as increased incidences of diffuser flooding. The increased number of stops also results in longer queues at the mill and an increased haulage cost to growers.

6.3 Conclusion

This research conservatively estimated that the length of the milling season has been extended by between six to ten days, due to cutter absenteeism. The cost of mill operations for each additional day is R50 000. An average of R1.3 million per year can be realised, if cutter absenteeism were mitigated. However, the impacts of mitigation of cutter absenteeism on sugar recovery are highly variable for each season. The increase in sugar recovery for the five seasons range from substantial gains to associated losses.

It can be concluded from this study that the mitigation of cutter absenteeism can reduce the system’s exposure to the rainy season. This will result in various benefits, in addition to higher sucrose recovery and daily mill operational available funds. Growers can benefit from the following: (a) reduced field damage, (b) better crop production levels in future seasons, (c) a reduction in the burn-harvest-to-crush delay, and (d) a possible reduction in total cutter costs. All of these have the potential to increase profits. Hauliers can benefit from reduced driver and maintenance costs. The mill may increase profitability by reduced incidences of breakdowns and maintenance at the end of the season.

7. THE FEASIBILITY OF A MECHANICAL HARVESTING SYSTEM TO MITIGATE CUTTER ABSENTEEISM – A CASE STUDY

Chapters 3, 5 and 6 confirmed that an inconsistent cutter workforce is a major factor that affects the profitability and consistency of cane supply to the Eston Mill. An alternative harvesting practice, such as mechanical harvesting, is one method that can be utilized to mitigate the negative effects of cutter inconsistencies. This Chapter studies the feasibility of a mechanised harvesting system, in order to mitigate cutter absenteeism.

7.1 Methodology – an Ad Hoc Mechanical Harvesting Solution – a Case Study

7.1.1 Introduction

The proposed case study solution involved switching partially to a mechanical chopper harvesting system after pay-weekends. The research involved the identification of various important factors that need to be considered and their associated costs, as well as other basic assumptions. During this exercise it was important to (a) identify the physical areas that will be harvested mechanically, and (b) compare the costs of the system to the funds available from the supply chain. The research carried out in this Chapter has been published by Kadwa and Bezuidenhout (2013).

7.1.2 Factors to consider when implementing a mechanised harvesting system

SASRI (1998) and Meyer (1999) identified various social, political and agricultural practices, which have to be considered for the change from a conventional to a proposed mechanised harvesting system. Some of the agricultural practices include:

(a) land preparation,
(b) field layout,
(c) row spacing,
(d) cane row profile,
(e) cane row length,
(f) cane variety,
(g) increased cane deterioration,

(h) soil compaction, and
(i) haul-out distance.

In addition, the implementation of a chopper harvester system may require loading, haulage and mill receiving facility adjustments. As discussed in Chapter 3, growers who are located less than 10 km from the mill are authorized to transport sugarcane on 15-ton payload vehicles. With the introduction of a mechanised harvesting system, in-field tractors and trailers will be required to load cane into larger intermediate hauliers, which will then deliver the cane to the mill. The spiller table at the Eston Mill (see Figure 3.8) is too steep to handle billeted cane. Therefore, in an effort to avoid the excessive cost for the installation of a new spiller table, it is proposed that billeted cane should be offloaded at the stockpile spiller and then push-piled onto the cane conveyor (see Figure 3.8).

To avoid deterioration, which occurs more rapidly in billeted cane, there should be a minimal delay from harvest to crush. It is proposed that the mechanised system only operates when there is a shortage of cane supply to the mill, hence the deterioration of cane in stockpiles should be negligible. When considering the above factors, it is clear that the change to a mechanised harvesting system requires detailed planning, implementation and management. Growers, hauliers and millers therefore need to be co-actively involved from the outset of such a project (SASRI, 1998).

The introduction of a mechanical harvesting system could significantly increase the cane bulk density. Olwage (2000) found that there was a 17% increase in the bulk density of billeted cane, compared to that of whole stalk cane. In addition, there will be less sand in billeted cane, which would reduce the ash %. However, it is likely that there would be a higher fibre % in billeted cane.

7.1.3 Identification of proposed fields to be mechanically harvested

As a result of the shortage of cane supply to the Eston Mill, the researcher, in consultation with stakeholders in the region, identified fields in close proximity to the mill that could potentially be allocated for mechanical harvesting. Parts of the Beaumont Estate, which is an average distance of 7 km from the mill, were used in the case study. Beaumont is owned and managed by the Illovo Sugar Company. The estate encompasses a total area of 1 302 hectares. Sugarcane on the estate is harvested bi-annually and yields between 78 and 84 $t.ha^{-1}$. The Beaumont Estate manager (Padayachee, 2012) was consulted to establish which fields are suited for mechanical harvesting, according to factors listed in Section 4.4.1. For example, these fields are generally flat and have long cane rows. A total of approximately 600 hectares, which is just over 46% of the Estate, can be utilized for mechanical harvesting. This is depicted in Figure 7.1.

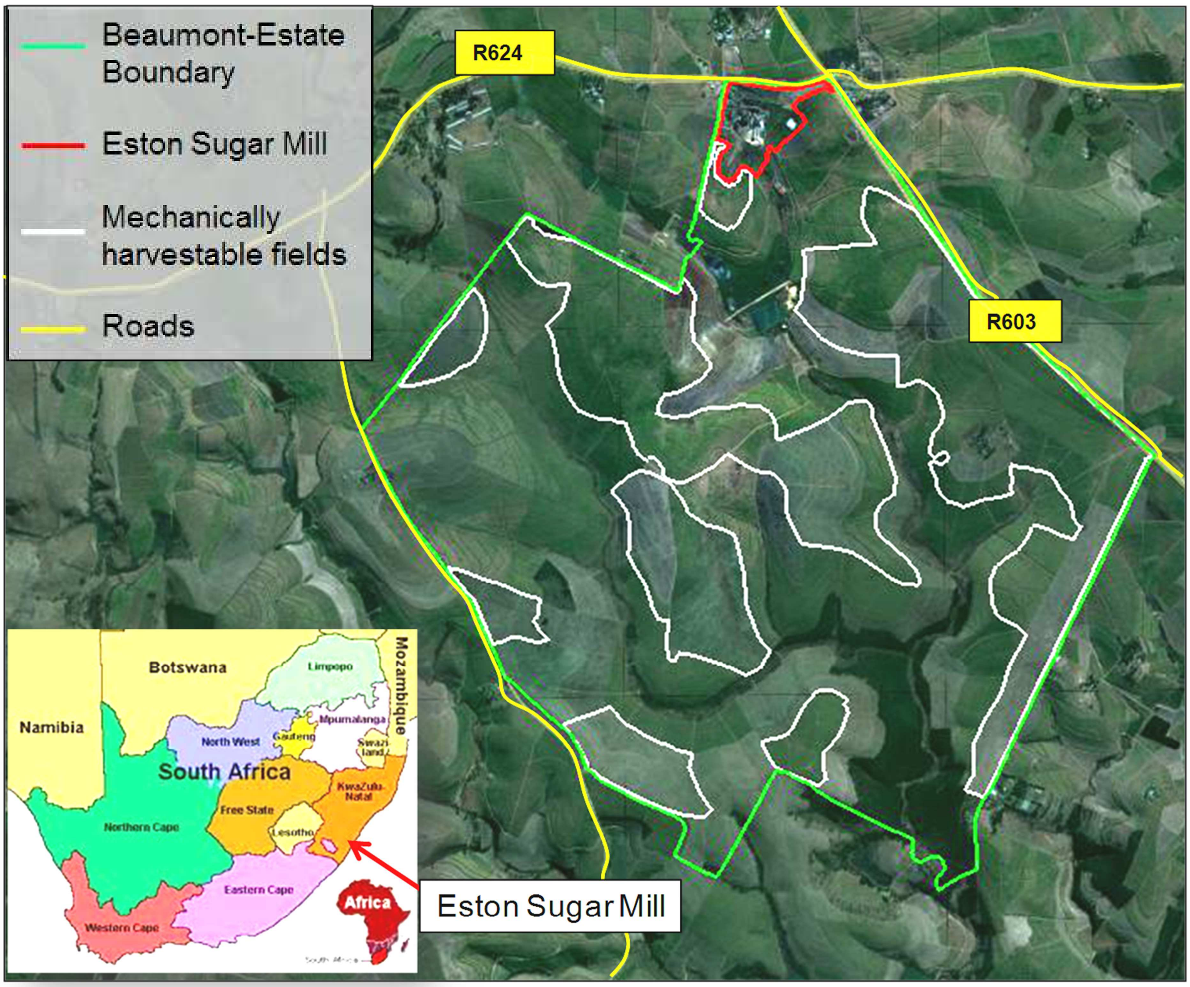

Figure 7.1 Mechanically harvestable fields at the Beaumont Estate

7.1.4 Conventional crop removal cost (R_B)

The proposed solution aspires to mitigate harvesting constraints, due to cutter absenteeism, rather than to expand sugarcane production. It is, therefore, proposed that existing fields should be mechanically harvested. Currently, the fields at the Beaumont Estate are manually harvested. This necessitates the cost of conventional harvesting to be quantified.

As mentioned in Section 7.1.1, mechanical harvesting requires various physical changes. Crop removal includes the cost of harvesting, loading and delivering cane to the mill. The cost of conventional crop removal must therefore also quantify all of these components, in order to compare the systems. The crop removal costs for the Beaumont Estate (R_B) in 2011 were estimated at R57.85 per ton of sugarcane (Padayachee and Mahabeer, 2011). A detailed breakdown of these costs can be found in Appendix E.

7.1.5 The estimated available funds for the proposed mechanical harvesting system

Any alternative harvesting system will have a maximum daily capacity. This may be in excess of, or less than, the daily crush deficit requirement at Eston. However, the crush deficit at the Eston Mill is variable and will demand different crushing rates on different days (see Figure 5.3). The Pareto Principle (Burrell, 1985; Egghe, 1986) was applied, to calculate a suitable harvesting capacity. This implies that a capacity is selected that will fulfil the crush deficit 80% of the time. The design capacity of the alternative harvesting system will, therefore, not be able to keep the mill processing continuously on the occasional days, with extremely high crush deficits.

The cost of the proposed alternative harvesting case study was compared to a conservative estimate of the total funds available, which is associated with the losses due to cutter absenteeism. All costs will be incurred by the Illovo Group, because both the mill and the Beaumont Estate are owned by Illovo. However, other growers in the area may indirectly benefit because of a shortened LOMS. The funds available to the Illovo Group, as well as to other growers, were quantified. The total funds available were calculated, by adding the OC (see Chapter 6.2.1) and the R_B (see Section 7.1.3). The total available funds are complicated and are systematically unpacked in Equation 7.1:

$$\begin{tikzcd}
TS & = & & OC \arrow[dl] \arrow[dr] & & + & R_B \\
 & = & M_C \arrow[d] & + & S_{ERC} \arrow[dll] \arrow[d] & + & R_B \arrow[dll] \\
 & = & S_M & + & S_G \arrow[d] \arrow[drr] & & \\
 & = & S_M \arrow[dr] & + & S_B \arrow[dl] & + & S_{G'} \\
 & = & & S_{Illovo} & & + & S_{G'}
\end{tikzcd} \qquad (7.1)$$

where:

TS is the estimated total available funds to the Eston area,

R_B is the current crop removal available funds, as discussed in Section 7.1.3,

OC is a function of the losses associated with cutter absenteeism, as calculated in Chapter 6.2.1,

M_C is the sum of the additional daily mill operational costs (see Chapter 6.2.1)

S_M is the estimated total available funds to the Eston Sugar Mill,

S_{ERC} is the value of the additional sugar that would have been processed without cutter absenteeism (see Chapter 6.2.1),

S_G is the component of the available funds, allocated to growers, as per the division of proceeds (64% of the total revenue of sugar),

S_B is the component of the total available funds that will be allocated to the Beaumont Estate,

$S_{G'}$ is the component of the total available funds allocated to all the other growers (Beaumont Estate excluded), and

S_{Illovo} is the total funds available to the Illovo Group.

The estimated total available funds should offset the cost of the proposed new case study, in order to determine the feasibility of the mechanised harvesting system.

7.1.6 The cost of a mechanised harvesting system

A commercial mechanical sugarcane harvester specialist, Mr Schroeder, who operates in the KwaZulu-Natal Midlands region in South Africa, was consulted to establish the most efficient and cost-effective mechanised harvesting system (Schroeder, 2012). The cost of the proposed mechanical harvesting system value was based on a 10-year repayment period. The finer details of the calculations and repayment period fall outside the scope of this study. The assumptions accounted for numerous variables (see Appendix F), including depreciation and the cost of capital, as well as the relatively low usage hours per season, compared to a full-time mechanised system.

The cost of the mechanical harvesting system can be broadly divided into three components, namely, (a) the combine harvester fixed and variable costs, (b) the in-field transport and loading costs for tractors and trailers, and (c) the haulage cost to the mill. It was assumed that new equipment will be required and that the use of mechanical harvesters will not alter the pattern of mechanical and maintenance breakdowns. It was also assumed that the ERC % will remain the same, with the change from the conventional to the mechanised system (Peacock and Schorn, 2002; Schroeder, 2012).

In addition to the above calculations, a simple sensitivity analysis was conducted to determine the total increase in the cost to the system, if the cost of diesel were to increase. Diesel was identified as a vulnerable factor in the new case study. The diesel price affects the cost of combine harvesters, as well as the in-field tractors (Schroeder, 2012).

7.2 Results and Discussion

Figure 7.2 illustrates the total annual quantity of sugarcane that is required for the five seasons, under different daily mechanical harvest capacities. The seasons follow similar patterns. It is apparent that only a limited gain could have been realised, if cutter absenteeism was mitigated. This is illustrated by the non-linear relationship that exists for all the seasons. It can be argued that the introduction of a mechanised harvesting system, which has a relatively small daily harvesting capacity of below 1 000 t.d.$^{-1}$, would probably reduce a large proportion of the impacts of cutter absenteeism. For example, the graph suggests that if a 800 t.d^{-1} harvesting capacity was available in 2010, a total of about 21 000 tons would be needed by this system (as indicated by an arrow in Figure 7.2). There appear to be diminishing returns by introducing a higher capacity harvesting system. The 2010 season had a higher opportunity to mechanise large parts of the area under cane. However, this season was dry, compared to the other seasons (see Figure 6.2). In the generally wetter seasons, rainfall events may have overlapped with cutter absenteeism, in which case the crush deficits would be attributed to rain, rather than the cutter absenteeism. Therefore, the 2010 season is perhaps a more true reflection of the real cutter absenteeism that could have been experienced, because these events were not overshadowed by rainfall. This confirms the strict conservative assumptions of rainfall events.

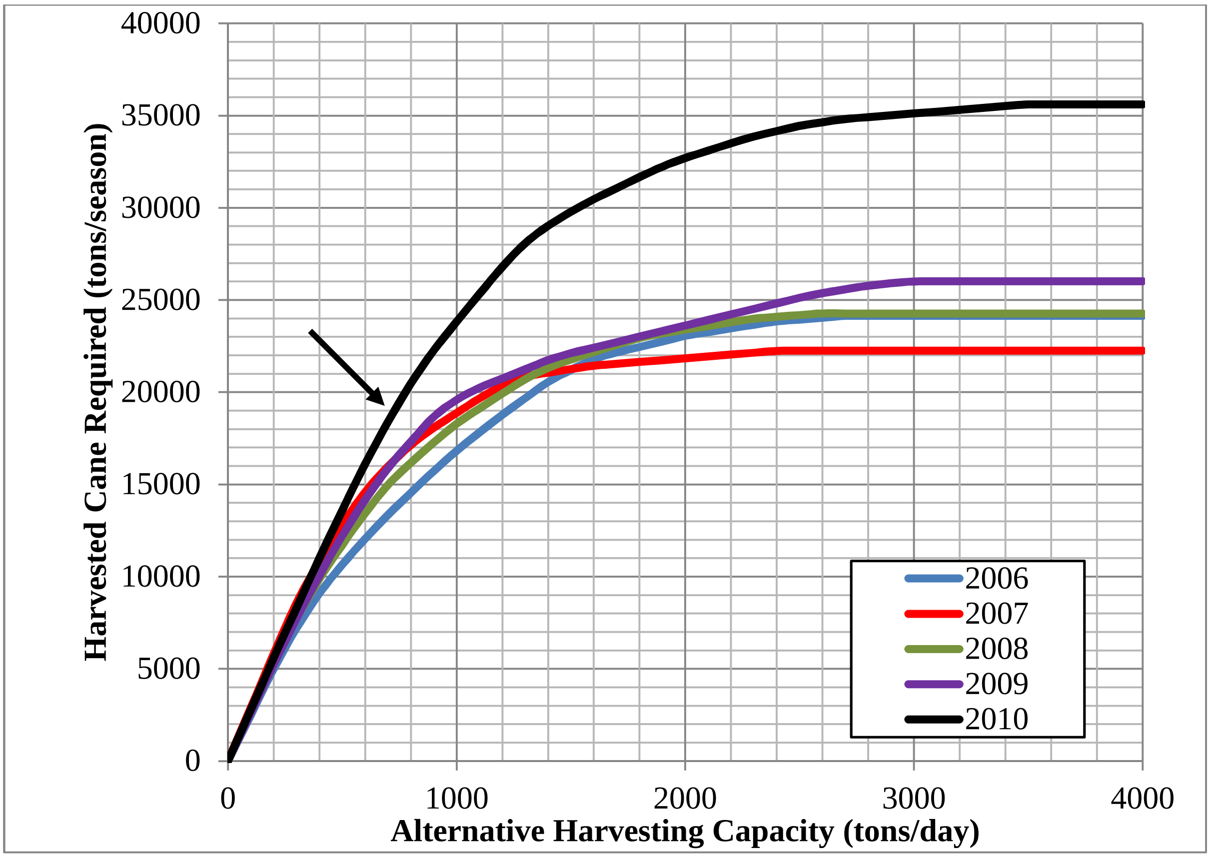

Figure 7.2 The quantity of harvested sugarcane that is required at different daily mechanical harvest capacities, for the period 2006 – 2010, Eston Mill

7.2.1 The proposed mechanised harvesting system

The mechanical harvester specialist was presented with the results in Section 5.1. The specialist estimated that a daily mechanical harvesting capacity of 800 t.d.$^{-1}$, for 27 days per season, would be the best-suited case study solution for the Eston region (Schroeder, 2012). This daily capacity results in a maximum of 21 600 tons of sugarcane, which could be harvested each season (Schroeder, 2012). It was assumed that this quantity would be harvested for all seasons. Approximately 550 hectares at the Beaumont Estate are required to produce 21 600 tons of cane per season (Padayachee, 2012). This will result in about 41% of the Beaumont Estate being converted to a mechanised system (see Section 7.1.2).

Figure 7.3 illustrates the daily 800 t.d^{-1} mechanical harvesting capacity on the days when cutter absenteeism exists in the 2009 season (dashed boxes). There will be some days during the season, marked by an ‘a’, when there will be an insufficient daily capacity to harvest the cane required. Therefore, the potential gain for the mitigation of cutter absenteeism will be limited. The introduction of the 800 t.d.$^{-1}$ daily capacity is due to the number of incidences of excess capacity, which is highly inefficient and expensive, because more harvesters and machinery will be required. The incidences of excess capacity are illustrated by ‘b.’

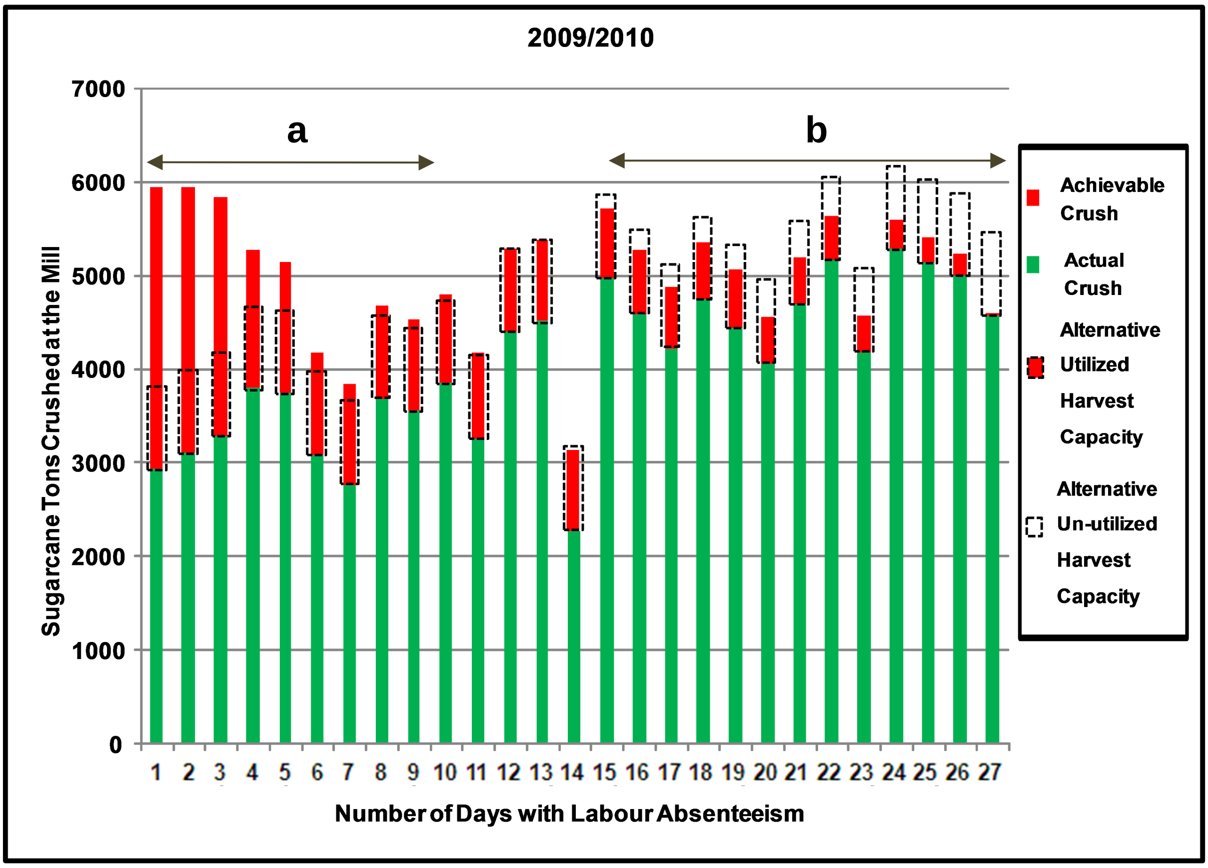

Figure 7.3 The introduction of a mechanical harvesting capacity of 800 tons per day, for the 2009 season, Eston Mill

The daily harvesting rate of 800 t.d^{-1} equates to two mechanical combine harvester machines, estimated at a total cost of R36.13 t.$^{-1}$ (Schroeder, 2012). The derivation of this value was based on a 10-year repayment period, with assumptions made by Mr Schroeder (see Chapter 7.1.5). The total cost of new trailers and tractors for loading billeted cane into a larger haulier were estimated at R18.89 t.$^{-1}$. It was assumed that the cost of haulage was the same for billeted and for manually-harvested cane. The cost of haulage was assumed as R27.75 t.$^{-1}$. Hence, the total cost of the introduction of a mechanical harvesting system, with a daily capacity of 800 tons and a ten-year repayment period, was conservatively estimated at R82.77 t.$^{-1}$ (Schroeder, 2012). This results in the total mechanical harvesting and haulage cost to the mill, for 21 600 tons of sugarcane, to be approximately R1.79 million per season.

As discussed in Section 7.1.4, all the costs of the proposed solution will be incurred by the Illovo Group. Therefore, the available funds to the Illovo Group (S_{Illovo}), as well as the available funds to other growers ($S_{G'}$), were quantified according to Equation 7.1. The estimated available funds that can be incurred under different harvesting capacities are shown in Figures 7.4 and 7.5. Figure 7.4 illustrates the different components that were estimated to contribute to the total available funds. As previously discussed (see Figure 7.2), the available funds display diminishing returns. On average, the current crop removal cost (R_B) for the five seasons contributes about 55% of total available funds. Additional sugar recovery (S_{ERC}) and daily mill operational (M_C) available funds contribute about 30% and 15%, respectively. Figure 7.5 displays S_{Illovo} and $S_{G'}$, respectively, at different daily harvesting capacities, for the 2009 season. The Illovo Group earns an average of about 75% of the total available funds in the Eston area, compared to other growers. This is due to the Illovo Group obtaining the benefits from the Eston Mill and from the Beaumont Estate. The tables used to construct these graphs, as well as the tables for the other seasons, are reflected in Appendix G.

The dark line (in Figures 7.4 and 7.5) displays the proposed daily capacity of 800 t.d^{-1}. This rate satisfies the Pareto Principle (see Section 7.1.5) and a pattern of diminishing returns is obvious for rates beyond 800 t.d^{-1}. The average total available funds for the five seasons is approximately R2 million. The total available funds for the proposed daily mechanical harvesting capacity of 800 t.d.$^{-1}$, for the 2009 season, is systematically unpacked as follows:

$TS_{800\ t.d.-1} = OC + R_B$

R 1 732 031 = R 736 451 + R 995 580

$= M_C + S_{ERC} + R_B$

= R 300 000 + R 436 451 + R 995 580

$= S_M + S_G$

= R 457 122 + R 1 274 909

$= S_M + S_B + S_{G'}$

= R 457 122 + R 1 021 764 + R 253 145

$= S_{Illovo} + S_{G'}$

= R 1 478 886 + R 253 145

The proposed solution, therefore, would be feasible if the total cost of the mechanised system was less than R1 478 886 for the 2009 season. This is on the assumption that the Illovo Group will finance the system.

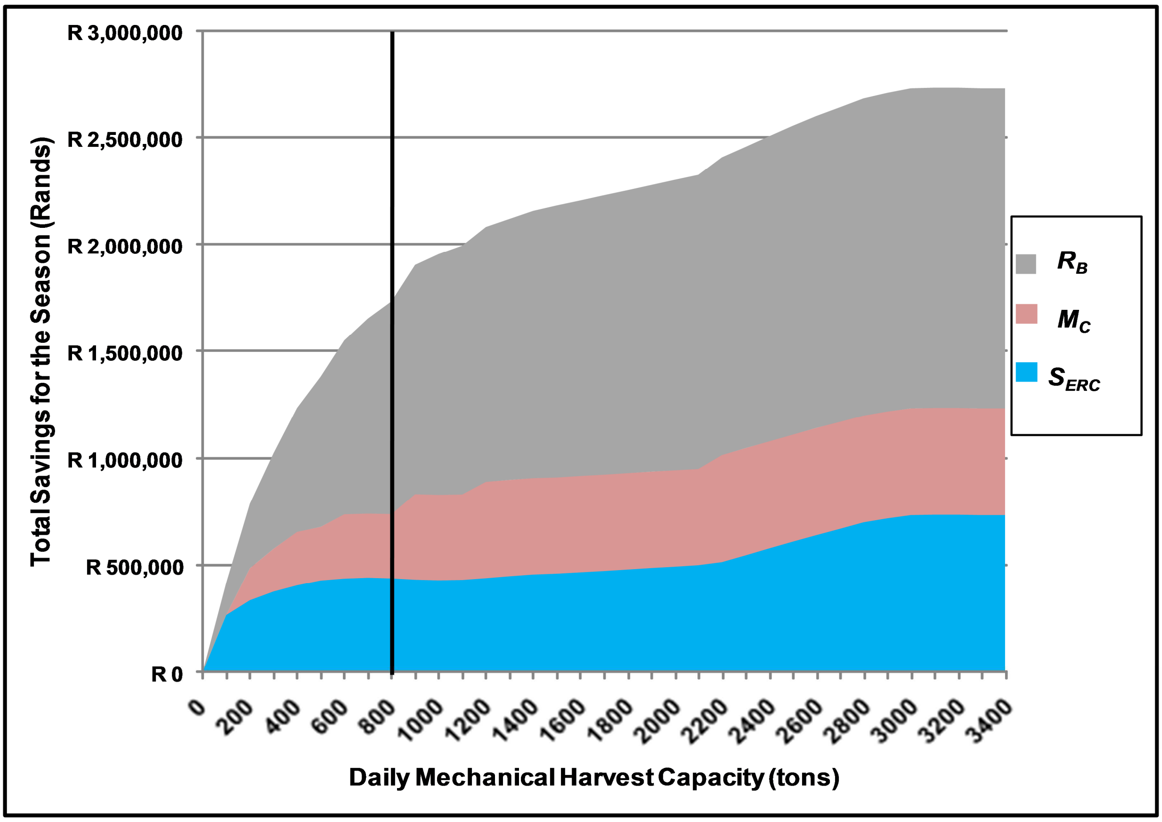

Figure 7.4 Summary of total available funds materialized by a mechanised harvesting system, with different capacities, for the 2009 season (R_B = conventional harvesting and haulage; M_C = mill operations; S_{ERC} = additional sugar recovery)

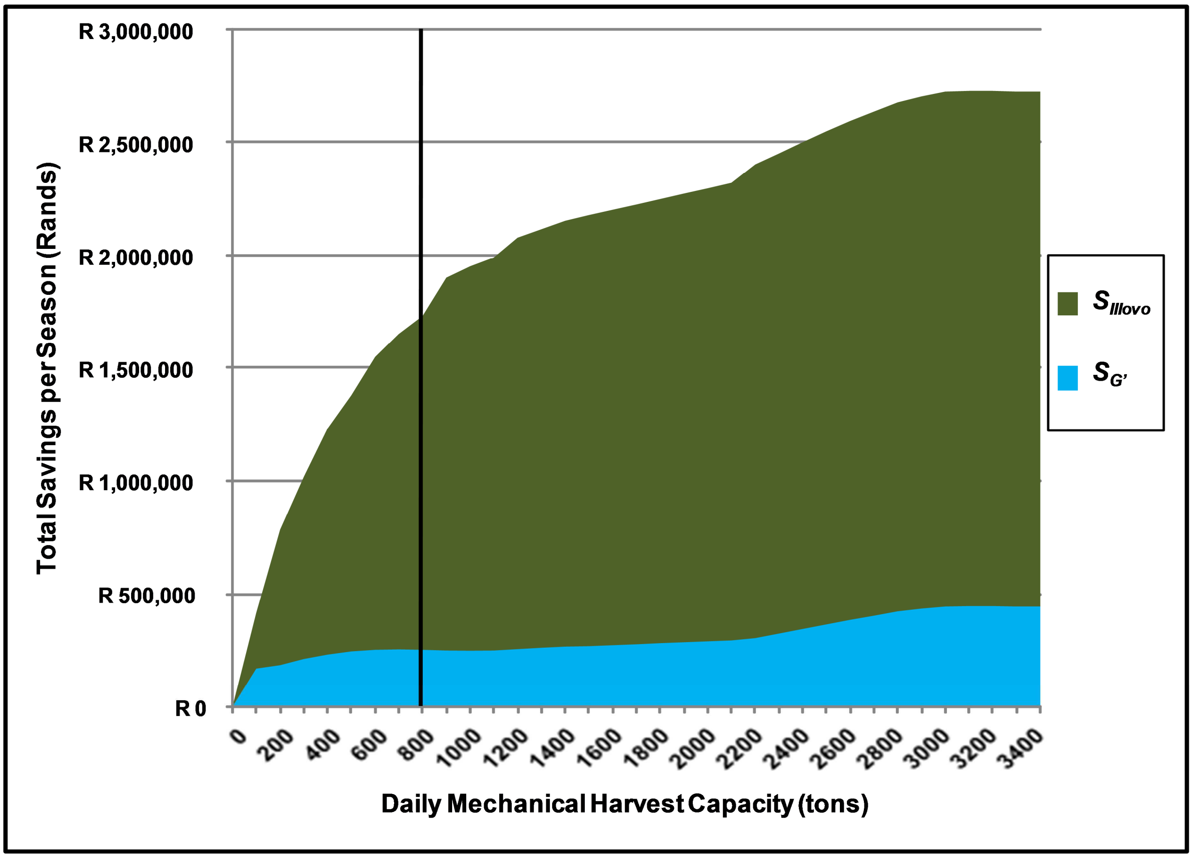

Figure 7.5 Summary of total available funds materialized by a mechanised harvesting system, with different capacities, for the 2009 season (S_{Illovo} = Illovo Group; $S_{G'}$ = other growers)

The cost of the proposed solution was estimated at R1.79 million per season. Table 7.1 displays the feasibility of the proposed solution. It compares the total available funds to the Illovo Group (S_{Illovo}) and the total cost of the proposed solution. On average, it appears that the solution is not feasible. Only the 2007 and 2008 seasons are conservatively estimated to be able to finance the proposed mechanised system. Furthermore, it should be noted that seasonal available funds are substantially variable, which results in a high risk solution. However, the mechanical harvester specialist (Schroeder, 2012) advised that second-hand equipment, which was available on the market, had the ability to reduce the total estimated costs to approximately R1.2 million. This would result in all seasons, apart from the exceptional 2010 season, being able to finance the proposed system.

Table 7.1 The feasibility of the proposed mechanical harvesting solution of 800 tons per day.

Mill Season	S_{Illovo} **(million Rands)**	**Cost of the proposed system (million Rands)**	**Difference (Rands)**
2006	1.21	1.79	-580 000
2007	2.00	1.79	210 000
2008	1.93	1.79	140 000
2009	1.48	1.79	-310 000
2010	1.17	1.79	-620 000
Average	1.56	1.79	-230 000

7.2.2 The estimated total available funds to an average grower in the Eston area

As illustrated in Figures 7.4 and 7.5, there are some benefits for growers in the Eston area, due to the mitigation of cutter absenteeism. These benefits result from an increase in sugar recovery. Collectively, all growers (Beaumont Estate excluded), could have conservatively earned an additional R253 145 under the proposed mechanical harvesting solution (see blue area in Figure 7.5).

It was estimated that the average grower in Eston produces approximately 7 000 tons of sugarcane annually. Table 7.2 summarizes the estimated available funds, as per the division of proceeds, which could have been realised by a typical grower, over the five seasons. The 800 $t.d^{-1}$ solution is highlighted. Hence, an average grower could have conservatively earned an additional R1 339 in the 2009 season. These available funds are negligible, but there are other benefits from the reduction in the LOMS, which could further provide incentives for growers and other stakeholders in the Eston area to support an alternative harvesting solution (see Chapter 6.2.2).

Table 7.2 The estimated total available funds per season to an average grower in the Eston area, at different daily mechanical harvest capacities

Alternative Harvest Capacity (t.d^{-1})	**2006**	**2007**	**2008**	**2009**	**2010**
0	R 0	R 0	R 0	R 0	R 0
100	R 320	R 968	R 845	R 899	-R 326
200	R 653	R 1,937	R 1,668	R 982	-R 651
300	R 917	R 2,851	R 2,446	R 1,122	-R 966
400	R 1,130	R 3,599	R 3,152	R 1,225	-R 1,277
500	R 1,258	R 3,931	R 3,619	R 1,301	-R 1,562
600	R 1,364	R 4,391	R 4,092	R 1,336	-R 1,812
700	R 1,447	R 4,712	R 4,559	R 1,348	-R 2,023
800	R 1,501	R 4,964	R 4,914	R 1,339	-R 2,216
900	R 1,564	R 5,159	R 5,222	R 1,324	-R 2,295
1000	R 1,617	R 5,323	R 5,426	R 1,314	-R 2,395
1100	R 1,678	R 5,486	R 5,542	R 1,321	-R 2,499
1200	R 1,732	R 5,570	R 5,637	R 1,354	-R 2,540
1300	R 1,775	R 5,657	R 5,731	R 1,383	-R 2,625
1400	R 1,809	R 5,702	R 5,798	R 1,412	-R 2,699
1500	R 1,858	R 5,746	R 5,820	R 1,424	-R 2,779
1600	R 1,904	R 5,787	R 5,815	R 1,446	-R 2,858
1700	R 1,939	R 5,807	R 5,810	R 1,468	-R 2,928
1800	R 1,969	R 5,828	R 5,768	R 1,490	-R 2,998
1900	R 2,000	R 5,848	R 5,749	R 1,513	-R 3,004
2000	R 2,031	R 5,869	R 5,720	R 1,535	-R 3,061
2100	R 2,028	R 5,890	R 5,691	R 1,557	-R 3,112
2200	R 2,050	R 5,910	R 5,662	R 1,611	-R 3,164
2300	R 2,072	R 5,931	R 5,634	R 1,718	-R 3,204
2400	R 2,092	R 5,951	R 5,620	R 1,825	-R 3,226
2500	R 2,108	R 5,954	R 5,605	R 1,933	-R 3,250
2600	R 2,125	R 5,954	R 5,593	R 2,037	-R 3,279
2700	R 2,140	R 5,954	R 5,593	R 2,136	-R 3,308
2800	R 2,140	R 5,954	R 5,593	R 2,235	-R 3,337
2900	R 2,140	R 5,954	R 5,593	R 2,300	-R 3,366
3000	R 2,140	R 5,954	R 5,593	R 2,349	-R 3,395
3100	R 2,140	R 5,954	R 5,593	R 2,357	-R 3,424
3200	R 2,140	R 5,954	R 5,593	R 2,357	-R 3,453
3300	R 2,140	R 5,954	R 5,593	R 2,349	-R 3,483
3400	R 2,140	R 5,954	R 5,593	R 2,349	-R 3,512

7.2.3 Sensitivity analysis

A simple sensitivity analysis was conducted to assess the risk associated with the current assumptions. The impacts, if the price of diesel were increased by 10%, together with the 5% increase in cutter absenteeism (see Chapter 6.2.1), are summarized in Table 7.3. The losses under more severe cutter absenteeism are substantial, compared to a 10% increase in the price of diesel. Each additional Rand increase in the price of diesel results in the total cost of the proposed mechanised system increasing by R1.03 $t.^{-1}$ (Schroeder, 2012). The increase in diesel is constant for all seasons (and in 2011 values), on the assumption that the same quantity of sugarcane will be allocated for mechanical harvesting for each of the seasons (see Section 5.2.1). It was concluded that a 5% increase in cutter absenteeism increases the total available funds by just over 50%, which would significantly increase the feasibility of the proposed solution, as summarized in Table 7.3.

Table 7.3 The estimated impacts of a 5% increase in cutter absenteeism and a 10% increase in the price of diesel, for the period 2006 – 2010, Eston Mill

	5% higher cutter absenteeism			**10% rise in the price of diesel**
Mill Season	**Increase in the LOMS (d)**	**Decrease in Sugar Recovery (t)**	**Associated total losses (R)**	**Increase in the cost of the proposed solution (R)**
2006	2	50	320 000	22 250
2007	3	170	930 000	22 250
2008	2	150	775 000	22 250
2009	2	290	1 405 000	22 250
2010	2	- 40	- 80 000	22 250
Average	**2**	**125**	**670 000**	**22 250**

7.3 Conclusion

A mechanical harvesting case study solution is proposed, to reduce a significant proportion of the impacts of cutter absenteeism. The Illovo Group is expected to finance the proposed solution from the available funds incurred. The average total available funds for the proposed solution is approximately R2 million. The Illovo Group earns an estimated average of about 75% of these total available funds. The annual cost of the proposed system is approximately R1.79 million. Unfortunately, the proposed system appears risky because of the variable sugar recovery net benefits over the seasons. Only two of the five seasons that were analysed, are estimated to be able to fully pay for the solution. But, acquiring second-hand equipment, which is available on the market, is estimated to make the solution more feasible. In addition, an increase in cutter absenteeism by 5% is conservatively estimated to make the solution significantly more viable. Total available funds increase by an average of R670 000, which is substantial, compared to a 10% increase in the price of diesel. In addition, there are other benefits from the reduction in the LOMS, which are not considered in this relatively conservative assessment (see Chapter 6.2.2). These benefits could further provide incentives for growers and other stakeholders in the Eston area to support an alternative harvesting solution.

8. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

8.1 Conclusions

The literature review confirms that a well-managed supply chain is usually important in any industry, especially in raw sugar production. In the sugarcane supply chain, the pertinent properties that cause quality inconsistencies include seasonality, harvesting techniques, a large number of cane varieties and the burn-harvest-to-crush delay. Cane processing inconsistencies are caused by weather and harvest time influences, transport issues and cane bulk density influences. These have negative impacts on mill operations and capacity. Strategies used to improve the sugarcane system include revised sugar payment systems, stockpiling, a daily rateable delivery system, vehicle scheduling and rearranged harvest schedules. However, these strategies will only be successful if there is constant communication and trust throughout the system. It is also unlikely that one improvement strategy will increase the efficiency of all systems simultaneously and there may even be some trade-offs between these strategies. Although research has been conducted on various properties that affect harvesting and transport issues in sugarcane supply chains, there has been little emphasis in the literature on the linkage between these issues and cane supply consistency.

This study refined and devised diagnostic techniques, to make sense of the complexities and to estimate the impacts of various disruptions, in a large agri-industrial system. Based on a literature search, this research is considered to be the most comprehensive analyses of sugarcane supply consistency at mill-scale. The overall research methodology can be expanded to critically evaluate different sugarcane milling regions and could potentially make significant contributions to the sugar industry.

The study included, firstly, the development of a network based on 10 general system domains that potentially drive some of the dynamics in the system. This assisted in making sense of parts of the system that are not scientifically workable. To the author’s knowledge, this technique did not appear in the literature prior to this study and has not been used before. A theme network was also devised, to identify pertinent issues in the Eston cane supply system. The above processes identified various pertinent problems, which hamper supply chain consistency in the Eston area.

Secondly, three different methods were used to rank and quantify the impacts of disruptions to cane crush rates, including a multivariate analysis of variance (MANOVA), a lower-trimmed mean (LTM) approach, as well as a mechanistic model. The MANOVA was found to be an easily-understood technique, but can only be utilized on historical data. It provided a broad indication of the impacts of cutter absenteeism, but failed to identify specific trends for each season. The novice LTM approach is a conservative, yet simple and well-structured, analytical process, but it relies heavily on historical data. The LTM approach can form the foundation of various studies to help identify the best-suited, most cost-effective and efficient solutions in a mill area. The modelling approach involved the calibration of parameters for mill maintenance and operational stops, rainfall events and days in the week when slow crush rates occurred. The model allocated approximately 64% of the variation observed in daily crush rates, to various disrupting factors. This is considered to be a moderately good predictor. The model can be utilized to critically evaluate different sugarcane milling areas and could potentially make significant contributions to commercial sugarcane operations.

An application that involved the residual of the model allowed for the development of a labour index, which predicts cutter absenteeism for each season. Such an index does not currently exist in the literature. It was statistically verified that a detectable degree of labour absenteeism occurs immediately after pay-weekends. The specific labour absenteeism coefficients for each season can possibly be extrapolated to other industries and comparisons can be drawn.

Pay-weekends have been found to reduce the supply of cane to the Eston Mill on the first Sunday and Monday of each month, on a decreasing scale. There has been a general increased trend in cutter absenteeism from about 2007 until 2010. This research conservatively estimated that annual total associated available funds of R1.3 million can be realised (revenue that could have been lost), if cutter absenteeism is mitigated. However, the impacts of the mitigation of cutter absenteeism on sugar recovery are highly variable for each season. The ERC % net benefits range from substantial gains to losses.

A mechanical harvesting case study solution, was proposed, to reduce a significant proportion of the impacts of cutter absenteeism. The Illovo Group is expected to finance the proposed solution from the available funds incurred. The average total available funds for the proposed solution is approximately R2 million. The Illovo Group earns an estimated average of about 75% of these total available funds. The annual cost of the proposed system is approximately R1.79 million. Unfortunately, the proposed system appears risky because of the variable sugar recovery net benefits over the seasons. Only two of the five seasons that were analysed, are estimated to be able to fully pay for the solution. However, acquiring second-hand equipment, which was available on the market, is estimated to make the solution more feasible. In addition, an increase in cutter absenteeism by 5% is conservatively estimated to make the solution significantly more viable. Total available funds increase by an average of R670 000, which is substantial, compared to a 10% increase in the price of diesel.

8.2 Recommendations and Opportunities for Future Research

In this section, the recommendations are targeted at the entities in the Eston sugarcane supply chain, including growers and personnel at the Eston Mill, as well as the government. In addition, this section briefly discusses various issues that could be further researched.

8.2.1 Issues related to the impacts of disruption factors

- Daily crush data were used to analyse the nine seasons (2004 – 2012). Hourly crush rates can allow for a more detailed analysis of crush deficits. The time during the day and the duration of crush deficits can be easily identified. The estimated achievable crush rates can, therefore, be more precise. Hence, sugar mills are recommended to record and retain hourly crush rate data. This can be conducted with relative ease.

- Daily crush data are recorded over a 24-hour period from 6:00 am on one day to 5:59 am on the next day. In contrast, rainfall data are recorded from 8:00 am on one day to 7:59 am on the following day. It is recommended that sugar mills record daily crush data in accordance with the rainfall data.

- All cutters were assumed to be paid on a Saturday, and pay-weekend related problems occur after these pay-days. However, some growers pay cutters on other days of the week, which could result in crush deficits. Further research can be conducted, to determine pay-day patterns for individual growers in the Eston region and their effects on the cutter-related crush deficits of each grower.

- The lower-trimmed mean (LTM) estimates the running average of the four highest values within a seven-day period and a daily crush rate deficit occurs when the actual crush rate is less than 10% of the LTM. This is conservative and it can, for example, be argued that a daily crush rate deficit could occur when the actual crush rate is less than 5% of the LTM. In addition, an average crush rate, based on the highest two or three days, may provide an even higher, yet still realistic, achievable crush rate.

- Rainfall events recorded at any of the homogeneous climatic zones (HCZs) were assumed to be the reason for crush deficits that occurred during the same period for the LTM approach. These estimates are once again conservative, because rainfall could have occurred at only one HCZ and cane supply from other areas could have been unaffected. It is, therefore, recommended that sugar mills categorise occurrences of slow crush rates and no-cane stops according to rainfall events and cutter-related shortages. This can be conducted with relative ease and should be introduced immediately. It is expected that the higher occurrence of cutter absenteeism supports this argument.

- The model was developed, using the 2004, 2005, 2011 and 2012 seasons, and verified utilizing the 2006, 2007, 2008, 2009 and 2010 seasons. The model can be recalibrated, using a larger number of seasons, in order to enhance reliability.

- Fibre loading was used for the model as a mill capacity limiter. An alternative capacity limiter, such as brix % cane, can be further investigated, which may increase the overall prediction of the model.

- The model examined the impacts of rainfall, maintenance stops and mill breakdowns. Many other factors could be added to the model, in order to explain some of the residual. These factors include, amongst others, labour strikes, logistical problems and DRD allocations.

- The model that was developed can be utilized to critically evaluate different sugarcane milling areas and could potentially make significant contributions to cane supply management and milling operations. By using stochastic weather generators, the model allows for the daily crush rates, mill breakdowns and rainfall events to be simulated for hypothetical seasons, whilst using the same calibration coefficients. The stochastic simulations can be further researched.

- The effectiveness of the model is dependant on its applicability in other milling areas, as well as other industries, such as timber. It is, therefore, recommended that the model be applied in other milling regions and industries. Fibre loading was used for the model as a mill capacity limiter for the Eston region. It is likely that other mills would have a different capacity limiter, which can substitute fibre loading. In addition, there may be other daily crush rate disruption factors in different mills, which can be included in the analysis, in order to increase the overall prediction of the model.

- According to the author’s knowledge, the research developed the first labour index of this nature for the sugar industry worldwide, in order to predict cutter absenteeism. It is advised that the index be utilized in other sugarcane milling areas and other industries, in the future.

- The impacts of cutter absenteeism were estimated for five seasons. In the future, with more seasons data, the trends of absenteeism can be investigated.

8.2.2 Issues related to the estimated losses due to cutter absenteeism

- The study attempted to estimate the typical cost of a no-cane stop associated with cutter absenteeism. Even though cutter absenteeism usually resulted in a slow crush, which did not involve any direct start-up or shutdown costs, there is a loss in milling efficiency. The cost of these losses should be further researched and quantified.

- The weekly average ERC % data were interpolated into daily averages, in order to suit the daily crush data. Daily ERC % data can provide more realistic estimates of actual and achievable sugar production. Growers have recommended that all sugar mill record and retain daily ERC % data. This can be carried out with ease and should be applied immediately.

- The available funds associated with sugar recovery and the daily mill operational costs, by the mitigation of cutter absenteeism, were the only factors that were quantified. The various additional benefits to stakeholders resulting from a reduction of the LOMS, such as the decrease in field damage and the reduction in mill and haulier maintenance costs, were only qualitatively identified. An attempt to quantify these benefits would be beneficial, to determine the increase in total available funds for the mitigation of cutter absenteeism. However, it would be difficult to accurately quantify these benefits.

- The benefits of a reduction in cutter absenteeism to an average grower in the Eston area were estimated. However, each grower’s farm conditions and RV % are different. The benefits to each grower are, therefore, different and can be quantified in the future.

- A simple sensitivity analysis estimated the impact of an increase in cutter absenteeism to be only 5%. Further research can be conducted to quantify the impacts of other increases and decreases in cutter absenteeism. This can be carried out with relative ease, prior to implementing a mechanical harvesting system.

- The 2010 milling season estimated that sugar recovery would decrease the mitigation of cutter absenteeism. It is believed that such an exceptionally dry season occurs infrequently. However, further research is required to determine the frequency of this type of season, which substantially increases the risk of an alternative solution. This should be conducted togethor with a more detailed sensitivity analysis (see previous bullet).

8.2.3 Mechanical harvesting system issues

- It was assumed that the causes and duration of mill breakdowns, as well as the ERC % curve, would be the same for the conventional and mechanised harvesting systems. In addition, the Beaumont Estate was assumed to be able to produce the same amount of cane yield per hectare for the proposed solution. This is not entirely realistic (Higgins and Murchow, 2003; Higgins *et al*., 2004) and an approximation of the differences in each system may provide a more realistic impact of the proposed solution.

- Besides the Beaumont Estate, there are other fields, which could have been chosen for the proposed change to the mechanised system, each with different costs. The most cost-effective system and fields can, therefore, be further researched. This would be essential prior to the introduction of a mechanised harvesting system.

- The proposed mechanised system assumed the same average haulage distance of 7 km to the mill, as well the same cost of haulage for the mechanised system and the conventional systems. Further research can be conducted, to determine the haulage cost from each field, which may alter the overall cost of the system. This should be carried out togethor with the previous recommendation.

- The current crop removal cost was assumed to be linear and the same for all fields in the Eston region. Further research is required to determine the different costs for each farm, which may result in alternative fields being more suited to mechanical harvesting. This should also be carried out togethor with the previous recommendations.

- The calculations and assumptions by Mr Schroeder, which were used to establish the cost of the mechanised system, were assumed to be equivalent with those of the Beaumont Estate. The calculations can, therefore, be researched to determine the compatibility for the Eston region, as well as for other sugarcane areas. This may change the overall cost of the proposed solution.

- An increase in the price of diesel is the only variable that was assumed to increase for the proposed solution. However, many of the other variables, including maintenance and the interest rate, may change. Hence, a sensitivity analysis of these variables may alter the feasibility of the proposed solution.

- Various overall system changes were not considered in this study. If stakeholders in the Eston region decide to change to mechanical harvesting, some additional factors need to be considered. These include: the agronomic costs, including land preparation; job search and training costs for drivers and managers; the off-loading system that will be used, either by push-piling from the stockpile or by altering the spiller table to handle billeted cane; the storage cost of the mechanical harvesters; as well as extensive planning from the cane supply management division. For example, there could be continuous DRD swaps between Beaumont and other growers. In addition, a pay-weekend will have to be predicted, so that the fields can be burnt and mechanically harvested at the time when the crush deficit is expected. Furthermore, the implementation of the system requires careful planning, to avoid labour discontent, such as strikes and cane fires.

8.2.4 Other unrelated issues for future research

- There is a need for more literature on the link between properties in the sugarcane supply chain, namely, from the field to the production of raw sugar, where inconsistencies have an impact on the system. Various properties, which affect harvesting and transport issues in sugarcane supply chains, have been researched, but the link between processing consistency and these issues requires further studies.

- Sugarcane quality and processing consistency are the two properties developed and reviewed as sources of supply chain inconsistencies. However, it is not always easy to differentiate between these properties and some of these relationships can be further researched.

- The Eston supply chain diagnostic study involved interviewing 13 stakeholders, in order to gain an understanding of the region and to identify pertinent issues. To the researchers' knowledge, the stakeholders chosen to be interviewed appeared to be the most representative of the Eston sugarcane supply chain. More comprehensive research, which involves interviewing more stakeholders, would be potentially less bias and could identify other pertinent issues, which could be further researched. Furthermore, the limited time allocation of one hour for each interview prevented further questions and discussion. A longer interview time could also potentially identify other pertinent issues, which could be further researched.

- The interviews were conducted over a period of one week in July 2011, which could potentially result in the risk of a bias towards recent problems experienced at that specific period of time. Therefore, the magnitude of these problems could have been enhanced. Research conducted over a longer period of time may provide more accurate conclusions.

- Interviews with cane cutters could have been beneficial for this study. The reasons for cutter absenteeism, as well as the potential, solutions to the problem could have surfaced. Further investigation should be carried out immediately by the Eston Mill Group Board.

- The system domains network (Chapter 3) appears to have value. However, to the author's knowledge, it has not previously been utilized. Further research, using this technique, is therefore required to demonstrate the effectiveness of the network, perhaps in various other supply chain systems.

- The proposed mechanical harvesting system is only one option that was further investigated, to mitigate the impacts of cutter absenteeism. There are many other solutions that could do the same. For example, an increase in wages to cutters after a pay-weekend may reduce cutter absenteeism. Another possible solution is for some growers to pay cutters on other weekends of each month, or even on other days of the week. A further proposed solution is to change the timing of a long maintenance stop to coincide with pay-weekends. This would result in the maintenance stop taking place once a month, rather than once in three weeks. However, there may be reduced milling efficiencies and increased incidences of mill breakdowns towards the end of each month. Further research on other possible solutions may therefore be useful, taking into consideration the estimated available funds.

- Based on the knowledge gained from this research, a general model for all sugarcane milling regions can be formulated. This may involve an integrated and holistic systems analysis and simulation technique, to expose and quantify opportunities in other sugar milling regions. The model could include various components, such as stochastic seasonal rainfall generators, harvest productivities under different conditions, mill wear and tear, transport efficiency and sugarcane deterioration under different conditions.

8.2.5 Other problematic areas for future research in the Eston region

Cutter absenteeism, particularly after pay-weekends, was identified as the major problem in the Eston region and was, therefore, further researched. However, the Eston supply chain diagnostic study identified various other problematic issues, which could potentially be addressed. The following are therefore recommendations, which could improve the Eston sugarcane supply chain area:

- Increased feedback from the mill, especially after mechanical breakdowns, may strengthen the relationship between the mill and growers. This can be conducted with relative ease.

- It is recommended that The Illovo Group provide more clarity with regards to diversions to the Eston Mill.

- Growers have recommended that the mill adjust trade agreements and offer subsidies to promote the usage of seed cane.

- Future research is required to determine the feasibility of harvest scheduling in different climatic zones in the Eston region, including Richmond and Eston, which may increase sugar recovery.

- Growers believe the government should assist them by re-evaluating employment requirements, aiding them to find and employ South Africans, or providing more work permits for foreigners. This would become a critical issue, if cutter absenteeism rates increase.

- The government is also advised to review its farm labour employment policies, particularly regarding farm tax regulations. This would also become a critical issue if cutter absenteeism rates increase.

- Small-scale growers believe that the government should assist them in reducing their cash flow problem, for example, by providing grants for farm ownership and establishment.

- The Illovo Group is advised to consider expanding the mill yard area.

- The potential to expand the Eston Mill, by purchasing a boiler, can be researched. It is recommended that this takes place after the expansion of the mill yard area.

- Future research is required to determine the causes of substantial undetermined losses.

- Efforts are required to increase public transport, for employees, to the mill and to provide accommodation, which are both likely to adequately attract skilled employees.

- A cost benefit analysis to purchase a storage shed for bagasse may be beneficial.

- Research to determine the feasibility of a sand-and-rock-remover is proposed, to reduce the problem of sand in cane.

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10. APPENDIX

Appendix A. A comparison between (a) the actual daily crush rates after the first weekend and (b) after the other weekends of every month, at the Eston Mill, 2006 – 2010

Effects coding used for categorical variables in model.

Categorical values encountered during processing are:

DAYNO (7 levels)
1, 2, 3, 4, 5, 6, 7

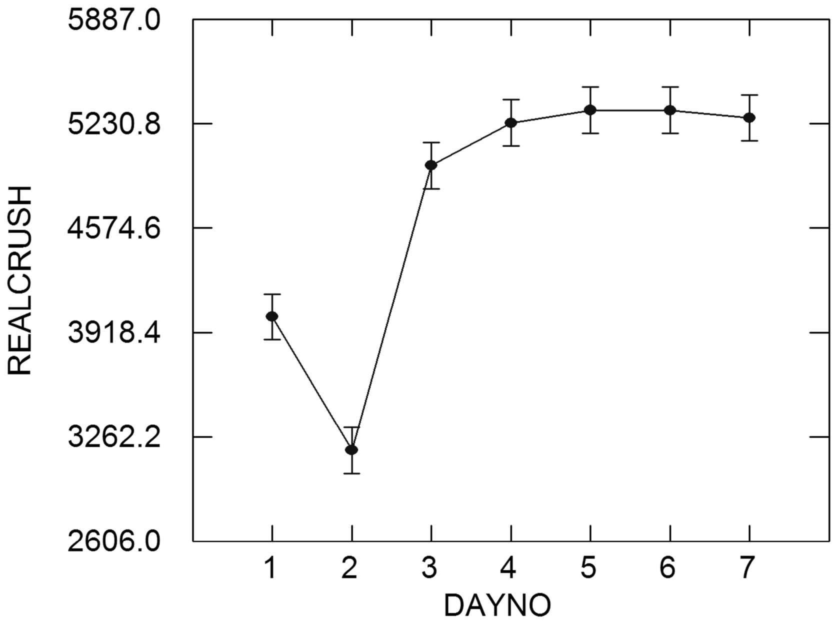
FIRSTWEEK (2 levels)
0, 1
1 case(s) deleted due to missing data.

Dep Var: REALCRUSH N: 1307 Multiple R: 0.422 Squared multiple R: 0.178

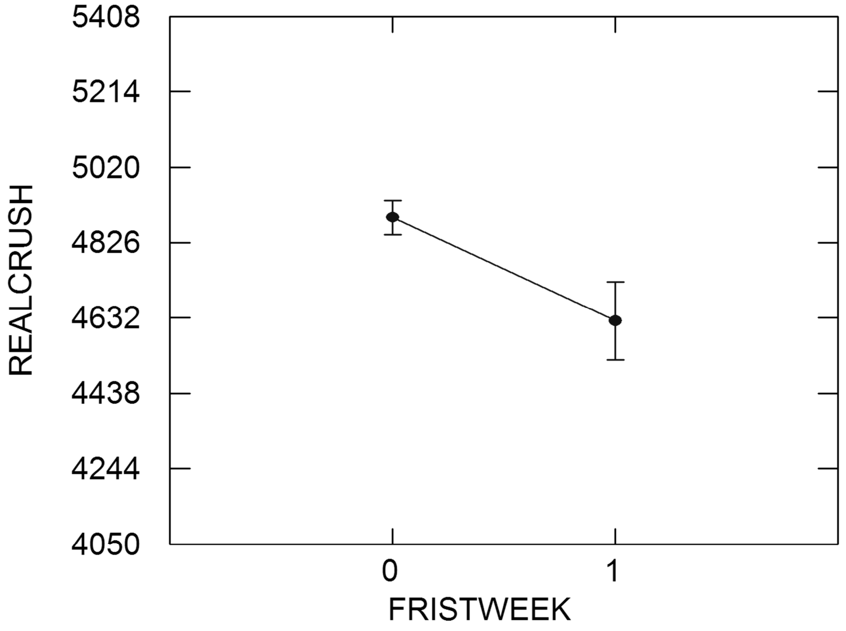
Analysis of Variance

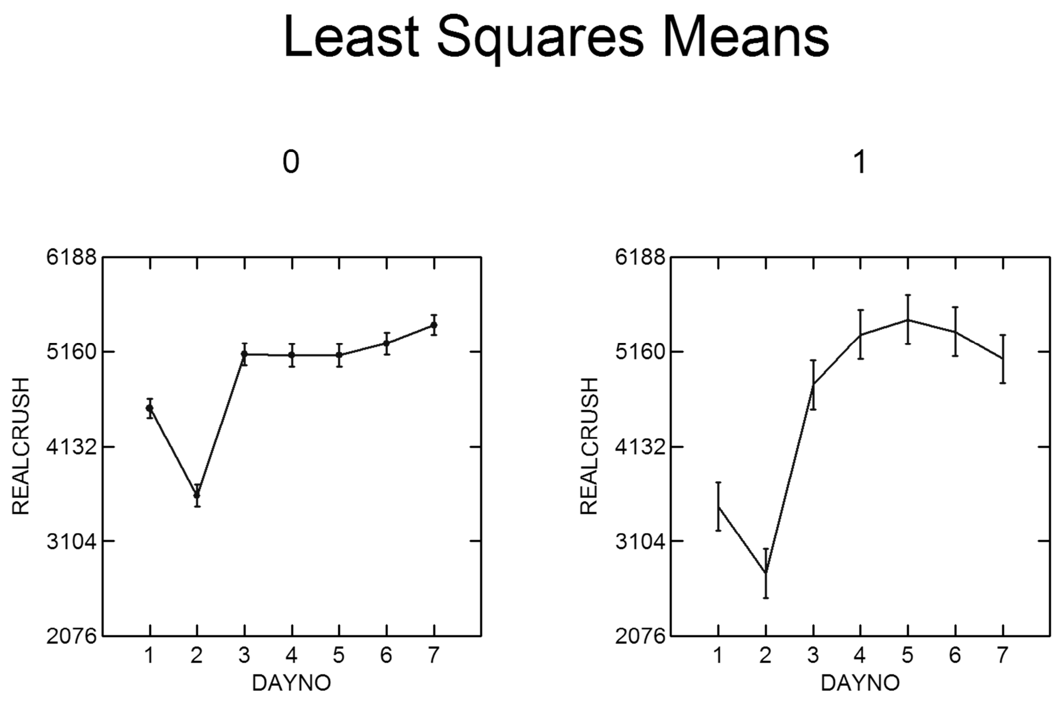
Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
DAYNO	4.21837E+08	6	7.03061E+07	33.478	0.000
FIRSTWEEK	1.24596E+07	1	1.24596E+07	5.933	0.015
DAYNO*FIRSTWEEK	4.58180E+07	6	7636333.700	3.636	0.001
Error	2.71540E+09	1293	2100076.327		

Least Squares Means

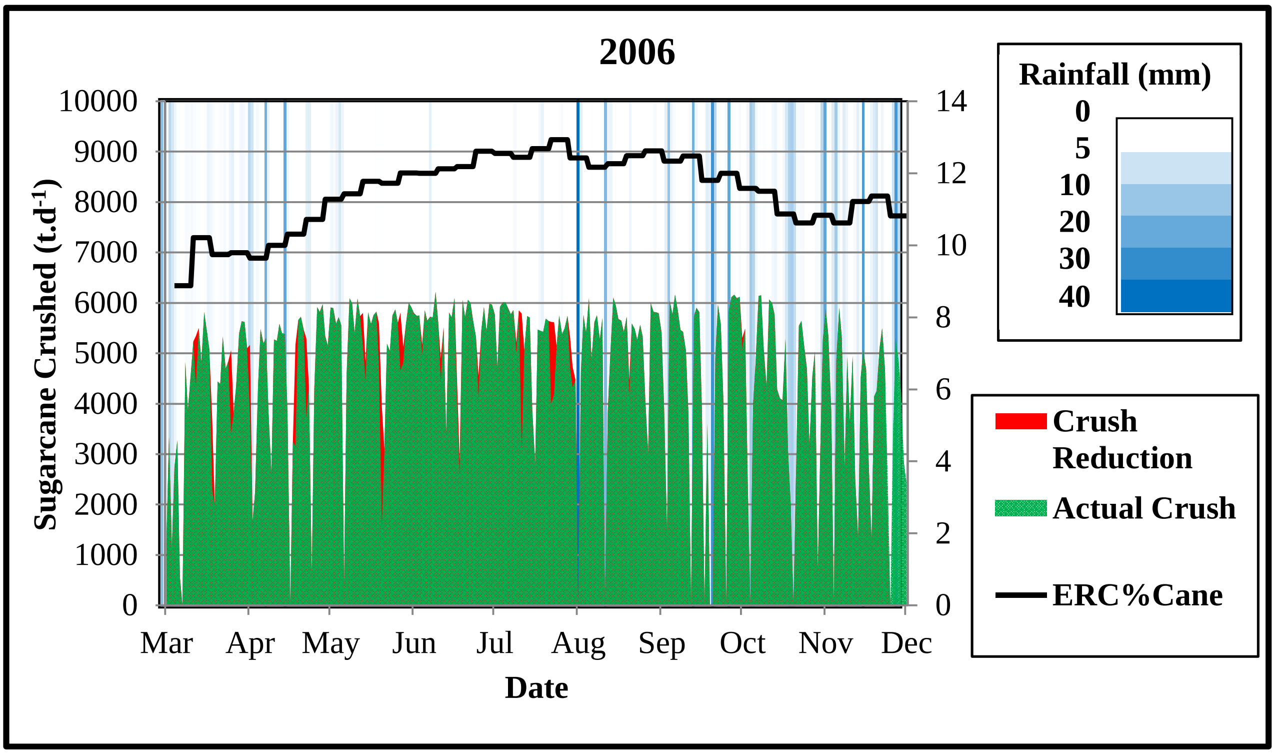


Least Squares Means

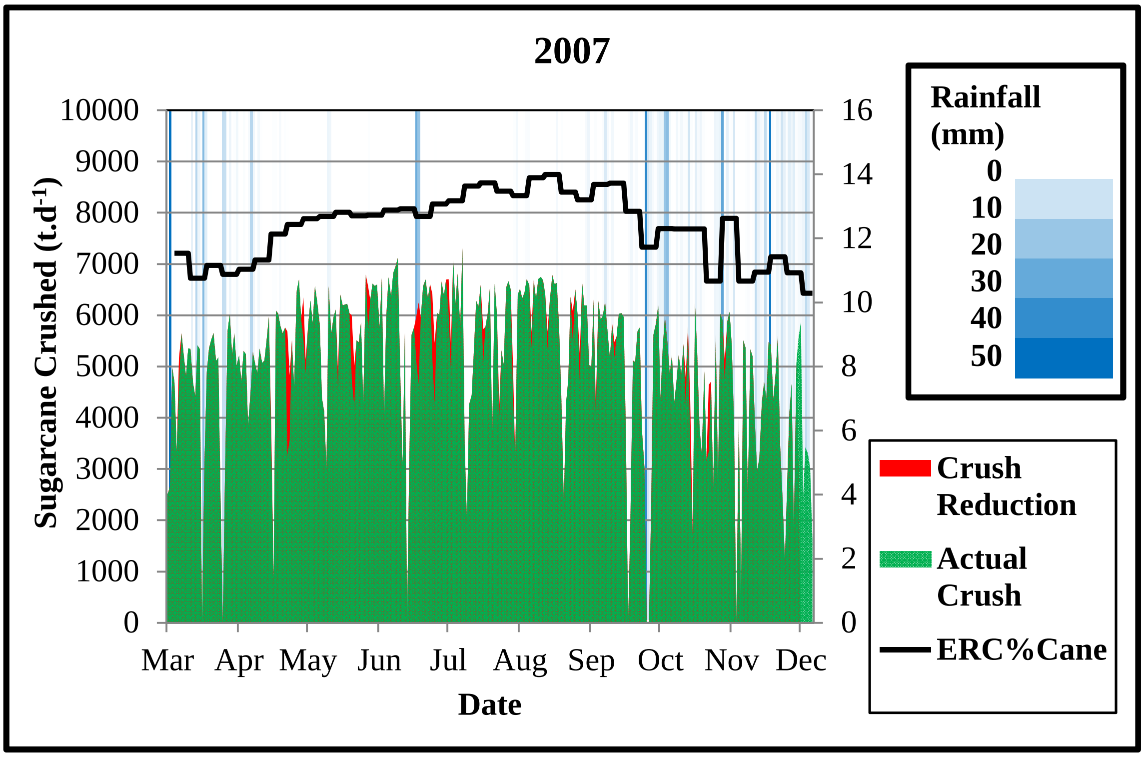




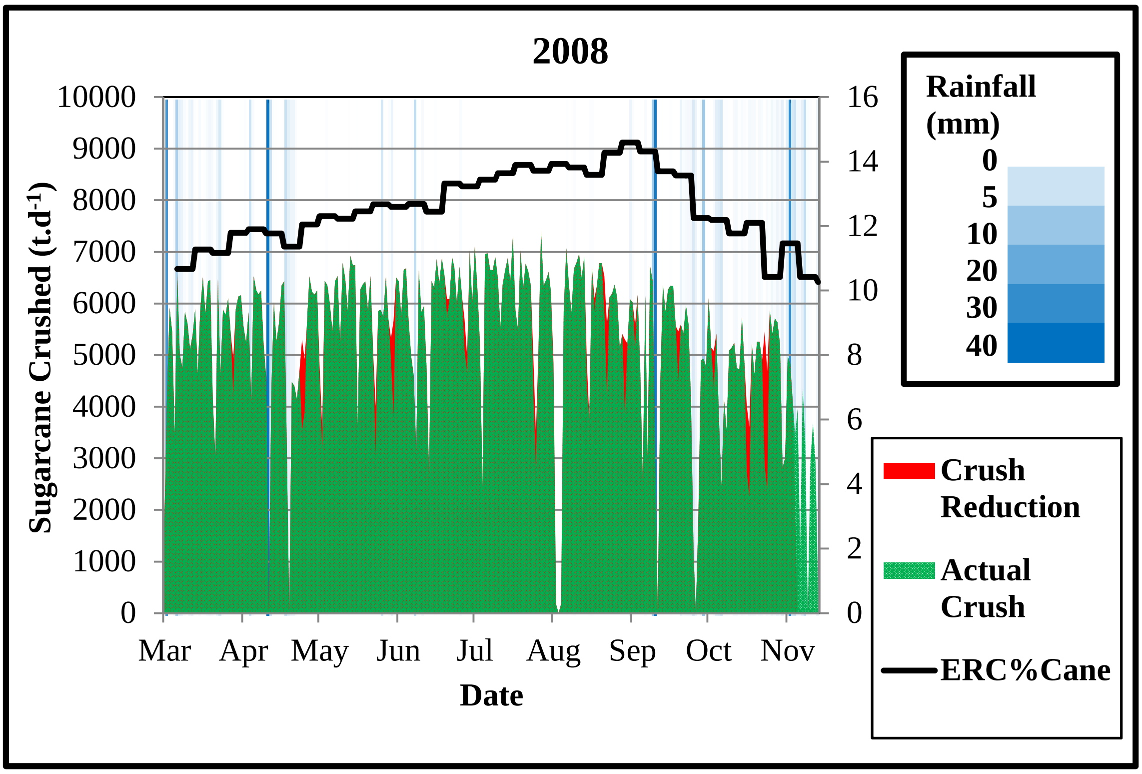
Appendix B. The potential reduction in daily crush rates (in red) associated with cutter absenteeism, at the Eston Mill



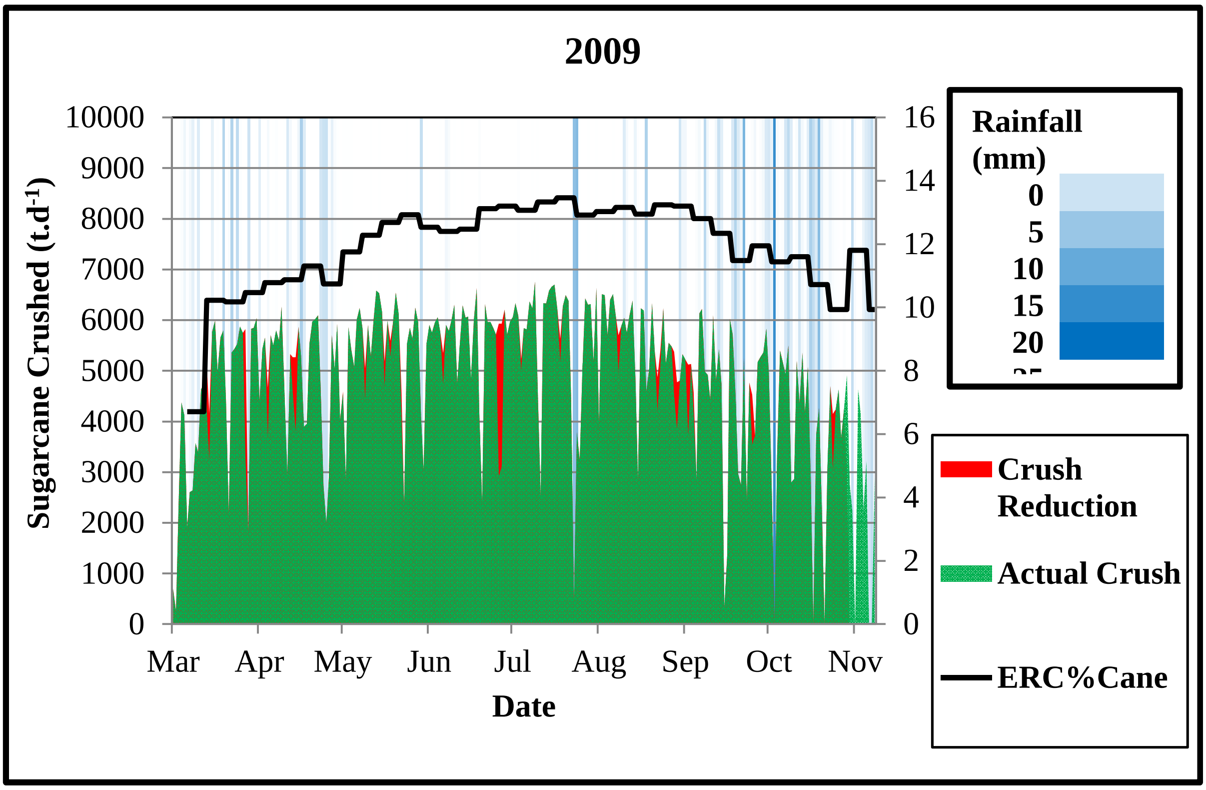
The potential reduction in daily crush rates (in red) associated with cutter absenteeism, for the 2006 milling season, Eston Mill



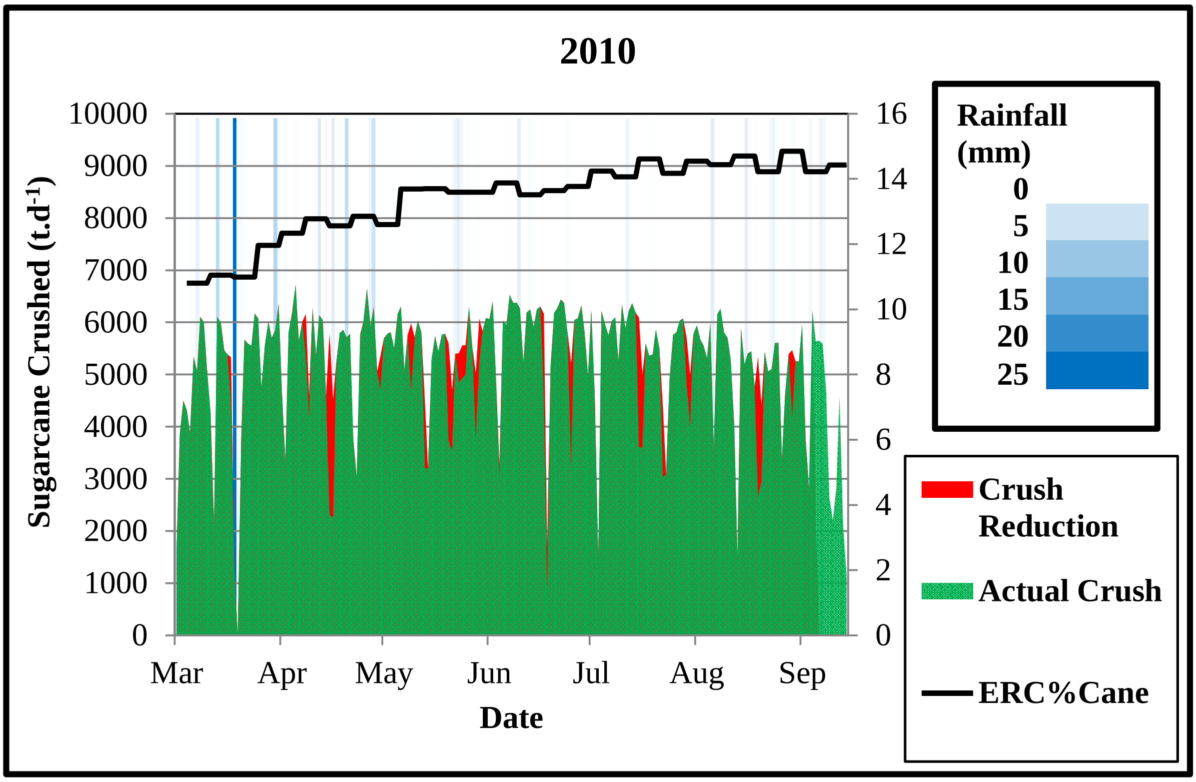
The potential reduction in daily crush rates (in red) associated with cutter absenteeism, for the 2007 milling season, Eston Mill



The potential reduction in daily crush rates (in red) associated with cutter absenteeism, for the 2008 milling season, Eston Mill

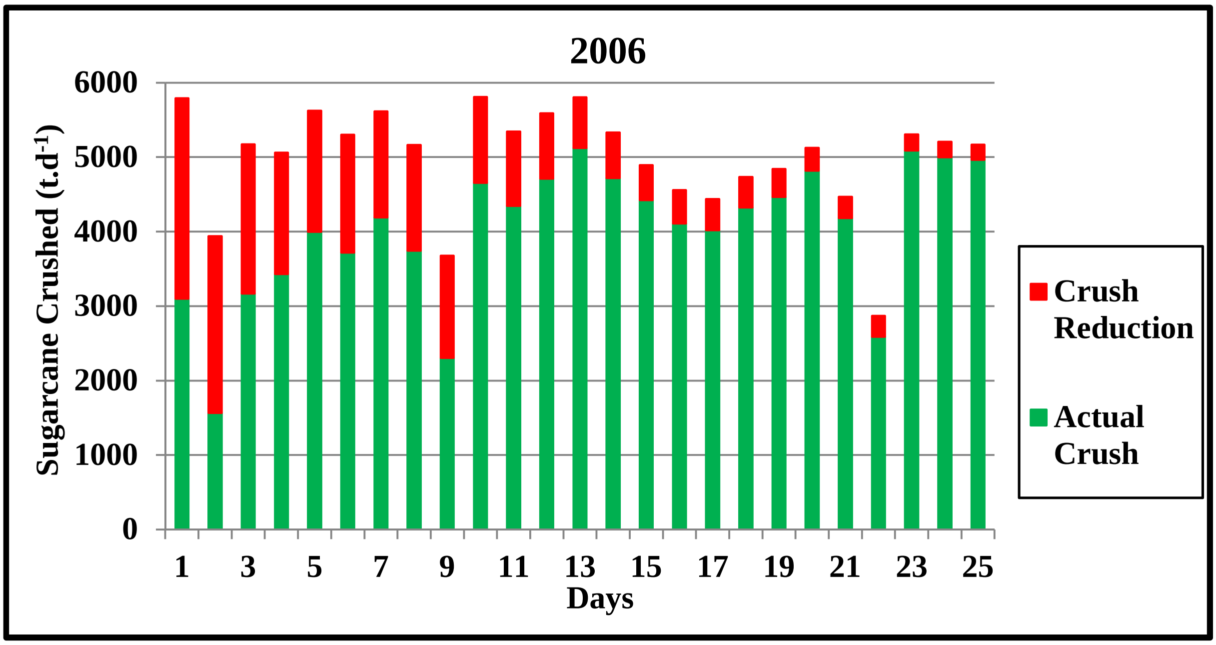


The potential reduction in daily crush rates (in red) associated with cutter absenteeism, for the 2009 milling season, Eston Mill

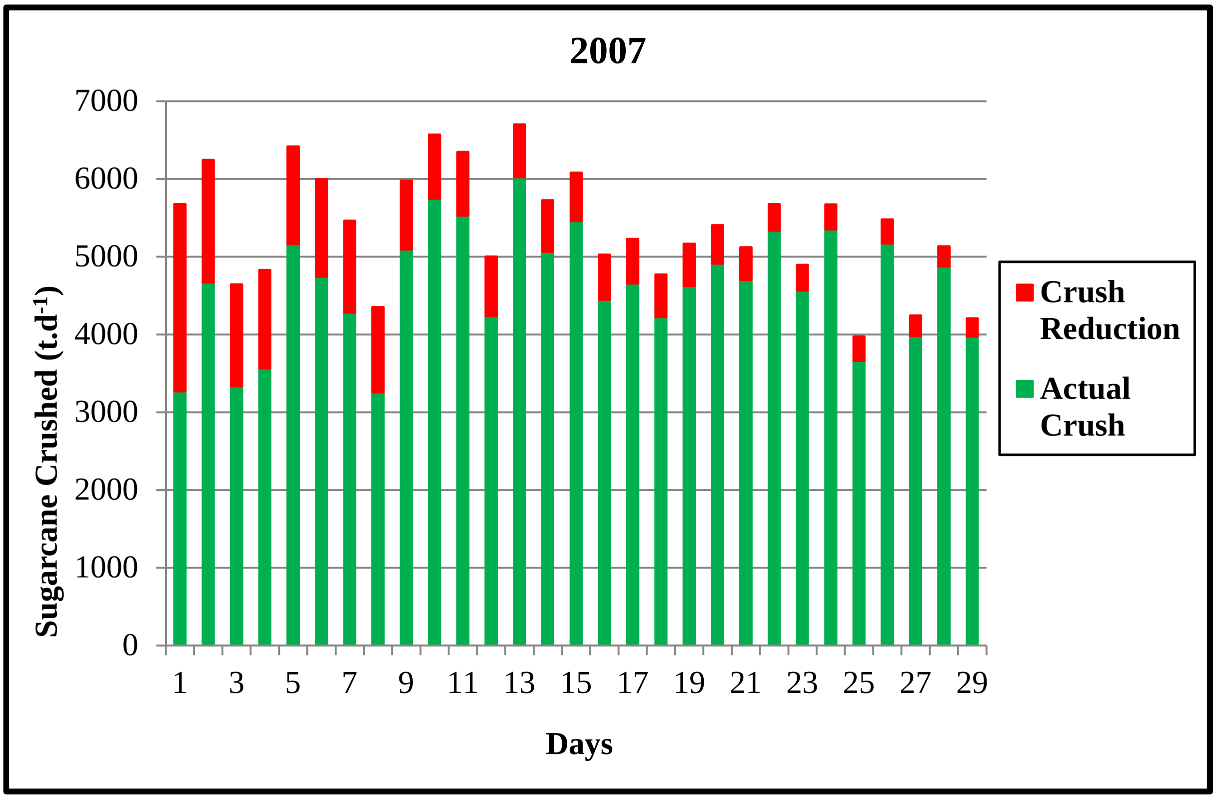


The potential reduction in daily crush rates (in red) associated with cutter absenteeism, for the 2010 milling season, Eston Mill

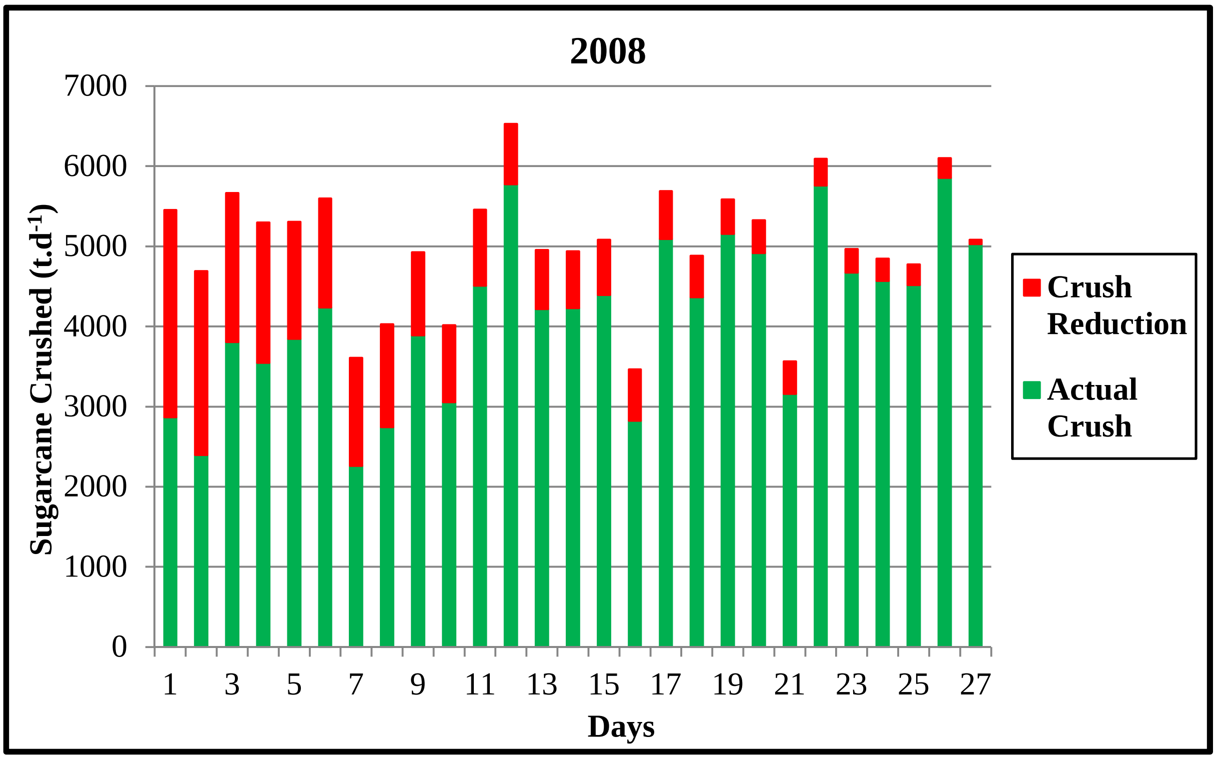
Appendix C. The potential reduction in daily crush rates on cutter-affected days, due to cutter absenteeism, at the Eston Mill



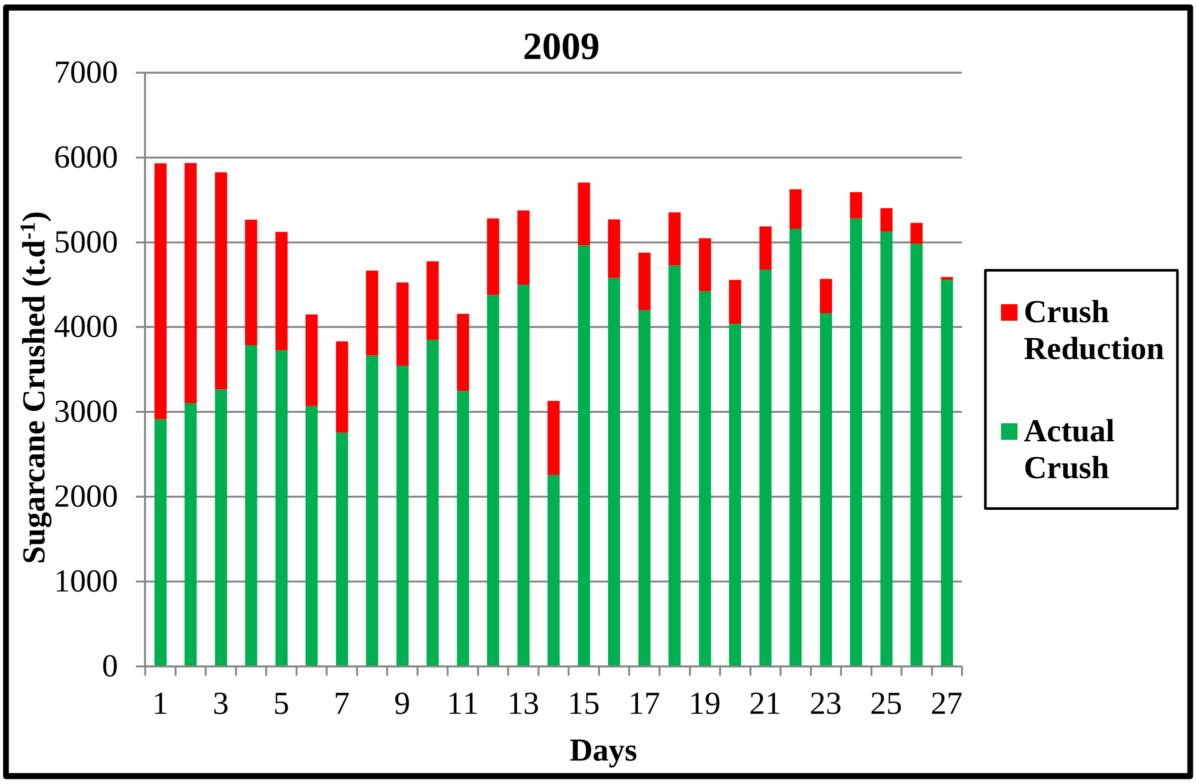
The potential reduction in daily crush rates on cutter-affected days, due to cutter absenteeism, for the 2006 season, Eston Mill



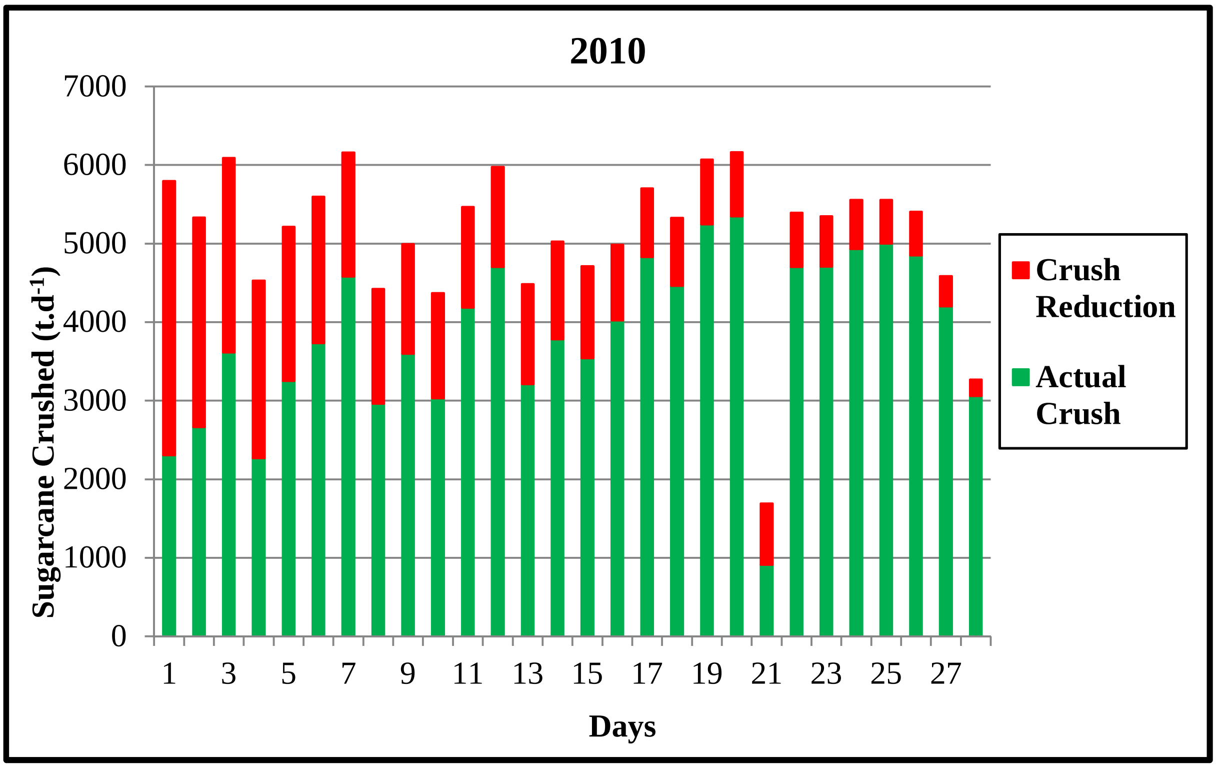
The potential reduction in daily crush rates on cutter-affected days, due to cutter absenteeism, for the 2007 season, Eston Mill



The potential reduction in daily crush rates on cutter-affected days, due to cutter absenteeism, for the 2008 season, Eston Mill

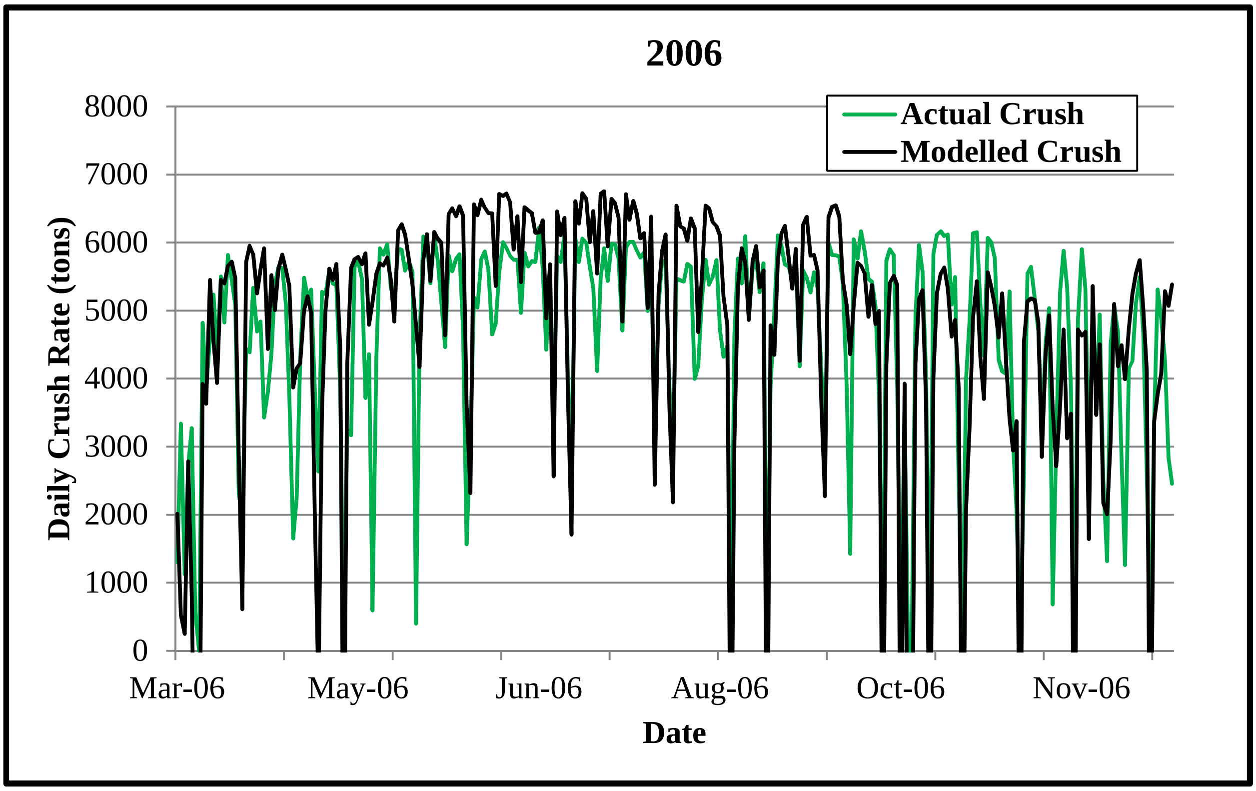


The potential reduction in daily crush rates on cutter-affected days, due to cutter absenteeism, for the 2009 season, Eston Mill

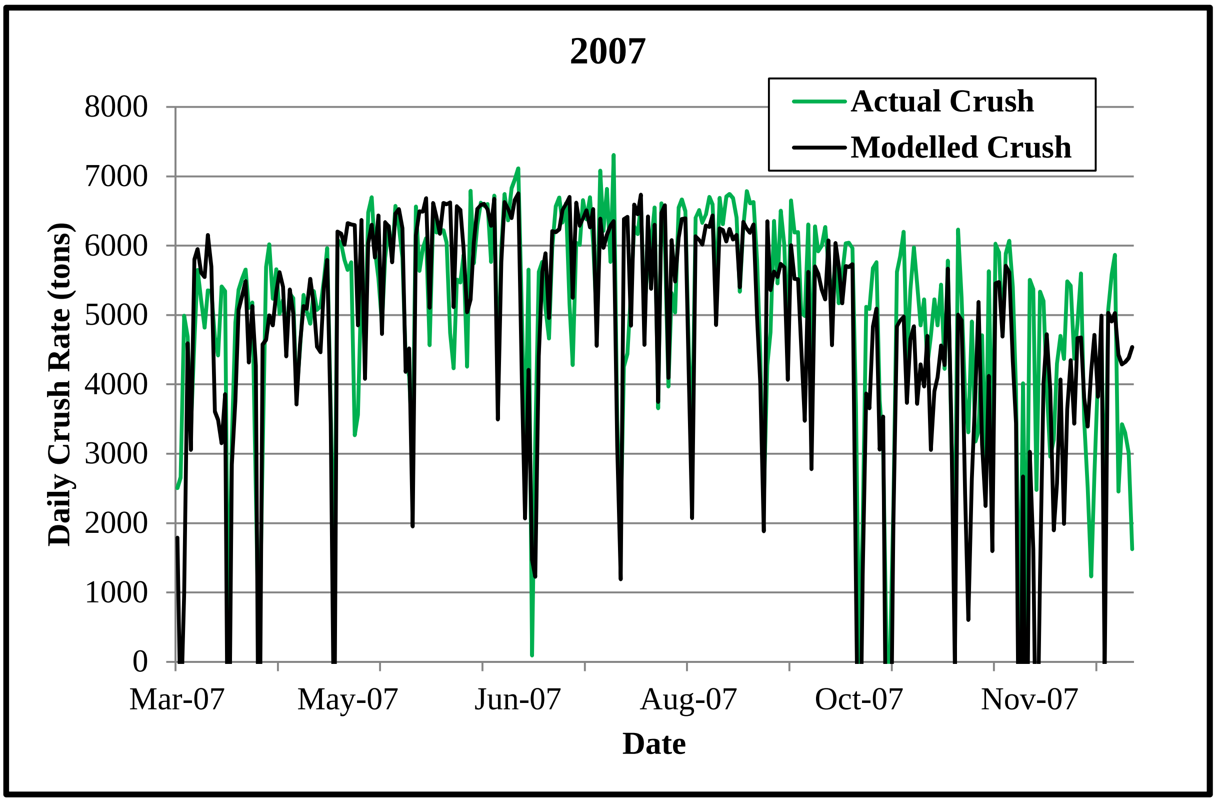


The potential reduction in daily crush rates on cutter-affected days, due to cutter absenteeism, for the 2010 season, Eston Mill

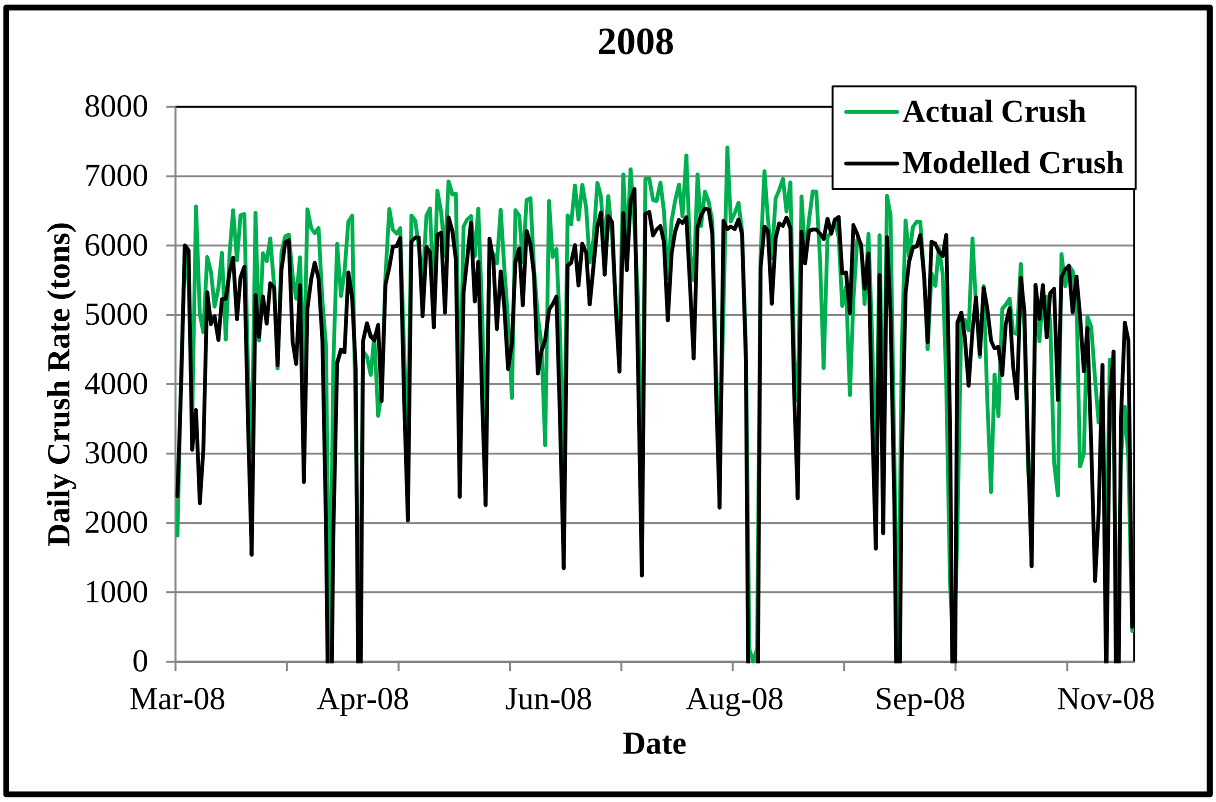
Appendix D. Comparison between the ADCR and the MDCR, Eston Mill



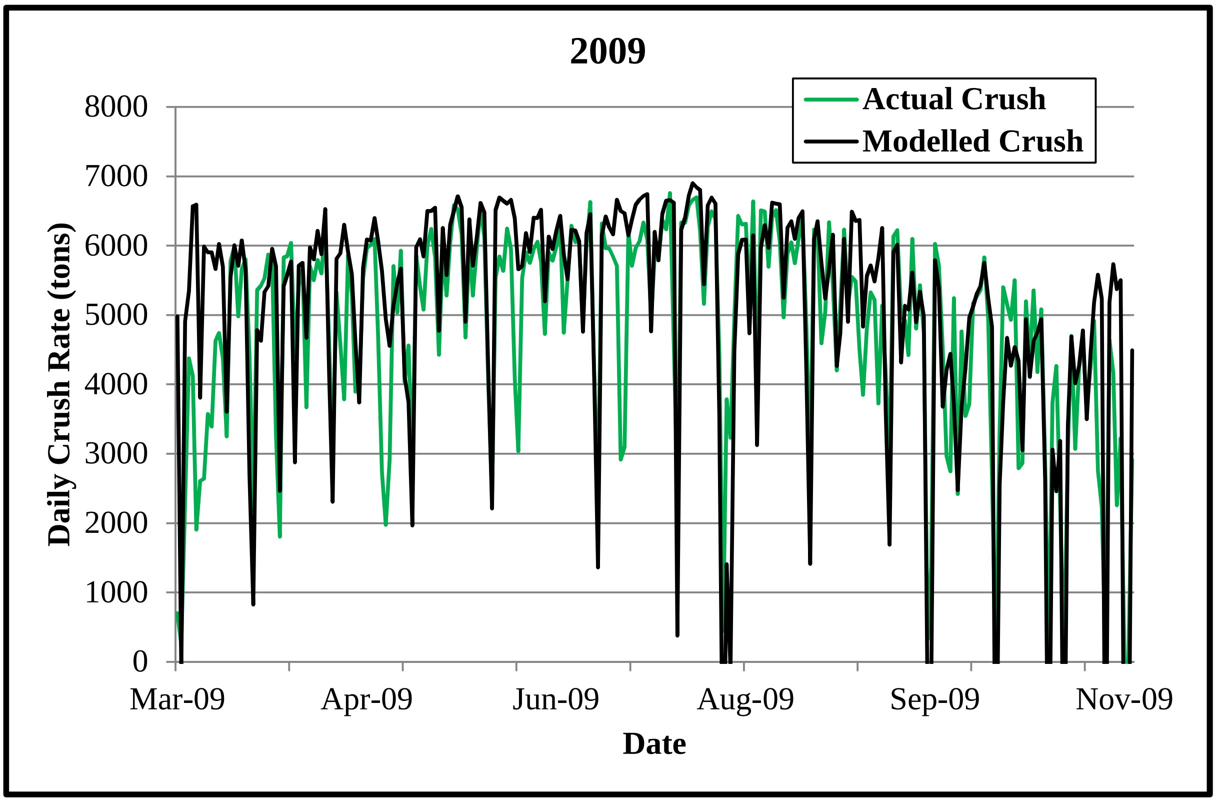
Comparison between the ADCR and the MDCR, for the 2006 milling season, Eston Mill



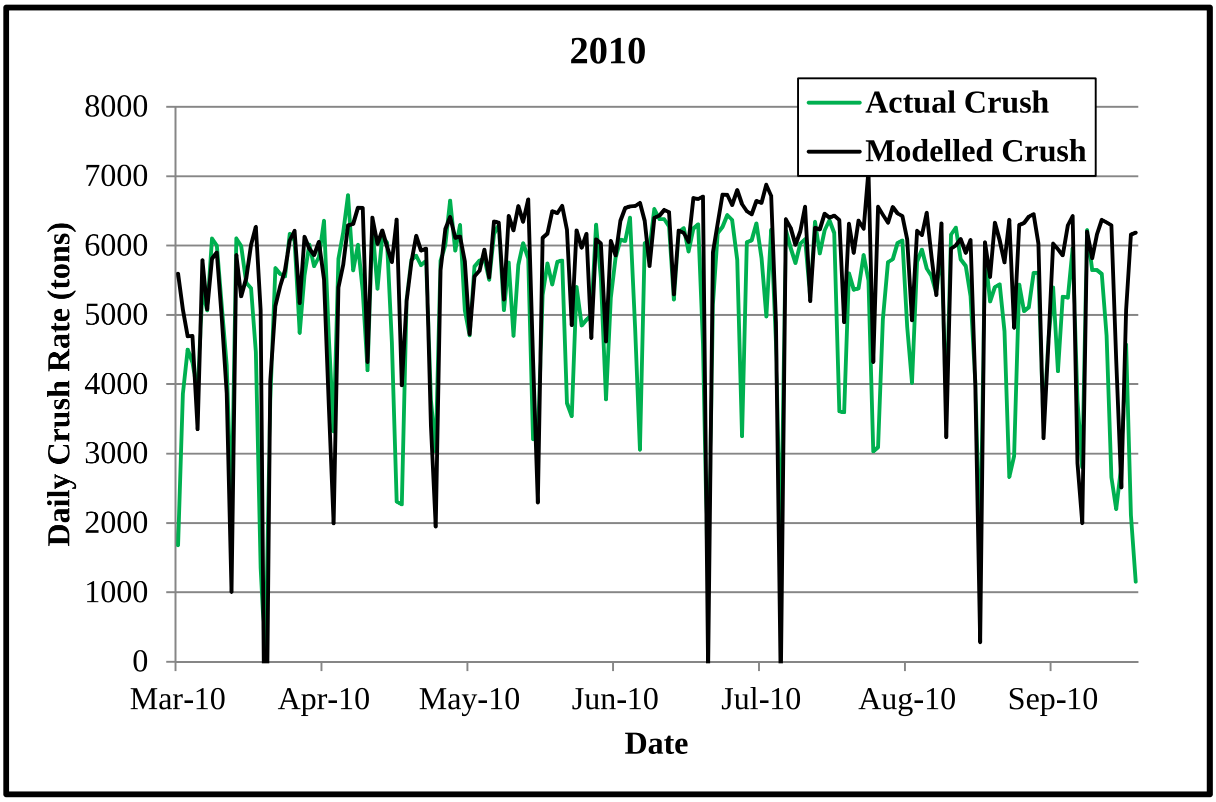
Comparison between the ADCR and the MDCR, for the 2007 milling season, Eston Mill



Comparison between the ADCR and the MDCR, for the 2008 milling season, Eston Mill



Comparison between the ADCR and the MDCR, for the 2009 milling season, Eston Mill



Comparison between the ADCR and the MDCR, for the 2010 milling season, Eston Mill

Appendix E. The conventional cost of farm labour for the Beaumont Estate (R_B), 2011

(Padayachee and Mahabeer, 2011)

Expense	**Cost per ton**
Manpower - Salaries, wages and insurance	R 22.31
Materials	R 1.38
Machinery	R 3.40
Other operating costs	R 3.87
Cane haulage	R 27.75
Depreciation	R 0.46
Expenses Recovered or Sundry revenue	-R 1.32
Total cost of labour(per sugarcane ton)	**R 57.85**

Appendix F. The cost of the proposed mechanical harvesting system of 800 t.d^{-1}

MECHANICAL COMBINE HARVESTER AND TRANSPORT ANALYSIS PROGRAMME				
SYSTEM PARAMETERS:				
Annual tonnage	21600			
Harvesting days/year	27			
Daily allocation (tons)	800			
FIELD & MACHINE INPUTS:	COMBINE	MACHINE INPUTS:	INFIELD TRANSPORT	
	HARVESTER		TRACTOR	TRAILER
Row width / width of cut (m)	2	No of bins/trailer or trailers	1	1
Row length (metres)	70	Trailer or bin capacity (tons)	8	8
Cane yield (tons/hectare)	85	Haulout distance (km)	1	1
Operating speed (km/h)	6	Travelling speed (km/h)	15	15
Average turn time (min)	1.20	Loading time (min)	4.71	4.71
Waiting for trailers (min/ha)	18	Turning time (min/cycle)	7.20	7.20
Downtime (%)	10.00	Total off-loading time (min)	5	5
Travelling time (h/day)	0.5	Op time while offloading (%)	75	75
Total hours per day	13.49	Travelling time (h/day)	0.5	0.5
MACHINE OUTPUTS:		MACHINE OUTPUTS:		
Potential harvest rate (t/h)	37.58			
Actual harvest rate (t/h)	30.21	Cycle time (hours)	0.46	0.46
Harvester efficiency (%)	29.62	No of cycles required	100.00	100.00
Harvester pour rate(t/h)	102.00	No of cycles/machine	25.00	25.00
Machine operating hours/day	11.75	Machine operating hours/day	10.88	10.88
Machines required	2	No of haulout units	4	4
Machine hours/year	317	Machine hours/year	294	294

Options:		Options:		
Add or delete number	1 or 2	Add or delete number	1,2,3 or 4	
of harvesters	2	of haulout units	2	
MACHINE COST PER HOUR	R 1 230.84		R 222.38	R 124.47
MACHINE COST PER TON	R 36.13		R 12.11	R 6.78
AVERAGE HAULAGE COST/TON	R 27.75			
		TOTAL MECHANISED SYSTEM COST/TON		
TOTAL MACHINERY COST/TON	R 55.02		R 82.77	
MACHINE COST INPUTS:-	COMBINE	MACHINE COST INPUTS:-	INFIELD TRANSPORT	
	HARVESTER		TRACTOR	TRAILER
Purchase price (Rand)	1600000	Purchase price (Rand)	280000	250000
Interest rate (%)	9	Interest rate (%)	9	9
Operator (Rand)	21600	Operator (Rand)	3888	6480
Licence & insurance (Rand)	15000	Licence & insurance (Rand)	1500	2500
Life (hours)	12000	Life (hours)	10000	20000
Tyres:-		Tyres:-		
Price (Rand)	35000	Price (Rand)	9000	42000
Life (hours)	6000	Life (hours)	3000	5000
Fuel :-		Fuel :-		
Litres/hour	25	Litres/hour	5.5	
Fuel cost (Rand/litre)	9.77	Fuel cost (Rand/litre)	9.77	
Maintenance:		Maintenance:		
% Price	150	% Price	100	45
Max. Life (years)	10	Max. Life (years)	10	15
Resale :-		Resale :-		
Base %	45	Base %	50	40
Base age (year)	5	Base age (year)	5	10
Yearly %	5	Yearly %	5	2
Minimum price (%)	10	Minimum price (%)	30	10
MACHINE COST OUTPUTS:-	COMBINE	MACHINE COST OUTPUTS:-	INFIELD TRANSPORT	
	HARVESTER		TRACTOR	TRAILER
Hours/year	317	Hours/year	294	294
Life (Years)		Life (Years)		
Calculated	37.85	Calculated	34.01	68.03
Actual	10	Actual	10	15
Resale :-		Resale :-		
Calculated	320000	Calculated	70000	75000
Actual	320000	Actual	84000	75000
Costs :-		Costs :-		
Depreciation	124500	Depreciation	18700	8867
Interest	86400	Interest	16380	14625
Fixed	247500	Fixed	40468	32472
Tyres	1849	Tyres	882	2469
Fuel	77427.25	Fuel	15798.09	0
Maintenance	63400	Maintenance	8232	1653.75
Total annual costs	390176.25	Total annual costs	65380.09	36594.75
Cost per hour	1230.84	Cost per hour	222.38	124.47
Cost per ton	36.13	Cost per ton	12.11	6.78

Appendix G. The summary of total available funds materialized by a mechanical harvesting system with different capacities, Eston Mill

The summary of total available funds materialized by a mechanical harvesting system with different capacities, for the 2006 season, Eston Mill

2006										
	TS (Rands)	**OC (Rands)**	**R_B (Rands)**	**M_C (Rands)**	**S_{ERC} (Rands)**	**S_M (Rands)**	**S_G (Rands)**	**S_B (Rands)**	**$S_{G'}$ (Rands)**	**S_{Illovo} (Rands)**
0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
100	R 291 051	R 147 301	R 143 750	R 50 000	R 97 301	R 85 028	R 206 023	R 146 272	R 59 751	R 231 300
200	R 532 102	R 244 602	R 287 500	R 50 000	R 194 602	R 120 057	R 412 045	R 290 022	R 122 024	R 410 078
300	R 790 230	R 375 800	R 414 430	R 100 000	R 275 800	R 199 288	R 590 942	R 419 492	R 171 450	R 618 780
400	R 960 784	R 437 837	R 522 947	R 100 000	R 337 837	R 221 621	R 739 163	R 528 009	R 211 154	R 749 630
500	R 1 141 778	R 529 323	R 612 455	R 150 000	R 379 323	R 286 556	R 855 221	R 620 075	R 235 146	R 906 631
600	R 1 253 341	R 560 386	R 692 955	R 150 000	R 410 386	R 297 739	R 955 602	R 700 575	R 255 027	R 998 314
700	R 1 352 261	R 584 658	R 767 603	R 150 000	R 434 658	R 306 477	R 1 045 784	R 775 223	R 270 561	R 1 081 700
800	R 1 490 837	R 654 234	R 836 603	R 200 000	R 454 234	R 363 524	R 1 127 313	R 846 800	R 280 512	R 1 210 325
900	R 1 577 210	R 672 869	R 904 341	R 200 000	R 472 869	R 370 233	R 1 206 977	R 914 538	R 292 438	R 1 284 771
1000	R 1 655 709	R 688 187	R 967 522	R 200 000	R 488 187	R 375 747	R 1 279 962	R 977 719	R 302 242	R 1 353 467
1100	R 1 731 221	R 706 199	R 1 025 022	R 200 000	R 506 199	R 382 232	R 1 348 989	R 1 035 219	R 313 770	R 1 417 451
1200	R 1 801 766	R 721 825	R 1 079 941	R 200 000	R 521 825	R 387 857	R 1 413 909	R 1 090 139	R 323 770	R 1 477 996
1300	R 1 866 210	R 734 518	R 1 131 691	R 200 000	R 534 518	R 392 427	R 1 473 783	R 1 141 889	R 331 894	R 1 534 316
1400	R 1 980 432	R 798 366	R 1 182 066	R 250 000	R 548 366	R 447 412	R 1 533 020	R 1 194 860	R 338 160	R 1 642 272
1500	R 2 032 321	R 812 804	R 1 219 518	R 250 000	R 562 804	R 452 609	R 1 579 712	R 1 232 312	R 347 400	R 1 684 921
1600	R 2 079 396	R 826 234	R 1 253 162	R 250 000	R 576 234	R 457 444	R 1 621 952	R 1 265 956	R 355 996	R 1 723 401
1700	R 2 110 262	R 836 265	R 1 273 997	R 250 000	R 586 265	R 461 055	R 1 649 207	R 1 286 791	R 362 415	R 1 747 847
1800	R 2 136 496	R 845 248	R 1 291 247	R 250 000	R 595 248	R 464 289	R 1 672 206	R 1 304 041	R 368 165	R 1 768 331
1900	R 2 162 729	R 854 232	R 1 308 497	R 250 000	R 604 232	R 467 524	R 1 695 206	R 1 321 291	R 373 914	R 1 788 815
2000	R 2 188 963	R 863 216	R 1 325 747	R 250 000	R 613 216	R 470 758	R 1 718 205	R 1 338 541	R 379 664	R 1 809 299
2100	R 2 308 209	R 970 601	R 1 337 608	R 350 000	R 620 601	R 573 416	R 1 734 793	R 1 355 653	R 379 139	R 1 929 069
2200	R 2 326 055	R 976 947	R 1 349 108	R 350 000	R 626 947	R 575 701	R 1 750 354	R 1 367 153	R 383 201	R 1 942 854
2300	R 2 343 902	R 983 294	R 1 360 608	R 350 000	R 633 294	R 577 986	R 1 765 916	R 1 378 653	R 387 263	R 1 956 639
2400	R 2 360 114	R 989 291	R 1 370 823	R 350 000	R 639 291	R 580 145	R 1 779 969	R 1 388 868	R 391 101	R 1 969 013
2500	R 2 370 646	R 994 073	R 1 376 573	R 350 000	R 644 073	R 581 866	R 1 788 780	R 1 394 618	R 394 162	R 1 976 484
2600	R 2 381 179	R 998 856	R 1 382 323	R 350 000	R 648 856	R 583 588	R 1 797 591	R 1 400 368	R 397 223	R 1 983 956
2700	R 2 391 162	R 1 003 389	R 1 387 773	R 350 000	R 653 389	R 585 220	R 1 805 942	R 1 405 818	R 400 124	R 1 991 038
2800	R 2 391 162	R 1 003 389	R 1 387 773	R 350 000	R 653 389	R 585 220	R 1 805 942	R 1 405 818	R 400 124	R 1 991 038

The summary of total available funds materialized by a mechanical harvesting system with different capacities, for the 2007 season, Eston Mill

2007										
	TS (Rands)	**OC (Rands)**	**R_B (Rands)**	**M_C (Rands)**	**S_{ERC} (Rands)**	**S_M (Rands)**	**S_G (Rands)**	**S_B (Rands)**	**$S_{G'}$ (Rands)**	**S_{Illovo} (Rands)**
0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
100	R 548 505	R 381 755	R 166 750	R 50 000	R 331 755	R 169 432	R 379 073	R 177 780	R 201 293	R 347 212
200	R 1 097 009	R 763 509	R 333 500	R 100 000	R 663 509	R 338 863	R 758 146	R 355 639	R 402 507	R 694 502
300	R 1 620 810	R 1 128 006	R 492 804	R 150 000	R 978 006	R 502 082	R 1 118 728	R 526 132	R 592 596	R 1 028 215
400	R 1 991 829	R 1 370 832	R 620 997	R 150 000	R 1 220 832	R 589 500	R 1 402 329	R 654 325	R 748 005	R 1 243 824
500	R 2 375 178	R 1 637 804	R 737 374	R 200 000	R 1 437 804	R 717 609	R 1 657 569	R 840 574	R 816 995	R 1 558 183
600	R 2 694 302	R 1 855 487	R 838 815	R 250 000	R 1 605 487	R 827 975	R 1 866 327	R 953 578	R 912 749	R 1 781 553
700	R 2 877 821	R 1 959 667	R 918 154	R 250 000	R 1 709 667	R 865 480	R 2 012 341	R 1 032 917	R 979 424	R 1 898 397
800	R 3 027 010	R 2 041 546	R 985 463	R 250 000	R 1 791 546	R 894 957	R 2 132 053	R 1 100 227	R 1 031 826	R 1 995 183
900	R 3 144 021	R 2 104 926	R 1 039 095	R 250 000	R 1 854 926	R 917 773	R 2 226 247	R 1 153 858	R 1 072 389	R 2 071 631
1000	R 3 243 062	R 2 157 967	R 1 085 095	R 250 000	R 1 907 967	R 936 868	R 2 306 194	R 1 199 858	R 1 106 336	R 2 136 726
1100	R 3 342 104	R 2 211 009	R 1 131 095	R 250 000	R 1 961 009	R 955 963	R 2 386 141	R 1 245 858	R 1 140 282	R 2 201 821
1200	R 3 476 808	R 2 306 407	R 1 170 401	R 300 000	R 2 006 407	R 1 022 307	R 2 454 502	R 1 296 812	R 1 157 690	R 2 319 119
1300	R 3 533 410	R 2 334 846	R 1 198 564	R 300 000	R 2 034 846	R 1 032 545	R 2 500 865	R 1 324 975	R 1 175 890	R 2 357 520
1400	R 3 559 932	R 2 349 197	R 1 210 735	R 300 000	R 2 049 197	R 1 037 711	R 2 522 221	R 1 337 146	R 1 185 075	R 2 374 857
1500	R 3 585 918	R 2 363 683	R 1 222 235	R 300 000	R 2 063 683	R 1 042 926	R 2 542 992	R 1 348 646	R 1 194 346	R 2 391 572
1600	R 3 609 587	R 2 376 835	R 1 232 752	R 300 000	R 2 076 835	R 1 047 661	R 2 561 926	R 1 359 163	R 1 202 763	R 2 406 824
1700	R 3 622 023	R 2 383 521	R 1 238 502	R 300 000	R 2 083 521	R 1 050 068	R 2 571 955	R 1 364 913	R 1 207 042	R 2 414 981
1800	R 3 634 459	R 2 390 207	R 1 244 252	R 300 000	R 2 090 207	R 1 052 475	R 2 581 984	R 1 370 663	R 1 211 321	R 2 423 138
1900	R 3 646 895	R 2 396 893	R 1 250 002	R 300 000	R 2 096 893	R 1 054 881	R 2 592 013	R 1 376 413	R 1 215 600	R 2 431 294
2000	R 3 659 331	R 2 403 579	R 1 255 752	R 300 000	R 2 103 579	R 1 057 288	R 2 602 042	R 1 382 163	R 1 219 879	R 2 439 451
2100	R 3 671 767	R 2 410 265	R 1 261 502	R 300 000	R 2 110 265	R 1 059 695	R 2 612 071	R 1 387 913	R 1 224 158	R 2 447 608
2200	R 3 684 203	R 2 416 951	R 1 267 252	R 300 000	R 2 116 951	R 1 062 102	R 2 622 100	R 1 393 663	R 1 228 437	R 2 455 765
2300	R 3 696 639	R 2 423 637	R 1 273 002	R 300 000	R 2 123 637	R 1 064 509	R 2 632 129	R 1 399 413	R 1 232 716	R 2 463 922
2400	R 3 709 074	R 2 430 322	R 1 278 752	R 300 000	R 2 130 322	R 1 066 916	R 2 642 158	R 1 405 163	R 1 236 995	R 2 472 079
2500	R 3 710 587	R 2 431 136	R 1 279 451	R 300 000	R 2 131 136	R 1 067 209	R 2 643 378	R 1 405 862	R 1 237 516	R 2 473 071
2600	R 3 710 587	R 2 431 136	R 1 279 451	R 300 000	R 2 131 136	R 1 067 209	R 2 643 378	R 1 405 862	R 1 237 516	R 2 473 071

The summary of total available funds materialized by a mechanical harvesting system with different capacities, for the 2008 season, Eston Mill

2008										
	TS (Rands)	**OC (Rands)**	**R_B (Rands)**	**M_C (Rands)**	**S_{ERC} (Rands)**	**S_M (Rands)**	**S_G (Rands)**	**S_B (Rands)**	**$S_{G'}$ (Rands)**	**S_{Illovo} (Rands)**
0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
100	R 498 588	R 345 953	R 152 636	R 50 000	R 295 953	R 156 543	R 342 045	R 167 511	R 174 535	R 324 054
200	R 985 380	R 683 245	R 302 136	R 100 000	R 583 245	R 309 968	R 675 412	R 330 849	R 344 564	R 640 817
300	R 1 450 979	R 1 006 099	R 444 880	R 150 000	R 856 099	R 458 196	R 992 783	R 487 540	R 505 244	R 945 735
400	R 1 801 454	R 1 233 912	R 567 541	R 150 000	R 1 083 912	R 540 208	R 1 261 245	R 610 201	R 651 044	R 1 150 409
500	R 2 202 656	R 1 528 494	R 674 161	R 250 000	R 1 278 494	R 710 258	R 1 492 398	R 745 045	R 747 353	R 1 455 303
600	R 2 526 377	R 1 753 482	R 772 895	R 300 000	R 1 453 482	R 823 254	R 1 703 123	R 858 058	R 845 065	R 1 681 312
700	R 2 765 296	R 1 904 273	R 861 023	R 300 000	R 1 604 273	R 877 538	R 1 887 758	R 946 186	R 941 572	R 1 823 725
800	R 2 948 824	R 2 018 838	R 929 986	R 300 000	R 1 718 838	R 918 782	R 2 030 042	R 1 015 149	R 1 014 893	R 1 933 931
900	R 3 111 367	R 2 118 131	R 993 236	R 300 000	R 1 818 131	R 954 527	R 2 156 839	R 1 078 399	R 1 078 441	R 2 032 926
1000	R 3 307 912	R 2 256 537	R 1 051 374	R 350 000	R 1 906 537	R 1 036 353	R 2 271 558	R 1 150 931	R 1 120 627	R 2 187 285
1100	R 3 466 167	R 2 366 721	R 1 099 446	R 400 000	R 1 966 721	R 1 108 020	R 2 358 147	R 1 213 511	R 1 144 636	R 2 321 531
1200	R 3 542 852	R 2 397 406	R 1 145 446	R 400 000	R 1 997 406	R 1 119 066	R 2 423 786	R 1 259 511	R 1 164 274	R 2 378 578
1300	R 3 618 088	R 2 427 611	R 1 190 477	R 400 000	R 2 027 611	R 1 129 940	R 2 488 148	R 1 304 543	R 1 183 605	R 2 434 483
1400	R 3 675 084	R 2 449 334	R 1 225 750	R 400 000	R 2 049 334	R 1 137 760	R 2 537 324	R 1 339 816	R 1 197 508	R 2 477 576
1500	R 3 708 677	R 2 456 384	R 1 252 293	R 400 000	R 2 056 384	R 1 140 298	R 2 568 379	R 1 366 358	R 1 202 020	R 2 506 657
1600	R 3 730 113	R 2 454 821	R 1 275 293	R 400 000	R 2 054 821	R 1 139 735	R 2 590 378	R 1 389 358	R 1 201 020	R 2 529 094
1700	R 3 751 550	R 2 453 257	R 1 298 293	R 400 000	R 2 053 257	R 1 139 173	R 2 612 378	R 1 412 358	R 1 200 019	R 2 551 531
1800	R 3 819 031	R 2 500 451	R 1 318 580	R 450 000	R 2 050 451	R 1 188 162	R 2 630 869	R 1 439 565	R 1 191 304	R 2 627 727
1900	R 3 827 766	R 2 494 225	R 1 333 541	R 450 000	R 2 044 225	R 1 185 921	R 2 641 845	R 1 454 525	R 1 187 320	R 2 640 446
2000	R 3 829 975	R 2 484 934	R 1 345 041	R 450 000	R 2 034 934	R 1 182 576	R 2 647 399	R 1 466 025	R 1 181 374	R 2 648 602
2100	R 3 832 185	R 2 475 644	R 1 356 541	R 450 000	R 2 025 644	R 1 179 232	R 2 652 953	R 1 477 525	R 1 175 428	R 2 656 757
2200	R 3 834 394	R 2 466 353	R 1 368 041	R 450 000	R 2 016 353	R 1 175 887	R 2 658 507	R 1 489 025	R 1 169 482	R 2 664 913
2300	R 3 836 555	R 2 457 270	R 1 379 285	R 450 000	R 2 007 270	R 1 172 617	R 2 663 937	R 1 500 269	R 1 163 668	R 2 672 886
2400	R 3 837 659	R 2 452 625	R 1 385 035	R 450 000	R 2 002 625	R 1 170 945	R 2 666 715	R 1 506 019	R 1 160 695	R 2 676 964
2500	R 3 838 764	R 2 447 979	R 1 390 785	R 450 000	R 1 997 979	R 1 169 273	R 2 669 492	R 1 511 769	R 1 157 722	R 2 681 042
2600	R 3 839 704	R 2 444 027	R 1 395 677	R 450 000	R 1 994 027	R 1 167 850	R 2 671 854	R 1 516 662	R 1 155 193	R 2 684 511
2700	R 3 839 704	R 2 444 027	R 1 395 677	R 450 000	R 1 994 027	R 1 167 850	R 2 671 854	R 1 516 662	R 1 155 193	R 2 684 511

The summary of total available funds materialized by a mechanical harvesting system with different capacities, for the 2009 season, Eston Mill

2009										
	TS (Rands)	**OC (Rands)**	**R_B (Rands)**	**M_C (Rands)**	**S_{ERC} (Rands)**	**S_M (Rands)**	**S_G (Rands)**	**S_B (Rands)**	**$S_{G'}$ (Rands)**	**S_{Illovo} (Rands)**
0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
100	R 416 963	R 265 607	R 151 356	R 0	R 265 607	R 95 619	R 321 344	R 151 356	R 169 989	R 246 974
200	R 784 992	R 484 137	R 300 856	R 150 000	R 334 137	R 270 289	R 514 703	R 329 050	R 185 653	R 599 339
300	R 1 020 350	R 574 571	R 445 779	R 200 000	R 374 571	R 334 846	R 685 505	R 473 309	R 212 196	R 808 154
400	R 1 232 433	R 653 954	R 578 479	R 250 000	R 403 954	R 395 424	R 837 010	R 605 338	R 231 672	R 1 000 761
500	R 1 379 735	R 676 302	R 703 433	R 250 000	R 426 302	R 403 469	R 976 266	R 730 292	R 245 974	R 1 133 761
600	R 1 550 000	R 735 719	R 814 281	R 300 000	R 435 719	R 456 859	R 1 093 141	R 840 464	R 252 677	R 1 297 323
700	R 1 652 077	R 739 211	R 912 866	R 300 000	R 439 211	R 458 116	R 1 193 961	R 939 049	R 254 912	R 1 397 165
800	R 1 732 031	R 736 451	R 995 580	R 300 000	R 436 451	R 457 122	R 1 274 908	R 1 021 763	R 253 145	R 1 478 886
900	R 1 903 030	R 829 815	R 1 073 215	R 400 000	R 429 815	R 554 733	R 1 348 297	R 1 098 030	R 250 267	R 1 652 763
1000	R 1 953 019	R 826 976	R 1 126 043	R 400 000	R 426 976	R 553 711	R 1 399 307	R 1 150 858	R 248 450	R 1 704 569
1100	R 1 992 779	R 828 988	R 1 163 790	R 400 000	R 428 988	R 554 436	R 1 438 343	R 1 188 605	R 249 738	R 1 743 041
1200	R 2 080 220	R 887 680	R 1 192 540	R 450 000	R 437 680	R 607 565	R 1 472 655	R 1 216 663	R 255 993	R 1 824 227
1300	R 2 117 661	R 896 371	R 1 221 290	R 450 000	R 446 371	R 610 694	R 1 506 968	R 1 245 413	R 261 555	R 1 856 106
1400	R 2 155 000	R 905 009	R 1 249 991	R 450 000	R 455 009	R 613 803	R 1 541 197	R 1 274 114	R 267 083	R 1 887 917
1500	R 2 180 093	R 908 285	R 1 271 808	R 450 000	R 458 285	R 614 983	R 1 565 111	R 1 295 930	R 269 180	R 1 910 913
1600	R 2 203 929	R 914 871	R 1 289 058	R 450 000	R 464 871	R 617 354	R 1 586 575	R 1 313 180	R 273 395	R 1 930 534
1700	R 2 227 765	R 921 457	R 1 306 308	R 450 000	R 471 457	R 619 724	R 1 608 040	R 1 330 430	R 277 610	R 1 950 155
1800	R 2 251 600	R 928 042	R 1 323 558	R 450 000	R 478 042	R 622 095	R 1 629 505	R 1 347 680	R 281 825	R 1 969 776
1900	R 2 275 436	R 934 628	R 1 340 808	R 450 000	R 484 628	R 624 466	R 1 650 970	R 1 364 930	R 286 039	R 1 989 396
2000	R 2 299 271	R 941 213	R 1 358 058	R 450 000	R 491 213	R 626 837	R 1 672 435	R 1 382 180	R 290 254	R 2 009 017

2100	R 2,323,107	R 947,799	R 1,375,308	R 450,000	R 497,799	R 629,208	R 1,693,899	R 1,399,430	R 294,469	R 2,028,638
2200	R 2,405,031	R 1,012,473	R 1,392,558	R 500,000	R 512,473	R 684,490	R 1,720,541	R 1,415,982	R 304,558	R 2,100,472
2300	R 2,453,999	R 1,044,191	R 1,409,808	R 500,000	R 544,191	R 695,909	R 1,758,090	R 1,433,232	R 324,858	R 2,129,141
2400	R 2,502,968	R 1,075,910	R 1,427,058	R 500,000	R 575,910	R 707,327	R 1,795,640	R 1,450,482	R 345,158	R 2,157,810
2500	R 2,551,936	R 1,107,628	R 1,444,308	R 500,000	R 607,628	R 718,746	R 1,833,190	R 1,467,732	R 365,458	R 2,186,478
2600	R 2,597,565	R 1,138,358	R 1,459,207	R 500,000	R 638,358	R 729,809	R 1,867,756	R 1,482,632	R 385,125	R 2,212,440
2700	R 2,638,364	R 1,167,657	R 1,470,707	R 500,000	R 667,657	R 740,356	R 1,898,008	R 1,494,132	R 403,876	R 2,234,488
2800	R 2,679,163	R 1,196,956	R 1,482,207	R 500,000	R 696,956	R 750,904	R 1,928,259	R 1,505,632	R 422,628	R 2,256,536
2900	R 2,705,696	R 1,216,010	R 1,489,686	R 500,000	R 716,010	R 757,764	R 1,947,933	R 1,513,110	R 434,822	R 2,270,874
3000	R 2,726,096	R 1,230,660	R 1,495,436	R 500,000	R 730,660	R 763,037	R 1,963,058	R 1,518,860	R 444,198	R 2,281,898
3100	R 2,729,294	R 1,232,957	R 1,496,338	R 500,000	R 732,957	R 763,864	R 1,965,430	R 1,519,762	R 445,668	R 2,283,626
3200	R 2,729,294	R 1,232,957	R 1,496,338	R 500,000	R 732,957	R 763,864	R 1,965,430	R 1,519,762	R 445,668	R 2,283,626
3300	R 2,726,997	R 1,230,660	R 1,496,338	R 500,000	R 730,660	R 763,037	R 1,963,960	R 1,519,762	R 444,198	R 2,282,799
3400	R 2,726,997	R 1,230,660	R 1,496,338	R 500,000	R 730,660	R 763,037	R 1,963,960	R 1,519,762	R 444,198	R 2,282,799
3500	R 2,726,997	R 1,230,660	R 1,496,338	R 500,000	R 730,660	R 763,037	R 1,963,960	R 1,519,762	R 444,198	R 2,282,799

The summary of total available funds materialized by a mechanical harvesting system with different capacities, for the 2010 season, Eston Mill

2010										
	TS (Rands)	OC (Rands)	R_B (Rands)	M_C (Rands)	S_{ERC} (Rands)	S_M (Rands)	S_G (Rands)	S_B (Rands)	$S_{G'}$ (Rands)	S_{Illovo} (Rands)
0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0	R 0
100	R 111 670	-R 49 330	R 161 000	R 50 000	-R 99 330	R 14 241	R 97 429	R 150 444	-R 53 015	R 164 685
200	R 223 341	-R 98 659	R 322 000	R 100 000	-R 198 659	R 28 483	R 194 858	R 300 780	-R 105 922	R 329 263
300	R 332 095	-R 145 821	R 477 917	R 150 000	-R 295 821	R 43 504	R 288 591	R 445 923	-R 157 332	R 489 428
400	R 440 636	-R 191 930	R 632 565	R 200 000	-R 391 930	R 58 905	R 381 730	R 589 688	-R 207 957	R 648 593
500	R 550 614	-R 231 451	R 782 065	R 250 000	-R 481 451	R 76 678	R 473 936	R 728 190	-R 254 254	R 804 868
600	R 664 627	-R 262 422	R 927 049	R 300 000	-R 562 422	R 97 528	R 567 099	R 862 062	-R 294 963	R 959 590
700	R 741 445	-R 316 144	R 1 057 589	R 300 000	-R 616 144	R 78 188	R 663 257	R 992 603	-R 329 346	R 1 070 791
800	R 812 082	-R 365 199	R 1 177 281	R 300 000	-R 665 199	R 60 528	R 751 554	R 1 112 295	-R 360 741	R 1 172 823
900	R 929 644	-R 350 306	R 1 279 950	R 350 000	-R 700 306	R 97 890	R 831 754	R 1 205 328	-R 373 574	R 1 303 218
1000	R 994 246	-R 375 792	R 1 370 038	R 350 000	-R 725 792	R 88 715	R 905 531	R 1 295 416	-R 389 885	R 1 384 131
1100	R 1 054 059	-R 402 229	R 1 456 288	R 350 000	-R 752 229	R 79 198	R 974 861	R 1 381 666	-R 406 805	R 1 460 863
1200	R 1 163 083	-R 377 914	R 1 540 997	R 400 000	-R 777 914	R 119 951	R 1 043 132	R 1 456 638	-R 413 506	R 1 576 589
1300	R 1 215 173	-R 399 507	R 1 614 680	R 400 000	-R 799 507	R 112 177	R 1 102 995	R 1 530 321	-R 427 325	R 1 642 498
1400	R 1 250 410	-R 418 325	R 1 668 735	R 400 000	-R 818 325	R 105 403	R 1 145 007	R 1 584 376	-R 439 369	R 1 689 779
1500	R 1 273 860	-R 438 788	R 1 712 648	R 400 000	-R 838 788	R 98 036	R 1 175 824	R 1 628 289	-R 452 465	R 1 726 325
1600	R 1 293 037	-R 458 753	R 1 751 790	R 400 000	-R 858 753	R 90 849	R 1 202 188	R 1 667 431	-R 465 243	R 1 758 280
1700	R 1 309 659	-R 476 631	R 1 786 290	R 400 000	-R 876 631	R 84 413	R 1 225 246	R 1 701 931	-R 476 685	R 1 786 344
1800	R 1 326 282	-R 494 508	R 1 820 790	R 400 000	-R 894 508	R 77 977	R 1 248 305	R 1 736 431	-R 488 126	R 1 814 408
1900	R 1 391 914	-R 461 441	R 1 853 355	R 450 000	-R 911 441	R 121 881	R 1 270 033	R 1 759 156	-R 489 123	R 1 881 038
2000	R 1 404 323	-R 475 828	R 1 880 151	R 450 000	-R 925 828	R 116 702	R 1 287 621	R 1 785 952	-R 498 331	R 1 902 654

2100	R 1,414,260	-R 488,891	R 1,903,151	R 450,000	-R 938,891	R 111,999	R 1,302,261	R 1,808,952	-R 506,691	R 1,920,951
2200	R 1,424,198	-R 501,953	R 1,926,151	R 450,000	-R 951,953	R 107,297	R 1,316,901	R 1,831,952	-R 515,051	R 1,939,249
2300	R 1,434,753	-R 512,247	R 1,946,999	R 450,000	-R 962,247	R 103,591	R 1,331,162	R 1,852,800	-R 521,639	R 1,956,392
2400	R 1,446,341	-R 517,909	R 1,964,249	R 450,000	-R 967,909	R 101,553	R 1,344,788	R 1,870,050	-R 525,263	R 1,971,603
2500	R 1,456,515	-R 523,899	R 1,980,414	R 450,000	-R 973,899	R 99,396	R 1,357,119	R 1,886,215	-R 529,096	R 1,985,612
2600	R 1,460,615	-R 531,300	R 1,991,914	R 450,000	-R 981,300	R 96,732	R 1,363,882	R 1,897,715	-R 533,833	R 1,994,447
2700	R 1,463,152	-R 538,700	R 2,001,852	R 450,000	-R 988,700	R 94,068	R 1,369,084	R 1,907,653	-R 538,569	R 2,001,721
2800	R 1,461,502	-R 546,101	R 2,007,602	R 450,000	-R 996,101	R 91,404	R 1,370,098	R 1,913,403	-R 543,306	R 2,004,807
2900	R 1,459,851	-R 553,502	R 2,013,352	R 450,000	-R 1,003,502	R 88,739	R 1,371,111	R 1,919,153	-R 548,042	R 2,007,893
3000	R 1,458,200	-R 560,902	R 2,019,102	R 450,000	-R 1,010,902	R 86,075	R 1,372,125	R 1,924,903	-R 552,778	R 2,010,979
3100	R 1,456,549	-R 568,303	R 2,024,852	R 450,000	-R 1,018,303	R 83,411	R 1,373,139	R 1,930,653	-R 557,515	R 2,014,064
3200	R 1,454,899	-R 575,704	R 2,030,602	R 450,000	-R 1,025,704	R 80,747	R 1,374,152	R 1,936,403	-R 562,251	R 2,017,150
3300	R 1,453,248	-R 583,104	R 2,036,352	R 450,000	-R 1,033,104	R 78,082	R 1,375,166	R 1,942,153	-R 566,988	R 2,020,236
3400	R 1,451,597	-R 590,505	R 2,042,102	R 450,000	-R 1,040,505	R 75,418	R 1,376,179	R 1,947,903	-R 571,724	R 2,023,322
3500	R 1,450,090	-R 597,265	R 2,047,355	R 450,000	-R 1,047,265	R 72,985	R 1,377,105	R 1,953,156	-R 576,051	R 2,026,140
3600	R 1,450,090	-R 597,265	R 2,047,355	R 450,000	-R 1,047,265	R 72,985	R 1,377,105	R 1,953,156	-R 576,051	R 2,026,140