

**A SIMULATION STUDY OF CANE TRANSPORT SYSTEM
IMPROVEMENTS IN THE SEZELA MILL AREA**

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ABSTRACT

The South African sugar industry is of significant local and international importance and covers an area in excess of 450 000 hectares. This area yields approximately 21 million tons of sugarcane per annum which is transported almost exclusively by road, from farms to the sugar mills. The industry is under increasing economic pressures to improve its productivity and competitiveness and sugarcane transport in the sugarcane supply chain has been identified as one area where large improvements and associated cost reductions can be made. This is mainly due to the excess in number of vehicles in the inbound transport system, the high relative cost of transport compared to other production costs in producing sugarcane, and the high fixed costs associated with truck fleet operations.

A simulation case study of the transport system was completed in 2005 in the Sezela Mill area in which approximately 2.2 million tons of sugarcane is transported per annum over an average distance of 29 km by approximately 120 independently managed vehicles owned by a wide range of hauliers and individual growers. This amounts to an estimated cost of R58 million per annum.

This study investigated the potential savings that could occur as a result of a central fleet control system with integrated vehicle scheduling. A scheduling software package named ASICAM, which resulted in significant savings in the timber industry (Weintraub *et al*, 1996), was applied within the Sezela region. Results suggested that the number of trucks in the fleet could theoretically be reduced by at least 50%, providing that a central office controls vehicle movements and that all hauliers serve all growers in an equitable fashion. In addition, investigations towards decreasing loading times, decreasing offloading times, changing vehicle speeds and increasing payloads by reducing trailer tare mass showed further reductions in the number of trucks required.

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1 INTRODUCTION

The growing and processing of sugarcane in South Africa began in the mid-1800s. As in countries such as Brazil, Australia, India and Thailand, sugarcane production is of significant national and regional importance, and contributes a large proportion of the export earning revenue. South Africa produces not only raw and refined sugar, but also a range of other sugarcane-derived products including refined sugar, syrups, specialised sugars and by-products. In terms of industry size and sugar tonnage, the South Africa industry ranks in the 11th position amongst more than 200 world sugar producers (Anon, 2009).

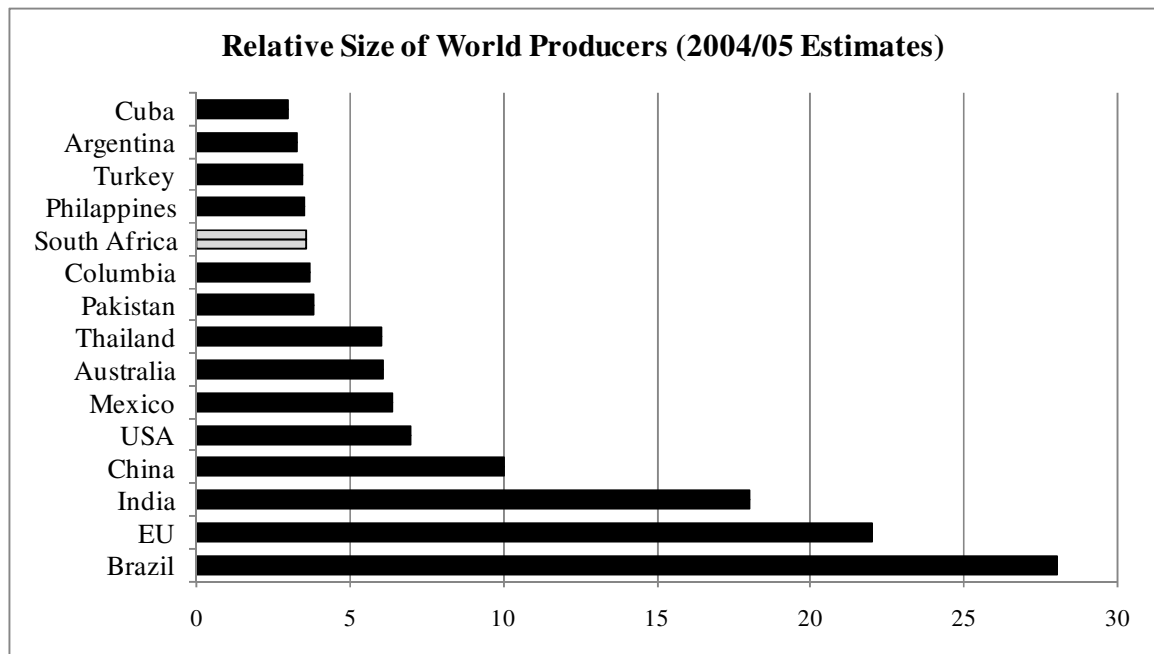


Figure 1.1 The relative position of the South African sugar industry in terms of annual tons sugar produced (Anon, 2006).

The South African sugar industry comprises approximately 430 000 hectares, which yield approximately 21 million tons of sugarcane per annum with yields varying from approximately 50 t/ha to more than 100 t/ha. This represents a significant percentage of the production of the agricultural sector in South Africa, and it is estimated that the sugar industry directly employs 85 000 people, while indirect employment is estimated at 350 000 people. Sugarcane is processed at 14 mills located predominantly along the east coast of the country (Figure 1.2). 80% of sugarcane grown in South Africa is rainfed. The mills produce approximately 2.5 million tons of sugar per annum, of which about

half is usually exported. Based on revenue from local and international sugar sales, the South African sugar industry generates an annual estimated average direct income of R6 billion (Anon, 2009).



Figure 1.2 The 14 sugar producing areas in South Africa including Sezela sugar mill in the south (Anon, 2009).

Sugarcane is grown and milled in 14 areas by five independent milling companies, *viz.* Illovo Sugar Limited, Tongaat-Hulett, TSB Sugar, Ushukela and Union Co-operative. South Africa is unique in that no sugarcane is grown as far south anywhere else in the world. Eighty percent of the sugarcane is grown in the relatively high rainfall area along the 400 km stretch from Northern Pondoland in the Eastern Cape Province, through the Natal Midlands to the north coast region of KwaZulu-Natal. The balance is grown in the dryer, irrigated areas of Pongola and the Mpumalanga lowveld. The total area represents approximately 430 000 ha planted to sugarcane, of which roughly 70% is harvested per annum (Anon, 2009).

The industry comprises approximately 47 000 registered growers, of which about 2 000 are large-scale commercial farmers on freehold property. The other 45 000 are small scale growers farming on tribal land. Milling companies with their own sugar estates (categorised as commercial growers) produce 16.5% of the crop, large-scale growers 66% and small-scale growers 17.5% (Anon, 2009).

Sugarcane transport in South Africa is predominantly by road, with only two mill areas having a small proportion of rail. This is in contrast to countries such as Australia, which has a large rail component. Typically, the sugarcane is loaded on-farm by specialised loaders into specifically designed transport vehicles. Loading can take place infield where the sugarcane is harvested, or at transloading zones where smaller loads from infield are accumulated. The sugarcane is delivered to a designated sugar mill where it is weighed in the millyard, offloaded and conveyed into the mill for crushing and processing into raw sugar. The raw sugar is then refined or used for other sugar-derived products. Some mills refine the raw sugar on site; others have specialised refining facilities.

Sugarcane is transported by more than 240 different transport companies or hauliers, operating over 1280 individual vehicles. Transport lead distances vary significantly in South Africa, from a few hundred metres to in excess of 200 km. However, relative to other bulk transport industries, such as timber and coal, sugarcane transport lead distances (± 25 km) are relatively short. Road conditions are relatively poor.

A high incidence of significant delays within the transport cycle is typical at all sugar mills in South Africa. Delays take place while loading and during driver shift changes, and also occur en route to and from the mill. However, the most significant delay is at the sugar mill, where queuing times average over 92 minutes per delivery. This excludes the time spent offloading and weighing (Crickmay, 2003). These delays significantly reduce the efficiency of the transport system.

Although each is different, all sugar mills in South Africa experience a large number of stoppages or shutdowns due to: (i) unforeseen mechanical failures, (ii) weather related stoppages, (iii) scheduled maintenance stoppages and (iv) supply chain related stoppages. These stoppages total 600-1300 hours per mill per season (Crickmay, 2003). Scheduled stops and some weather related stops are unavoidable; however, unforeseen mechanical stops can be minimised through prudent preventative maintenance. Supply chain related stops are of significant concern to the industry as they are deemed to be unnecessarily high, and occur mainly as a result of supply chain inefficiency. The costs associated

with supply chain stops are significant (tens of thousands of Rands per hour), as in most cases sugar mills use the fibre residues from the sugarcane known as bagasse as a feedstock for mill power generation. When supplies of bagasse are low, the mills have to burn coal to keep the continuous factory process fed with power.

A further symptom of the inefficient supply chain is the excessively high Burn Harvest to Crush Delay (BHTCD). Although results differ somewhat between mill areas, the average BHTCD is 65 to 85 hours, and costs the industry many millions of Rand per annum through deteriorated product. One reason for the high BHTCD is a lack of education on the subject, but can also be due to uncertainty within the supply chain which causes growers to carry more sugarcane stock than necessary (Crickmay, 2003).

There are a multitude of independent hauliers in South Africa, many of whom have operated for a number of years in subtly different sugarcane production environments and have differing objectives and business strategies. As a consequence, there are many variations in sugarcane transport equipment now in use, from the old modified farm truck to the multipurpose agricultural tractor and trailer unit to state of the art, purpose built high capacity sugarcane vehicle combinations. This has resulted in a fragmented system with a complex transport equipment-grower matrix that has the effect of constraining the transport system and has introduced significant inefficiencies (Crickmay, 2003).

Currently, little supply chain level control, coordination nor management exists within the industry. In addition, communication regarding operations between growers, hauliers and millers is relatively poor. Individual transport companies use crude methods of coordination within their own fleets and within their own client sets, but little or no coordination occurs between fleets. This has resulted in conflicting delivery plans and uncoordinated arrivals of vehicles at the mills, creating the classic problem of feast or famine, or over-supply resulting in a queuing scenario and under-supply resulting in a mill supply chain stop. This phenomenon is demonstrated in Figure 1.3 which shows the variability in the number of vehicles entering Sezela mill per hour relative to the desired delivery rate of 14 per hour (Crickmay, 2003).

According to Milan *et al.* (2006) transport costs are the largest unit costs in raw sugar production. In the Australian and South African sugar industries transport costs amount to 25% and 20% of total production costs, respectively (Higgins and Muchow, 2003; Giles *et al.*, 2008). Sugar industries worldwide are facing reduced profits due to significant increases in the cost of production and a fairly

static real selling price of sugar. The efficiency of the present South African sugarcane supply chain, from growing through to milling, has therefore come under scrutiny. The transport component of the sugarcane supply chain has been identified as one area where significant savings can be realised at relatively low cost for all three parties concerned: the growers, the hauliers and the miller (Lyne, 2004)

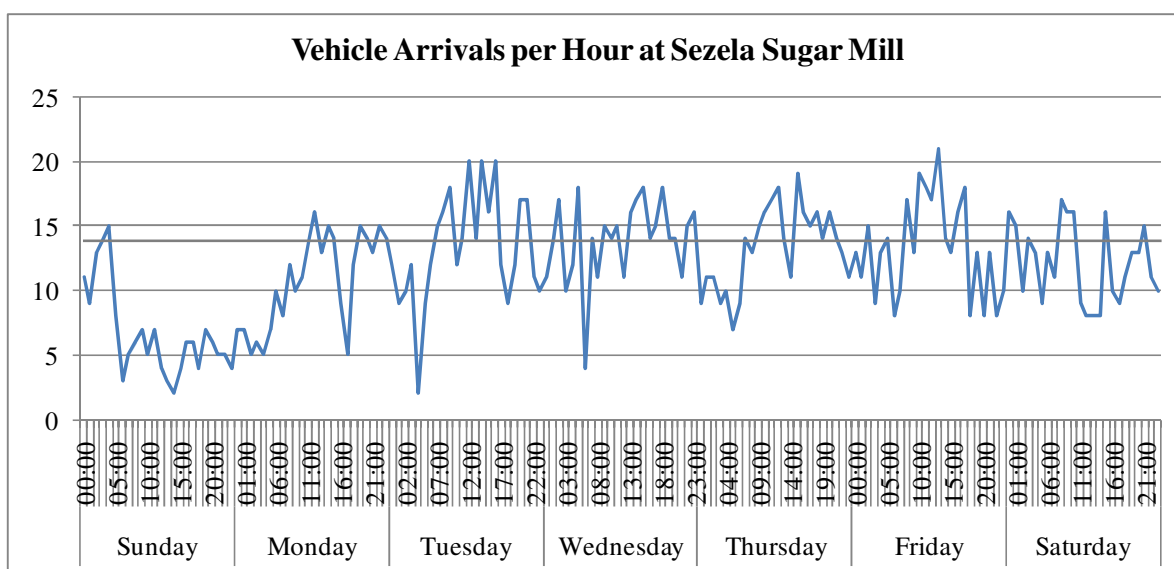


Figure 1.3 Variability in the number of vehicles delivering sugarcane per hour to Sezela Mill for Week 18 in the 2005/6 milling season (Crickmay, 2003).

It is hypothesised that the root cause of the supply chain inefficiency at a single mill is three-fold and interdependent:

- i. Lack of supply chain central coordination,
- ii. Supply chain vehicle over fleetings, and
- iii. Supply chain complexity.

Rönnqvist (2003) explains that the timeline, namely operational, tactical or strategic, is an important aspect of management. In the literature two broad approaches have been used to address the sugarcane supply chain inefficiency problem, depending on whether in the strategic and tactical or operational environment.

In the strategic and tactical environment, computer simulation models have been specifically designed that are capable of evaluating transport scenarios and identifying bottlenecks within the systems, and

are used either to optimise or evaluate scenarios of interest. In the South African sugarcane industry, transport optimisation and scheduling has been studied since as early as 1957, when a local consultancy made recommendations for the introduction of vehicle scheduling (Dent, 1973). Libunao (1977) studied the testing of alternative strategies within the sugarcane transport system, taking into account weather conditions, travel times, equipment capacity and equipment breakdowns. Amongst other outcomes was the simulation of a reduction of $\pm 40\%$ of required fleet capacity at two sugar mills. Pinkney and Everitt (1997) considered the use of a scheduling simulation program named ACTSS to simulate an integrated approach to harvesting and rail transport control in the Australian sugar industry. Barnes *et al.* (1998) used the ARENA simulation tool to develop a computer based model of sugarcane harvesting and delivery systems to investigate scenarios pertaining to the reduction of sugarcane harvest-to-crush delays. Hahn and Ribeiro (1999) developed a heuristic simulation tool used for the operational planning of transportation into sugar mills which focused on flexibility and user interactiveness during planning. Diaz and Perez (2000) used transport and harvest simulation modelling to identify bottlenecks and provide information on resource allocation and risk management. Arjona *et al.* (2001) developed a discrete event simulation model of harvest and transport systems for the Mexican sugar industry to assess the problem of machinery over-capitalisation and under-utilisation. The model showed that less machinery operated more efficiently could maintain production levels and that the inefficiencies result mainly from an inability to manage the complex system. Gaucher *et al.* (2003) developed a computer model to simulate the planning and operation of mill sugarcane supply throughout the season, with the objective of assessing, amongst other aims, the impact on the transport capacity. Higgens and Davies (2004) developed a simulation model for capacity planning, to estimate the number of locomotives and shifts required; the number of bins required; and the period of time harvester operators spend waiting for bins. The benefits of integrating the capacity planning model with a model for scheduling harvesters into sidings is demonstrated by the Mossman case study, which showed significant reductions in the daily variability of demand on the transport system. Prichanont *et al.* (2005) used discrete-event simulation and empirical data to investigate the effects of improvement factors on the cane delivery system. The results showed that by implementing the proposed improvement schemes, truck utilization, truck average waiting time, and hence transportation costs, can be significantly reduced. Paula-Lannoni and Morabito (2006) described the use of discrete simulation techniques to study the reception area of a sugarcane mill, analyzing the performance of the system and investigating alternative configurations and policies for its operations. Higgens (2005) developed a mixed integer programming model for Maryborough Mill in Australia, to improve on the manual scheduling protocols used. The research showed that significant improvements in efficiency could be made that would realise a potential saving of AUD\$240 000 per annum. Milan *et*

al. (2006) developed a mixed integer linear programming model to solve the problem of cost minimisation of sugarcane crop removal and transportation by rail. The results showed that the model was not only useful for minimizing transportation cost, but also for scheduling daily cane road transport and harvesting quotas of cutting means. Lejars *et al.* (2008) designed a supply chain wide simulation tool to facilitate discussions and negotiations between stakeholders.

In contrast and in the operating environment, scheduling tools have been used to improve efficiency to great effect (discussed in further detail in Chapter 5). In 1971 the use of a manual type real-time vehicle scheduling system was designed and successfully operated at Tongaat Sugar (Pty) Ltd. (Dent, 1973). Dines *et al.* (1999) designed and introduced an operational vehicle scheduling system named FREDD into the New South Wales sugar industry in Australia.

This aim of this study is to use a hybrid modelling approach, using an operational scheduling package as a simulation tool thereby accurately simulating a central coordinating system of scheduling vehicle deliveries in the Sezela mill area. The system aimed to supply sugarcane to a sugar mill using the least possible vehicle resources minimising queuing delays and reducing mill stoppages. This would increase profitability for all three role players, the miller, hauliers and growers.

Specific objectives include:

- A review of the Sezela supply chain environment. (Chapter 2)
- A costing of the 2004 Sezela transport system using a commercial costing model (Chapter 3).
- A review of vehicle routing and scheduling problems, followed by a more specific review of agricultural type routing and scheduling (Chapter 4 and 5).
- Configuring the operational scheduling package to enable simulations of an optimum transport system to be performed (Chapter 6).
- Using the operational scheduling package, evaluate system productivity and subsequent relative impacts on cost (Chapter 7).
- Simulating and costing a set of additional scenarios aimed at investigating the sensitivity of the transport system to changes in various key logistics parameters (Chapter 8).
- A discussion of results and thereafter drawing conclusions based on the results of the simulations (Chapter 9).
- Recommendations for future research (Chapter 10).

2 AN OVERVIEW OF THE SEZELA SYSTEM

The Sezela Sugar Mill is one of the largest in South Africa, and has some of the most diverse and challenging transport operating conditions in the sugar industry (Simpson, 2004). At present the logistics system is inefficient and costly to all three role players: the miller, grower and haulier. This chapter's objective is to briefly review the Sezela mill area in the context of the South African sugar industry. The individual elements of the sugarcane supply chain, the harvesting, transloading, transport and millyard operations are discussed and described in detail. This highlights the complexity of the present system and supports the need for a central coordination centre.

2.1 An Overview of the South African Sugar Industry and the Sezela Mill Area

The Sezela Sugar Mill, owned and operated by Illovo Sugar Ltd., is located approximately 60km south of Durban on the South Coast (Figure 1.3). It is one of the largest of South Africa's sugar mills and crushes in excess of two million tons of cane during the approximate 37-week milling season (Figure 2.1). The Sezela mill produces not only raw sugar, but is unique in that it has a supplementary industrial plant for producing artificial flavourings and additives.

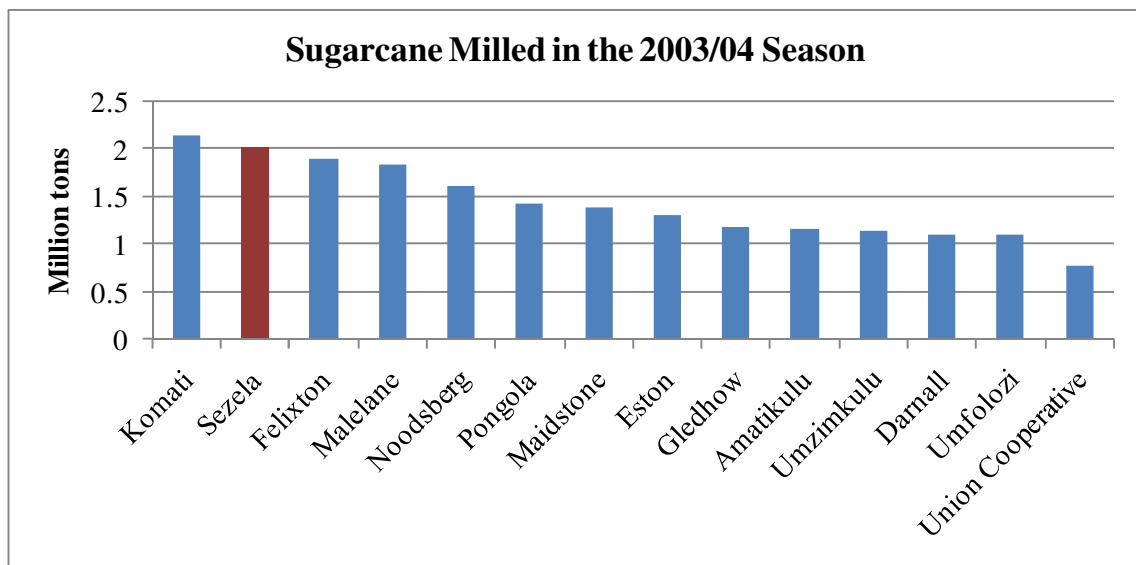


Figure 2.1. Tons sugarcane crushed at the 14 sugar mills in South Africa during the 2003/2004 milling season (Anon, 2003).

The mill is located on the coast and therefore has lead distances ranging from a few kilometres in the Ifafa Beach area, to approximately 120 km in the Highflats/Ixopo area (Figure 2.2). The terrain, and therefore the road gradients, differs significantly from relatively flat conditions in the Scottburgh and Hibberdene areas to the steeper inland regions.

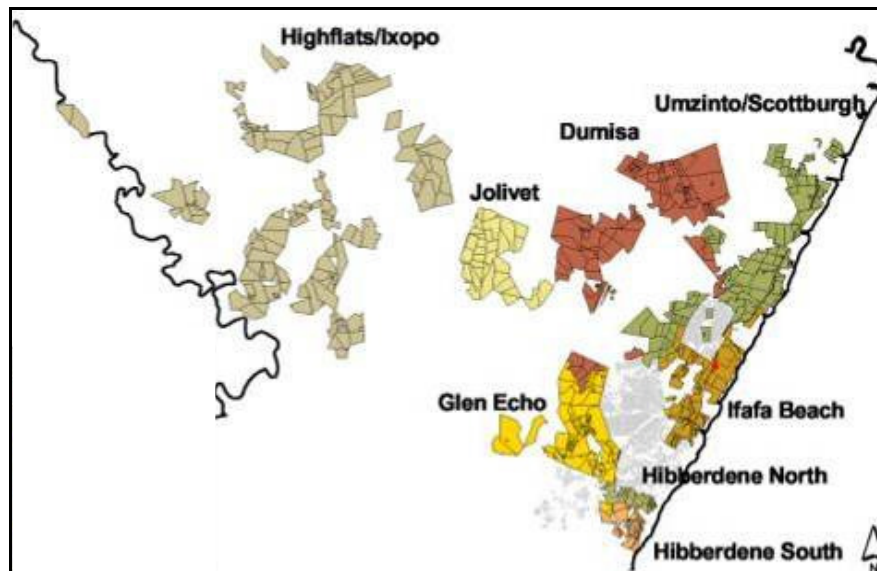


Figure 2.2 The eight sugarcane growing regions within the Sezela mill area (Tedder, 2004).

The Sezela Mill was selected as the case study area because data pertaining to transport, harvesting and mill operations was readily available. In addition, a good relationship existed between the School of Bioresources Engineering and Environmental Hydrology at the University of KwaZulu-Natal, the members at the mill, and the growers and hauliers in the area. Also, several previous studies relating to transport had been conducted in this mill area, such as Barnes *et al.* (1998) and Le Gal *et al.* (2003) and those conducted by SASRI since the early 1990's (Lyne, 2004).

Sugarcane in the Sezela mill area is farmed over an area of 42 507 ha, of which approximately 30 000 ha is harvested per year (Table 2.1). Farmers can be broadly categorised into large-scale commercial farmers and small-scale farmers. The commercial farmers, of which there are 164 in the Sezela mill area, can be subdivided into Miller-Cum-Planters (MCPs) and title deed farmers. The MCP farms are those that are owned by the milling company and are farmed by their own farm managers. These few MCP farms supply approximately 20% of sugarcane delivered to the mill. The balance of the commercial large-scale farmers account for approximately 70% of the mill supply.

Table 2.1. Properties of the Sezela Mill and mill area (Simpson, 2004).

Total area under cane	42 507 hectares
Area harvested	±30 000 ha or 70%
Number of large growers (including MCPs)	164
Number of small growers	±2442
Miller-cum-Planter (MCP)	19.5% of supply
Large growers	70.7% of supply
Small growers	9.8% of supply
Average tons crushed per season	2.2 million tons
Normal season length	37 weeks, complete before Christmas

The MCPs and commercial large-scale farms are responsible for the bulk of the high quality cane delivered regularly during the milling season. The remaining cane supply, of the order of 10%, is grown by small-scale farmers and is typically of lower yield and quality (Simpson, 2004).

For various reasons, on which this review will not attempt to elaborate, South African sugar mills regularly experience a situation of over or under-supply. To minimise deterioration of the harvested sugarcane, and to help balance supply and demand within the Sezela mill, sugarcane is diverted from and to neighbouring sugar mills at a cost to the miller. Figure 2.3 shows, in percentage terms, the origins of cane crushed at Sezela for the 2003/04 milling season. Sezela, due to its excess design milling capacity, rarely diverts cane to neighbouring mills, but rather accepts a significant percentage of sugarcane from the Eston mill area, and lesser amounts from the Noodsberg and Union Co-operative mill areas. During the 2003/04 milling season, 13% of the cane crushed at Sezela mill originated from neighbouring mill areas (Crickmay, 2003 and Simpson, 2004).

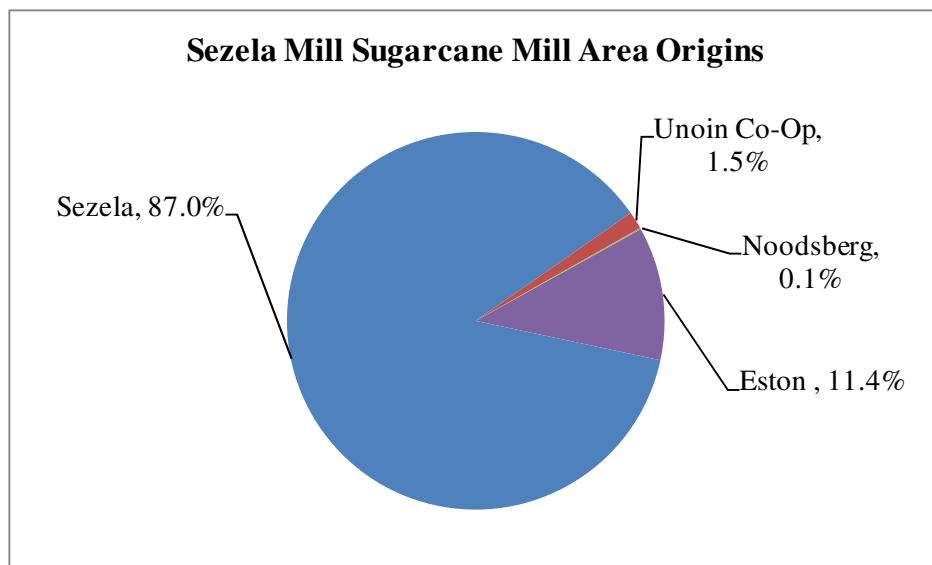


Figure 2.3. The origins of cane deliveries at Sezela mill during the 2003/04 milling season (Simpson, 2004).

The flow of sugarcane from farms where it is harvested, extracted, loaded, transloaded, and transported to the Sezela Sugar Mill, where it is processed, is shown in Figure 2.4. This complex and varied system, with further sub-systems, is discussed in the following sections:

- Section 2.3 contains a description of the most common forms of harvesting, extraction and loading of sugarcane.
- Section 2.4 contains a description of the road transport system that forms the focus of this review.
- Section 2.5 contains a description of the millyard and mill operations, including sugarcane offloading and testing, are described and discussed.

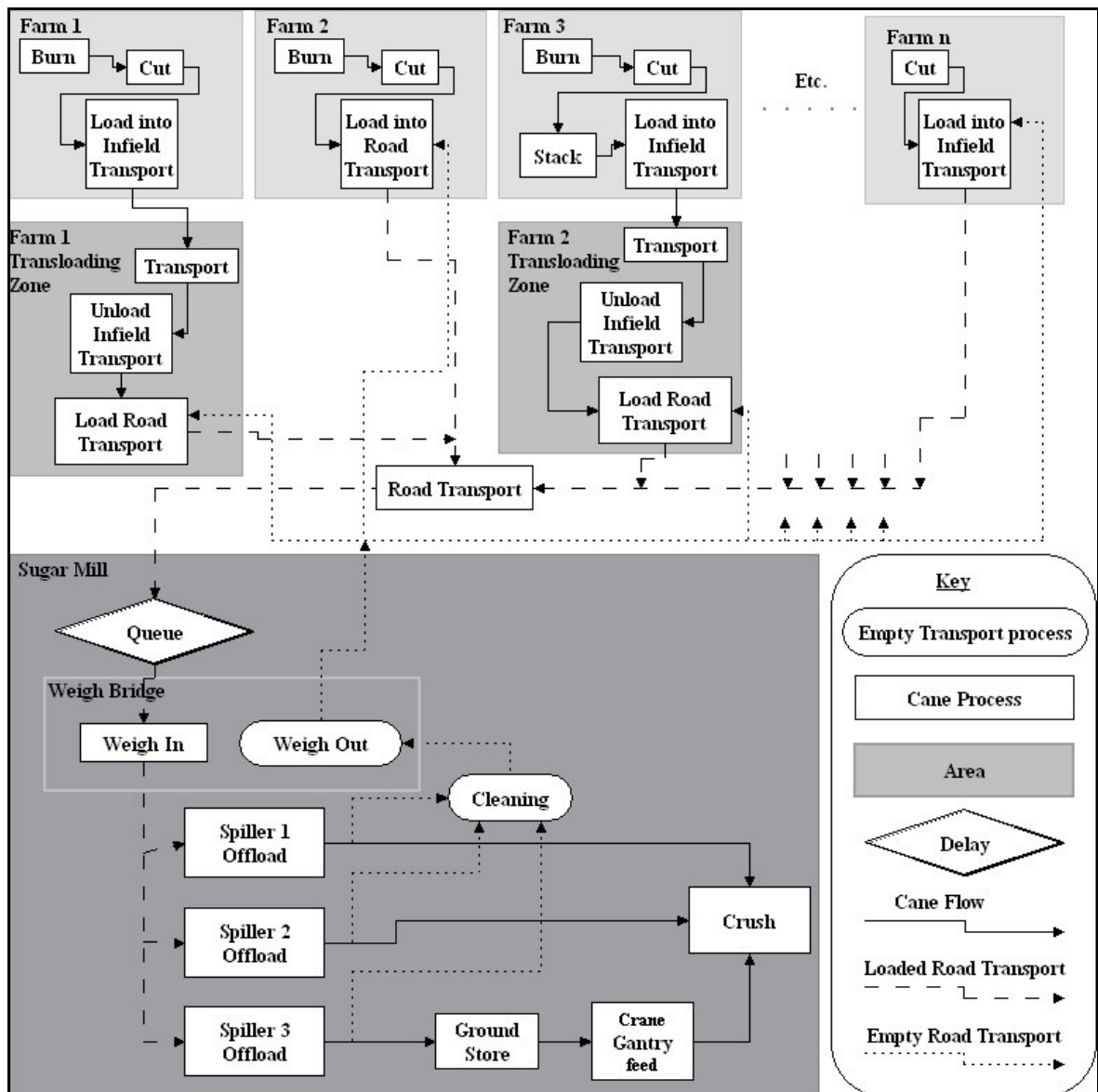


Figure 2.4 A flow diagram detailing the harvest, transport and millyard operations with regard to the flow of sugarcane (after Barnes *et al.*, 2000).

2.2 Harvesting , Extraction and Loading Systems

The process of harvesting normally begins by identifying a block of cane defined as a demarcated area separated by fire breaks, to be cut. This is then burnt by a controlled fire to remove the majority of the leaves from the sucrose-containing stalk (upper most area of figure, Farms 1 through 3, shown in Figure 2.4). Burning is typically performed in the early morning or late evening when conditions are less conducive to runaway fires.

A portion of the cane in the Sezela area is not burnt before harvesting (Farm n, Figure 2.4), and is harvested unburnt and is termed trashing or green harvesting. Trashing is practised where it is desirable to reduce the harvest-to-crush delay, and thus the accelerated deterioration associated with burning. Trashing is also used when weather conditions are not suitable for burning, such as rainy or windy periods, or where local legislation prohibits burning.

Harvesting is usually performed by teams of semi-skilled labourers who use a specifically designed cane knife to cut the stalks as close to the ground as possible. This is because a significant amount of the sucrose is stored in the lower portion of the stalk. The labourers cut off the topmost immature portion of the cane stalks in a process known as topping, and the stalks are then placed in windrows which are multiple rows of cut sugarcane accumulated into one larger continuous row facilitating efficient loading or are accumulated in stacks which are discrete piles of sugarcane of approximately 5 tons.

Not all cane is cut manually, with a small proportion being cut by mechanical self-propelled harvesters that are capable of harvesting both burnt and green cane. This method of harvesting is becoming increasingly popular, but is currently not used in the Sezela mill area.

After cutting, a number of different transloading processes may occur, depending on the system the farmer chooses to operate, the properties of the farm and the distance to the mill. These are:

- i. If the cane is manually cut and stacked, a tractor-drawn self-loading trailer will load the stack and transport the cane to a transloading zone. Here several stacks are accumulated for loading by mobile crane for later transportation to the mill by specifically designed long-haul on-road trucks.
- ii. If the cane is manually cut and windrowed, a grab loader will normally:
 - a) load the cane into basket-type trailers drawn by an agricultural tractor that will, depending on lead distance to the mill, travel either directly from the field to the mill or travel to a transloading zone, or
 - b) load straight into a modified long-haul on-road truck that will travel from the field directly to the mill.

Cane brought to the transloading zone is delivered in one of two forms, depending on whether method (i) or (ii-a) is used. In the case of (i.) the cane is held in bundles on the transloading zone by chains used in the self-loading trailer process. This cane is loaded by cranes into specifically designed on-road trucks that transport the cane directly to the mill. In the case of (ii-a) the cane is typically accumulated in a large pile on the zone. It is loaded by a grab loader into on-road trucks that transport the cane directly to the mill.

2.3 Road Transport

Within the Sezela mill area, in excess of 120 different vehicles are operated by approximately 22 different hauliers who transport sugarcane to the mill which range in age, configuration, payload, engine power, braking ability and management policies for numerous historical, political, economic and personal reasons (Crickmay, 2003 and Simpson, 2004). The road transport begins at the grower's farm where the vehicle is loaded, either infield or on the zone, depending on the loading practices chosen by the grower, and terminates at the offloading points at the mill as shown in Figure 2.4. At the time of this study, the transport vehicles at Sezela ranged in age from 1969 to 2003 models. Figure 2.5 shows the age distribution in percentage terms, of vehicles in use. This information was captured from a telephonic survey and is described further in Chapter 3.

A description of the vehicle configurations and payload, including the effects of engine power and braking ability, on the transport system are included in the sections below. The delays incurred in a typical transport operation are discussed and a brief summary of the various management practices follows.

2.3.1 Vehicle Configurations and Payload

At present a wide variety of vehicle configurations with associated payloads transport sugarcane into mills in South Africa. These range from the multipurpose agricultural haulage tractor to specifically designed cane hauling trucks, such as the interlink and rigid-and-drawbar configurations.

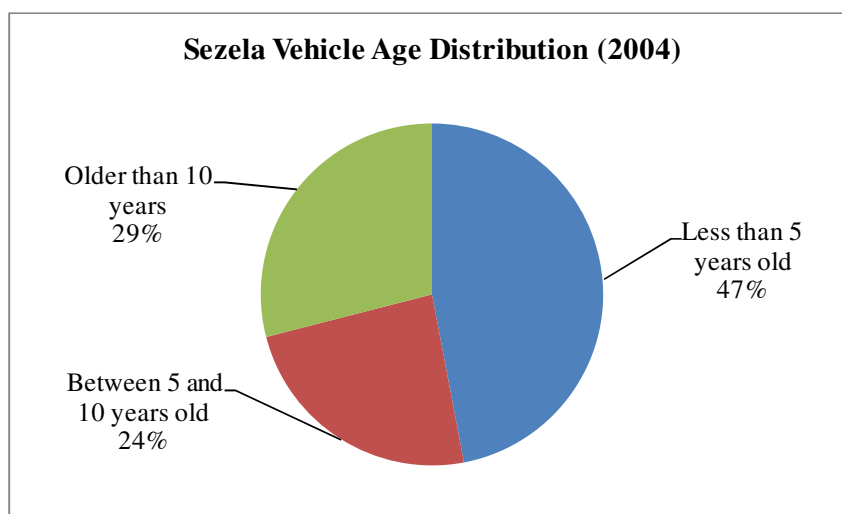


Figure 2.5 The age distribution of vehicles delivering cane to Sezela mill at the time of this study.

With reference to Table 2.2 and Figure 2.6, historically no single choice of power unit and trailer is the universal choice. The selection is seemingly a function of the lead distance to the mill, cane tonnage to be transported per season, cost of the vehicle and whether infield or zone loading was preferable. Further additional factors influencing the choice of vehicle, such as a minimum payload requirement at the mill, whether the vehicle will be used in the off-crop season for other purposes and the terrain on which the vehicle will be operating, also exist but are of lesser importance than the points mentioned previously. To demonstrate this, each of these factors can be broadly divided further. The tons weighted average lead distance of the sugarcane to be transported can be divided into short leads (less than 10 km), intermediate leads (between 10 and 60 km) and long leads (more than 60 km). Slower moving agricultural tractors with lower payloads are typically used for short leads, with relatively fast and high payload double trailer (interlinks) and rigid-and-drawbar configurations being used for intermediate and long leads. The total tonnage to be transported is significant in that, for a given tonnage, the higher the payload the fewer trips will be needed. Small tonnage would be of the order of less than 5000 tons, moderate tonnage between 5000 and 20 000 tons, and large tonnage more than 20 000 tons per annum. Once again, for small tonnages an agricultural tractor would be appropriate, while interlinks and rigid-and-drawbars are used for large tonnages. The cost of the vehicle is important and therefore choice is a function of the financial position of the buyer. Whether the unit could be used to perform other operations on the farm, or to transport other goods would dilute the fixed costs and could be a contributing factor. The cost of vehicles varies significantly, from the relatively low cost multipurpose agricultural tractor and trailer, to the dedicated rigid-and-drawbar cane truck costing well

over R1 million. The loading strategy of the grower will influence the choice of vehicle, as only certain vehicles are capable of transporting cane from the field due to traction requirements, stability and soil compaction. Typically, only agricultural tractors, and in some cases rigid-and-drawbar vehicles, load infield due to their inherently better tractive ability.

Table 2.2 A categorisation of the factors affecting the choice of sugarcane transport vehicle (Crickmay, 2003).

Factor	Category		
	Short	Intermediate	Long
Lead distance	Short	Intermediate	Long
Cane supply tonnage	Small	Moderate	Large
Capital investment	Low	Medium	High
Loading strategy	Infield	Zone	

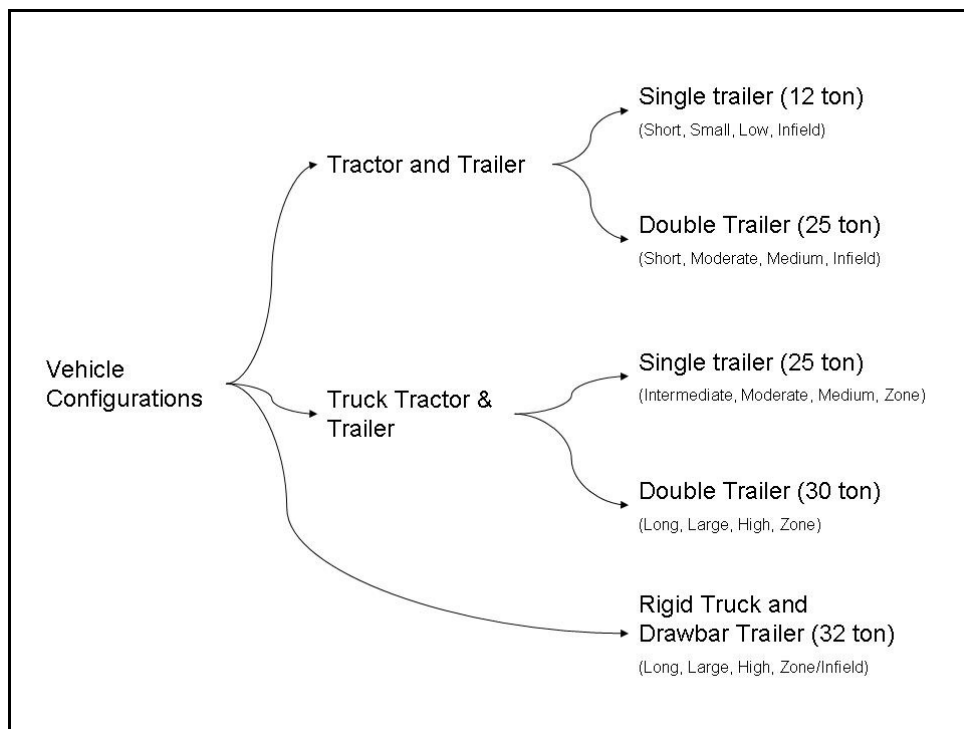


Figure 2.6 A summary of the common vehicle configurations used to transport sugarcane in South Africa (Crickmay, 2003).

The double trailer-tractor configurations are appropriate when operating infield at a short lead distance where significant tonnage needs to be transported, whereas the single trailer-truck tractor is applicable for zone loading at intermediate lead distances where moderate tonnages are being transported.

2.3.2 Vehicle Power and Braking Systems

For a given vehicle mass, the greater the power of the vehicle's engine, the faster it can travel and therefore deliver the load to the mill, consequently reducing cycle time and increasing the productivity of the vehicle.

$$T_c = T_i + T_f + T_o + T_l + T_d \quad (2.1)$$

where

- T_c : cycle time,
- T_i : inbound travel time,
- T_f : offload time,
- T_o : outbound travel time,
- T_l : load time, and
- T_d : delays.

The maximum speed of the vehicle is determined by legislation, road conditions and safety. Road surface condition restricts the speed of the vehicle, since poor road conditions could cause significant damage to the vehicle. In contrast, a well maintained, smooth surface produce negligible damage to the vehicle and also allows higher travel speeds. The camber and super-elevation of the road on corners limit the speed in most cases. For example, a correctly selected super-elevation would allow for maximum speed through the turn, but a poorly selected super-elevated corner would require a reduction in speed if the vehicle is to avoid overturning. A largely super-elevated road corner is not always desirable as a vehicle needs to be stable both when in motion and when stationary. A high centre of gravity, and thus the overturning moment, may be negated by the sideways force generated as the vehicle rounds corners, but will cause the vehicle to overturn when stationary.

Road gradient is another factor that significantly affects the speed of the vehicle and therefore its cycle time. In the case of a straight uphill climb and for a set of gear ratios, the speed would be determined by the power of the vehicle; the greater the power of the engine, the higher the uphill speed. When

descending, the speed is governed by the ability to maintain a safe, lawful speed and to safely stop the vehicle in an emergency. Various systems exist to increase the braking ability of the vehicle, especially for prolonged periods of time as in the case of a long, steep downhill descent. Here, pneumatic actuated brakes, using mechanical friction to slow down the vehicle, can overheat and become inadequate and dangerous.

To allow for faster downhill speeds, and in addition to the pneumatic brakes fitted to the vehicle, an exhaust brake is normally included. This has the effect of slowing down the engine, and thus the vehicle, without using the pneumatic brakes. The pneumatic brakes are then reserved for emergency braking only. Retarders and intarders are two of many devices designed to achieve the same safe braking potential. They give the driver an independent method of slowing down with the ability to stop in emergencies. This prolongs safe braking ability and allows the vehicle to travel faster on down slopes. In the past, when pneumatic brakes alone were used, the only way to achieve a safe descent was to select a low gear ratio and maintain a safe, slow descent speed, while still having the pneumatic brakes in an emergency.

2.3.3 Vehicle Management Strategies

There are no cases in South Africa where the mill manages all the vehicles that deliver cane. Vehicles are managed mostly by the individual hauliers themselves. Examples exist in Mpumalanga where a small proportion of the fleet is owned by the mill, but this is certainly not the case at Sezela. Haulier management strategies within the Sezela mill area differ, and the broad categories depend on whether the vehicle is owned and operated by a contract haulier, or by a grower (grower-cum-transporter).

Generally, in the case of the contract haulier, high vehicle efficiencies are vital as they determine the profitability of the business. Management typically strives to reduce long-term costs and increase throughput per vehicle in an ongoing fashion, thus minimising the transport cost per ton of cane. They operate on a relatively strict time schedule and organise regular, as well as preventative maintenance, to minimise downtime caused by mechanical failures.

In contrast, several growers choose to transport their own cane. They believe that the apparent cost saving realised by doing this is significant enough to justify the financial investment and management demand. Often this choice is due to a desire for flexibility with regard to their harvesting and

transloading operations, which may not be as convenient when using a contract haulier. Vehicle utilisation is normally lower, as are levels of management and preventative maintenance.

Examples do exist in contrast to these two generalisations. Some contract hauliers have old, low utilisation vehicles, and some grower-cum-hauliers have significant tonnages and thus can operate vehicles at high utilisations (Crickmay, 2003).

2.3.4 Time Delays Encountered in Sugarcane Transport

Within each individual delivery cycle, time delays vary from nil to a few hours at some South African mills. Delays are highly undesirable as they decrease utilisation and thus the tonnage transported per vehicle per season. This ultimately results in more vehicles being needed to transport a given amount of sugarcane, and increases the cost per ton.

The time delays of interest to this study are those that occur when loading, en route to the mill, queuing at the weighbridge, unloading at the spillers (including vehicle cleaning) and travelling to the following loading point (Figure 2.8).

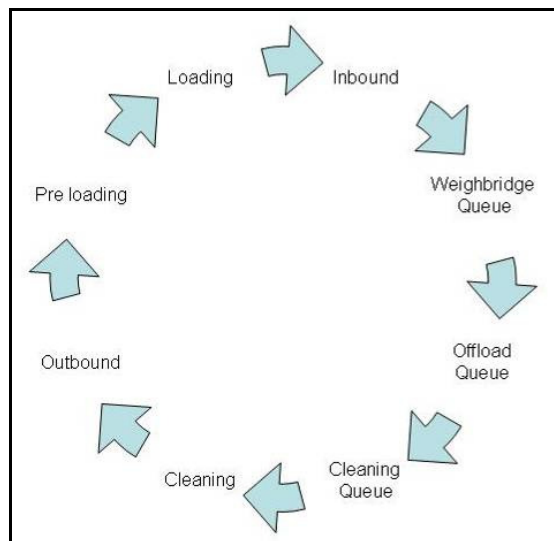


Figure 2.7 The operations at which delays may occur within each sugarcane delivery cycle.

A loading delay is any time over the required time to fully load the vehicle within a predetermined loading window. Delays at the loading point may be caused by loading equipment malfunction or loader operator delay. Equipment malfunction can be caused by mechanical failure or getting stuck.

Loader delays may be caused by insufficient training of the loader operator. Insufficient cane to supply the entire payload is a common cause of loading delays on the zone, and can be due to poor management and/or unavoidable circumstances such as bad weather. Delays incurred before loading commences are also common, and are often due to loaders not being available or a truck being dispatched to a zone/infield before the load is ready. Alternatively, more than one vehicle may be dispatched in close succession to a single zone which does not have the capacity to load multiple vehicles concurrently.

Delays can occur during both inbound and outbound trips, and can be caused by inclement weather, road maintenance taking place and road accidents. These occur randomly and can be dealt with only by good management. Delays also occur when drivers stop for reasons other than those detailed in their contracts.

Queuing delays outside the mill at the weighbridge occur due to the uncoordinated arrival patterns between hauliers and within hauliers themselves, relative to the fairly constant rate at which the vehicles can be offloaded by the mill. To demonstrate this fact and with reference to Figure 2.9, the individual arrival pattern of the largest haulier in Sezela on Wednesday, Week 18, 2005, can be seen to be highly variable. The number of arrivals per hour varies from one to ten, with an average of five. The level of scheduling of vehicle arrivals within specific hauliers is often primitive. Scheduling in the Sezela mill area is done by individual haulier controllers, and is inaccurate, ineffective and cumbersome.

Individual haulier arrival patterns at the mill are not necessarily the only factor affecting queuing delays; the combination of arrival patterns of all the hauliers relative to the mill offload rate is important. Figure 2.10 describes the cumulative effect of all the haulier arrival rates is highly variable relative to the offload rate of approximately 14 vehicles per hour. Thus, during periods of excessive arrivals, for example during the middle of the day, queuing is inevitable. For the 2003/04 milling season at Sezela, the average mill queue time outside the mill was 1,14 hours per delivery (SLIP database, Crickmay, 2003).

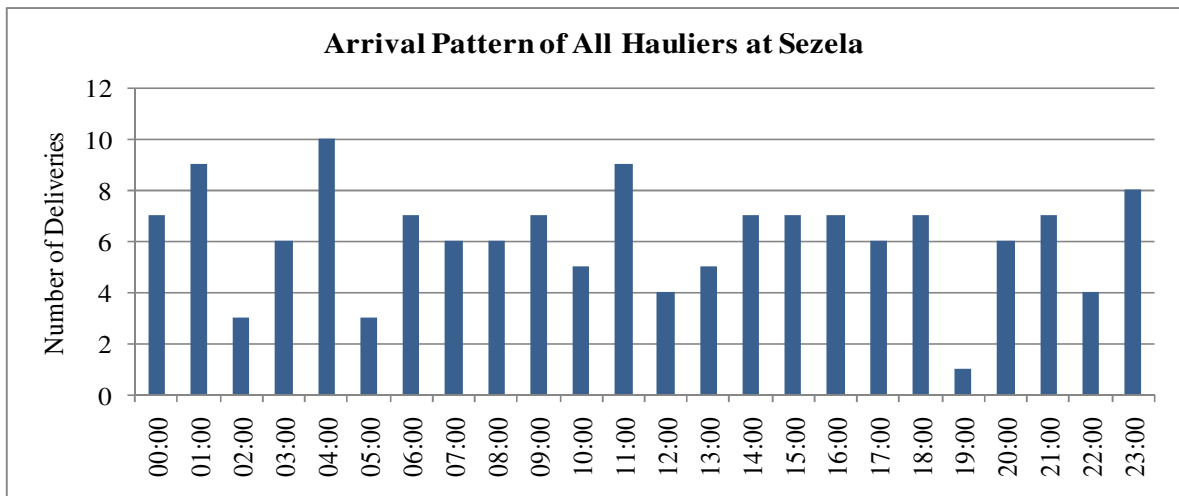


Figure 2.8 The irregular pattern and number of a major haulier’s vehicles crossing over the weighbridge at Sezela mill over a 24-hour period on a Wednesday in week 18, 2005 (after SLIP database, Crickmay, 2003)

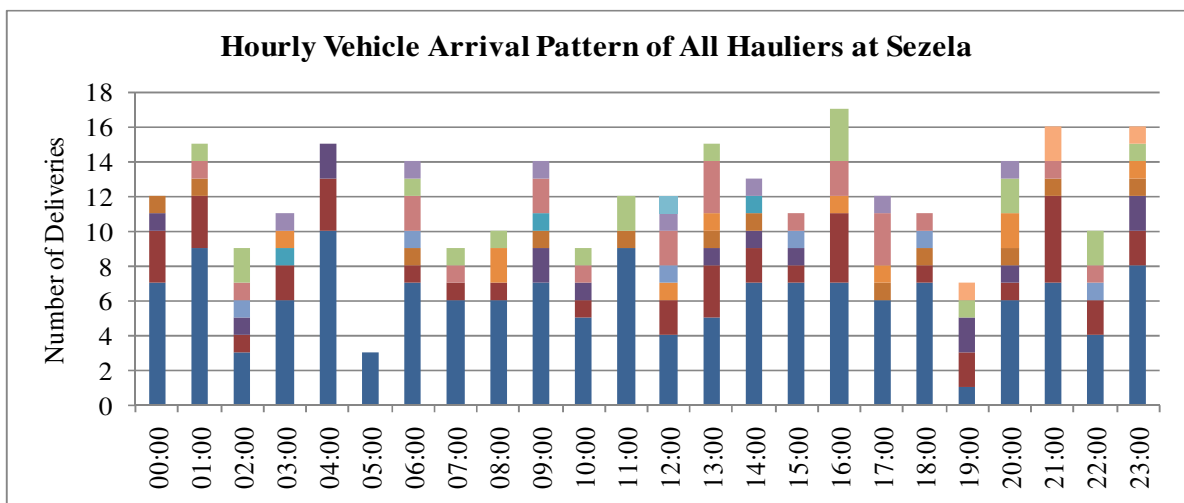


Figure 2.9 The individual haulier arrival pattern (each haulier shown as different colour) at Sezela on Wednesday, Week 18, 2005 (after SLIP database, Crickmay, 2003).

Delays sometimes occur at the spiller offload points in the Sezela millyard. The mill requires a constant feed of cane and cannot tolerate gaps in supply. The strategy of the weighbridge clerk is therefore to create a short queue of two vehicles at the spiller, thus ensuring that as one vehicle leaves the spiller, another will immediately replace it and begin offloading.

There are also significant delays in the post-offloading cycle, due to vehicles needing to be manually cleaned of cane not offloaded in the spilling process. Hand cleaning of leftover cane stalks is the result of incorrect loading or using incorrect lengths of spilling chains, which are used to eject the load. The necessity for hand cleaning can be reduced through correct management. Further delays may be incurred at the cleaning bay when a large quantity of sugarcane needs to be removed from a single vehicle, and a queuing situation arises due to the series cleaning strategy at the cleaning bay.

Significant delays can also be caused by driver shift changes. Not only is time lost due to the process of driving to the haulier depot and performing the driver change-over (e.g. 30 minutes), but is also lost prior to the change-over because of fixed shift change times. i.e. a vehicle will not be sent on a trip if that trip will not be completed by shift change time. This is because hauliers wish to avoid paying overtime to the drivers, and the drivers having to use public transport to and from work. Therefore a significant amount of time is lost not only during the shift change, but also over the period that the vehicle stands waiting for the next shift driver to arrive. Another source of delay is the 'go slow' strategy used by drivers towards the end of a shift in an attempt to avoid being sent out on another trip.

2.4 Millyard and Milling Operations

Any vehicle delivering sugarcane to the mill must be registered with the Sezela Cane Supply Department. Information on each vehicle, trailer(s) and owner/operator is stored. Each vehicle is issued with a transponder (a remote identification device using radio technology) that is carried in the vehicle cab. Each transponder is unique and contains sufficient information to identify the vehicle. This data is stored in a database known as the Laboratory Information Management System (LIMS), which holds all pertinent information regarding growers, agronomics, harvesting, transport and cane quality specific to each vehicle load. LIMS is accessible at strategic points throughout the mill and is updated on a near real-time basis as loads are processed through the mill.

Access to the weighbridge is not coordinated and operates on a 'first come, first served' basis as described in Chapter 2.3.4. A system of three queues existed in the past: one for a prominent commercial haulier, the second for bundled cane and a third for other hauliers and growers who transport their own cane. The system was abandoned for various reasons, including violent behaviour between drivers who were under pressure to deliver (Simpson, 2004).

Under the 'first come, first served' basis and with little coordination of vehicles within and between hauliers, queuing at the weighbridge is inevitable. The queue at Sezela can be seen clearly in grid blocks A2 and B2 in the aerial photograph shown in Figure 2.11. On arrival at the mill, it is compulsory to scan the transponder at a checkpoint located approximately 150 m from the mill gate (top left corner of quadrant A3). This allows for calculation of a queue time for every vehicle, given that the queue does not extend beyond the transponder receiver. This information allows the mill operators to plan ahead, knowing what cane can be expected in the near future, and can also be used in studies to aid strategic decisions.

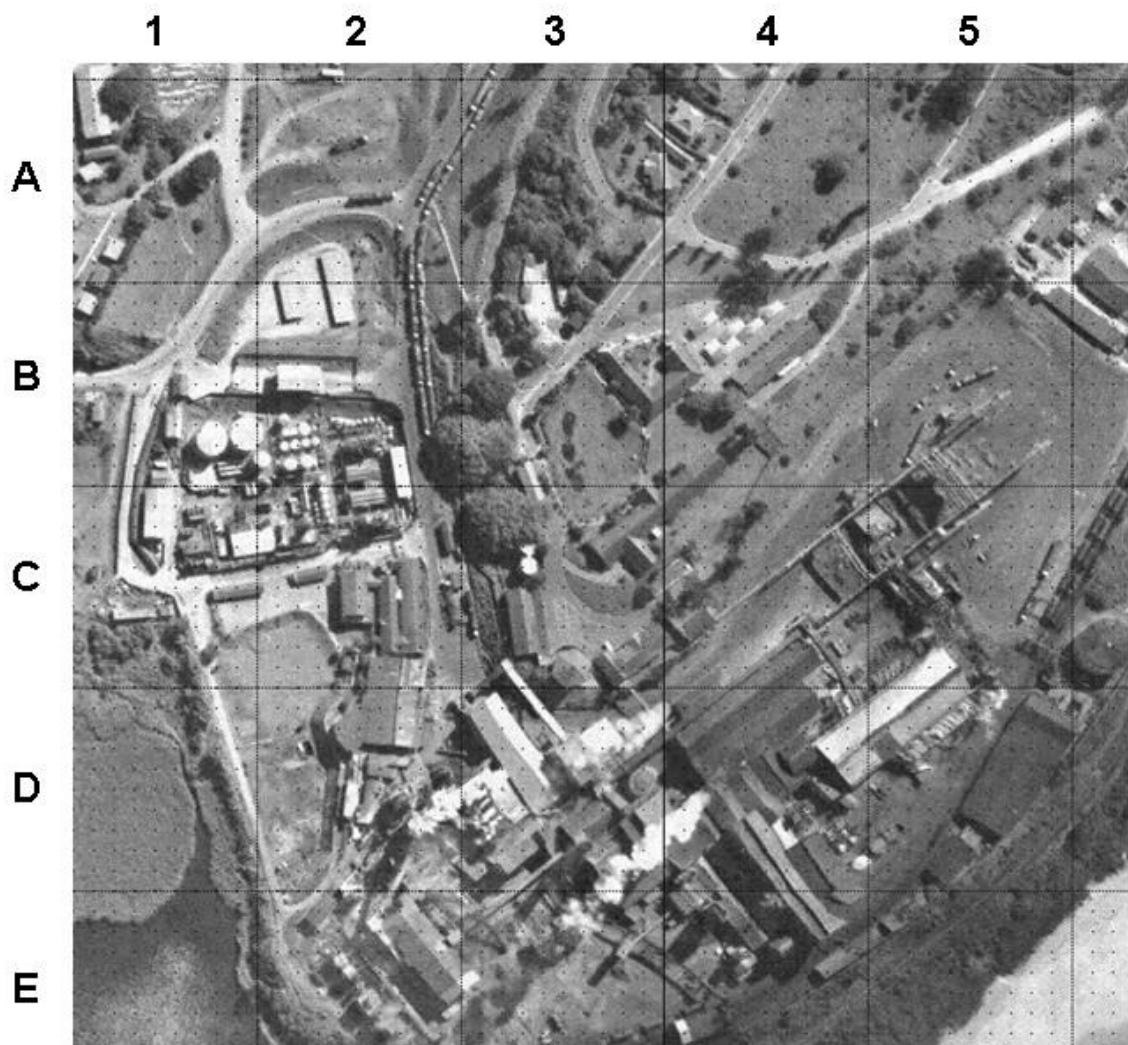


Figure 2.10 An aerial photograph of Sezela Sugar Mill showing the mill infrastructure, vehicles waiting and offloading (Simpson, 2004).

When a vehicle reaches the front of the queue it is signalled to move forward onto an automated weighbridge ('Weigh In' in Figure 2.5; top right grid block C2, Figure 2.11). The rate at which vehicles are called depends on the mill's current crushing rate, and whether the cane supply manager wishes to create a stockpile inside the millyard. The stockpile is used to buffer low delivery periods (cf. Figure 2.9, Hour 5). Each load arriving at the mill is accompanied by an information card. Information such as grower code, transloading zone number, burn date, harvest date, cane variety are reflected on the card. This information, along with the load mass, is used for grower payment purposes.

As a truck leaves the weighbridge, it is directed to one of four offloading points: a bundle offloader crane gantry (central C4), the east spiller offloader (central C5), the west spiller offloader (intersection B4 and B5 and C4 and C5) or the dummy spiller offloader (central B5). Because this system is becoming less popular, only a few vehicles use the bundle offloader crane gantry, which is presently being phased out (Simpson, 2004). The east and west spillers are devices that offload spiller type trailers by hoisting a removable bar on one side of the trailer and rolling the load out upwards and sideways (Figure 2.12). The load falls directly onto the spiller table located next to the parked vehicle, which conveys the cane into the mill for crushing. The dummy spiller is identical, but offloads onto a concrete stockpiling area. This stockpile is fed into the mill by a large rubber tyre grab loader or by an overhead crane gantry fitted with a high capacity cane grab.

After offloading, the empty vehicles are cleaned of any remaining loose cane (top right B5). This not only ensures that all the cane is emptied at the mill, but also helps to minimise unsightly and slippery spillage on the roads during the outbound trip.

Vehicles are again weighed when leaving the millyard so that the payload mass can be calculated. This is the difference between the laden and unladen mass of each vehicle.



Figure 2.11 An example of a spiller offloading a load of cane onto the spiller table (Simpson, 2004).

Through a process of negotiation between the growers and the miller, a milling season length is agreed upon. Length of Milling Season (LOMS) usually ranges between 32 and 38 weeks, and ideally ends before Christmas (25th December). It is a function of grower cane yield estimates, historical data and modelling procedures. From this information, a daily quota, or Daily Rateable Delivery (DRD) is calculated for each grower, based on estimated mill crush performance figures and probable days of lost milling, due to instances such as rain. DRD is the quantity of sugarcane each grower is committed to deliver to the mill per day. This should ensure that the mill has a uniform inflow of fresh cane for the period that it is operating, and should enable the grower to draw up a harvesting roster and plan off-season farm operations. Growers DRDs are reviewed weekly and updated monthly as the season progresses, as a function of mill performance and estimated cane quantities yet to be harvested. This approach, although practical, is fundamentally flawed from the perspective of vehicle scheduling, in that the mill is highly sensitive to variable cane supply on an hourly basis and DRD, by definition, is on a daily basis.

DRDs can be accumulated amongst growers in order to form harvesting groups, and can be temporarily adjusted in consultation with the mill area legal authority (the Mill Group Board) in extenuating circumstances, such as in the case of cane burnt in run-away fires or damaged by severe frost.

Payment to the grower for cane delivered is based on an indicator which assesses the potential amount of sucrose that can be extracted from the cane. This is known as the Recoverable Value percentage (RV%), and is multiplied by the tons delivered, and the current RV price to calculate the payment to the grower. Potential sucrose recovery is measured by an independent body, the Cane Testing Services (CTS), which samples 67% of all cane consignments entering the mill. Samples are taken within the mill and an accurate tracking system has been devised to link the sample to a specific consignment. In South Africa, the monetary value of the cane to the grower is based not only on the sucrose content of the cane, but also on the non-sucrose and fibre contents.

2.5 Chapter Discussion

Approximately 2 500 registered growers deliver sugarcane to the Sezela mill, which is one of the largest in the South African sugar industry. Cane is delivered by 22 hauliers with different business objectives. A complex and ultimately costly system exist comprising the multiple systems of harvesting, loading and transloading, and in transport vehicle configurations, payloads, power and braking systems.

Although these constraints result in a challenging system to manage, none of them prevent the efficient coordination of the system but rather due to the lack of coordination between hauliers, and between growers, the miller and hauliers, significant delays are incurred within the transport cycle as each individual haulier attempts to deliver 24 hours per day, to a mill which offloads at a relatively constant rate. It becomes apparent that there is a need for a single controller who, using a relatively sophisticated scheduling tool, will be able to manipulate vehicle loading and delivery patterns for each haulier. This system would minimise delays and increase the cost effectiveness of the entire operation.

3 COSTING OF THE CURRENT SEZELA TRANSPORT SYSTEM

For a typical sugarcane grower in South Africa, transport expenses are high and amount to approximately 20-25% of production costs (Giles *et al.*, 2005). Costs include maintenance, labour, fuel, administration, licensing and insurance. For the purposes of this study at Sezela, grower-cum-transporters are defined as those who haul cane not for profit, i.e. their own cane or on a partnership basis. Commercial hauliers haul cane for profit. The difference is reflected in the overhead costs of the vehicle, and is usually lower in the case of the grower-cum-transporter. Often this occurs because many of the overhead and management costs are incorporated into other farm management costs.

This chapter aims to briefly discuss the costing of the current Sezela transport operation, including the individual costing components comprised of the fixed and variable costs of the transport vehicles. Through the use of telephonic surveys, the distribution of vehicle age, amongst other costing inputs, was used to estimate the present cost of transport per annum in Sezela. The present transport system cost estimate provides a benchmark against which the scenarios of central scheduling, loading time reduction, offloading time reduction, vehicle power decrease and payload increase, can be compared (*cf.* Chapter 7).

Throughout this chapter much of the information has been drawn from consultants and experts at Hellberg Transport Management, Unitrans Sugar and Agriculture, South African Sugar Research and Kevard Sugar.

3.1 Fixed Costs

The fixed costs associated with any vehicle are those that are incurred whether the vehicle is being used or not. These costs can be proportioned over the tons transported or over the kilometres travelled per annum, or both. Therefore, the more tons transported and/or kilometres travelled, the more the fixed costs are diluted and the lower the cost of transporting a ton of sugarcane. The components that constitute the fixed costs are: capital cost of buying the truck-tractor and trailer and associated interest/cost of capital, wages, insurance fees, licensing fees and overheads costs.

The capital cost is the cost of purchasing a truck-tractor and a trailer and is usually depreciated over a period of 3-5 years, with a residual value of 0-40% of the purchase price. Although some vehicles are bought outright, in many cases they are purchased on an instalment basis. In both cases there is a cost over and above the vehicle purchase price that is calculated as either the interest rate quoted by the lending institution, or the opportunity cost of capital (interest that could have been earned if the capital was invested). In both cases the interest is calculated on the remaining balance.

Driver and driver assistant wages vary significantly across the sugar industry, and depend on the size and type of vehicle, the shift duration, task complexity, remuneration packages, experience and whether the transport operation is of a commercial nature or grower-cum-transporter. For a given day, two or three shifts are operated with different drivers for reasons of fatigue and legislation.

For the purposes of this study, two groupings of wage packages are assumed: (i) commercially aligned wages as determined by the National Bargaining Council (NBC) (which include uniforms, unemployment package, overtime and driver assistant wages) and (ii) farm labourer wages. The wage component of the cost of transport is one of the items that varies significantly between commercial hauliers and grower-cum-transporters. Drivers are typically paid only for the harvest season (approximately 8-10 months), but in some cases are paid a retainer for the balance of the year.

The cost of insurance of both the truck-tractors and the trailers varies considerably. The magnitude of the monthly insurance premium is a function of various factors, for example risk profile and risk history, onboard tracking technology and driver training. Haulier insurance can be broadly categorised as those who self-insure, and those who insure with a contracted broker. Generally, the larger commercial hauliers self-insure, and the smaller hauliers and grower-cum-transporters insure with an insurance broker. The insurance cost per annum can vary from a few percent to as much as 10% of revenue earned.

Licence fees for the truck-tractor and each individual trailer need to be paid annually, and are a function of tare weight (unladen mass) and licensing province.

Overhead costs are associated with the running of the transport operation. These costs vary significantly according to whether the operation is of a commercial nature, or is a grower-cum-haulier operation. Typically, overheads constitute approximately 25% of the fixed cost of the vehicle in the case of a commercial haulier, and approximately 10% in the case of a grower-cum-transporter.

Overhead costs include radio fees, traffic fines, computer expenses, ancillary vehicles, building costs, telephone, lights, water, vehicle washing, tyre handling, stationery, tachometers, accounting services, advertising, marketing, vehicle maintenance staff, managers, clerks, fleet controllers and sundries.

3.2 Variable Costs

Variable costs are incurred only when the vehicle is used for transporting product. This includes both the laden and unladen travelling costs, as well as the costs associated when the vehicle is idling. The variable costs include: fuel, top-up lubricants, tyres and maintenance.

Fuel consumption is mainly a function of terrain and the power of the truck tractor, but is quoted by the manufacturer under normal operating conditions. The quoted amount should be inflated by approximately 10% to account for the nature of a short haul operation, and for the rough terrain over which the vehicles drive very slowly. Prices include the bulk rebates provided by government, and are a function of distance from Durban from where the fuel is distributed.

Tyre wear is a function of kilometres travelled, but can be accelerated by poor road surface conditions. Although retreads are used extensively within the sugarcane transport industry because they are significantly cheaper, new tyres are always used on the steering axel for safety purposes.

Both preventative and corrective maintenance is provided either 'in-house' by the haulier, or contracted out in the form of a Full Maintenance Lease (FML). Commercial hauliers and grower-cum-transporters use both options, although the larger hauliers tend to perform their own maintenance.

For the purposes of this study, the variable cost component does not include toll fees and permits, nor does it include any other expenses such as tracking, engine protection or other optional equipment.

3.3 Methods for Calculation of the Cost of the Current Transport System

Considerable data were utilised for the calculation of the present cost of transport in Sezela. The sources, grouping and brief description of the data are provided in this section. Details are discussed in further subsections. Calculations of these costs were performed externally by a consultant (Maxwell, 2004) using the Unitrans in-house operating cost model with certain specific inputs provided by the author after being provided access to various hauliers confidential accounts. This provided the most

accurate and meaningful cost figure as the model is used frequently, both operationally and for consulting purposes within the South African sugar industry.

A telephonic survey of all the hauliers in the Sezela area was performed to capture information regarding the age and make of each vehicle. The survey excluded vehicles that were no longer in circulation due to either being sold or having been in a significant accident or that service small scale growers only, or deliver diversion cane only. These data, along with associated data from the LIMS 2003 database, were categorised by age and by commercial haulier or grower-cum-transporter. The age categories were: (i) vehicles of less than five years of age, (ii) between five and ten years of age and (iii) older than ten years.

This 3x2 matrix was further interrogated to find the median age in each category, the total tons transported per vehicle for the 2003 season and the tons weighted average lead distance for the vehicles in that set.

Other information was provided by Unitrans personal who are specialists in the field of sugarcane transport costing. Information that was gathered from other experts within the transport sector includes vehicle and trailer prices, tyre prices and typical life spans, fuel prices and maintenance rates. Certain grower-cum-transporters provided confidential information to the author detailing the costs of their transport operations (Cole, 2004). All these costs were synthesised and are reported in the sections that follow.

3.3.1 Fixed Cost Inputs

The value of a typical truck-tractor is mainly a function of the age and make of the vehicle. Based on the median age (cf. Chapter 3.4.1) of vehicles within each of the six sets discussed previously, values were sourced for typical truck-tractors and trailers. Values were obtained from Mercedes Benz, as this manufacturer is the most prominent in the Sezela area (Table 3.1). The value of the trailers is more a function of condition than of age. Therefore, it was assumed that trailers were valued at R280 000, independent of age category. This equates to approximately 50% of the value of a new trailer set.

Table 3.1 The value of typical Mercedes Benz truck-tractors as a function of age.

	Commercial hauliers and grower-cum-transporters		
	0-5 years	6-10 years	>10 years
Truck tractor value (R)	411 272	261 162	120 000

Two categories of wages were assumed for each of the driver shifts discussed in Chapter 3.1. NBC wages at the time of calculation were assumed for commercial hauliers, and wage rates from specific operators' personal accounts for grower-cum-transporters. In this study, two shifts of 12 hours per day were assumed.

Insurance premiums were assumed to be 3.5% and 5% of revenue earned for commercial hauliers and grower-cum-transporters, respectively. No provision for excess was made in the calculations.

The overhead costs were again split according to whether the vehicle was operated in a commercial environment or by a grower-cum-transporter. For the commercial haulier a value of R162 000 per vehicle per annum was used, and for a grower-cum-transporter an overhead cost per vehicle per annum of R12 000 was chosen by referencing the balance sheets of three grower-cum-transporters in the Sezela area. The reasons for these significant differences are complex and not well understood and are an area requiring further research.

As sugarcane is harvested and transported for only ± 35 weeks per annum, and vehicles are often used to transport other goods during the off-crop, a portion of the total fixed costs were apportioned to the off-crop work. A conservative figure of 10 weeks off-crop work per vehicle per annum was chosen (Meyer, 2004). The fixed costs were therefore reduced by 19% to account for this.

3.3.2 Variable Cost Inputs

As mentioned previously, the cost of fuel is a function of distance from Durban's fuel depot and, to some degree, of discount due to quantity bought. The price of diesel used by commercial hauliers was the March 2005 Sezela bulk delivered price, less the Unitrans discount. The price for grower-cum-transporters was assumed to be the March Sezela bulk delivered price (Maxwell, 2004). Top-up oil and grease was set at a value of 0.5% of the fuel cost for sugarcane haulage (Dammann, 2004).

Tyre costs are a function of kilometres travelled and whether new or retread tyres are used. The steering tyres were assumed to have a life span of approximately 80 000 km. The drive axles are fitted with dual tyres, therefore eight tyres need to be replaced approximately every 100 000 km in the case of new tyres, and every 90 000 km in the case of lower quality retreads. The tyre costs were as per Unitrans tyre rate, with a 30% reduction in costs for retreads as at March 2005. Trailers use the same type of tyres as the drive axles, and these are replaced every 100 000 km in the case of new tyres, and every 90 000 km in the case of retreads. The costs were as above for the new and retread tyres. In all cases provision was made for 5% unplanned failures, and the cost of the first set of tyres purchased with the vehicle was excluded from the tyre cost schedule (Dammann, 2004).

Preventative and corrective maintenance of the vehicles was based on a market related rate based on the mileage covered per annum and on vehicle age (Dammann, 2004).

3.4 Results of the Survey and Costing of the Present Sezela Transport System

Presented below are the results from the telephonic survey, followed by a summary of the cost of the Sezela sugarcane transport system. Over 88% of the vehicles in Sezela were captured in the survey. This represents a sample of 107 of the total of 121 vehicles and excluded only those vehicles that had been sold or that were owned by hauliers who had since liquidated.

The results of the survey show the age of vehicles employed to transport sugarcane to the Sezela mill ranged significantly, from 1969 to 2003. Figure 3.1 gives the distribution of vehicle age, showing a prominent spike for the 1994 model. This is due the fact that the largest hauling company in the area has a fleet made up solely of 1994 vehicles. A significant percentage of the vehicles are relatively new, with approximately 50% aged five years or younger.

The survey included vehicle manufacturers represented in the area. The choice of manufacturer may be historical, but is frequently related to after-sales service and availability of spare parts that can be installed quickly, thus minimising downtime. Distribution of vehicle makes: Mercedes Benz (3335 and 2637) ±70%, MAN (F2000 33.374) 7%, Volvo (FM12 380) 7% and other 16%.

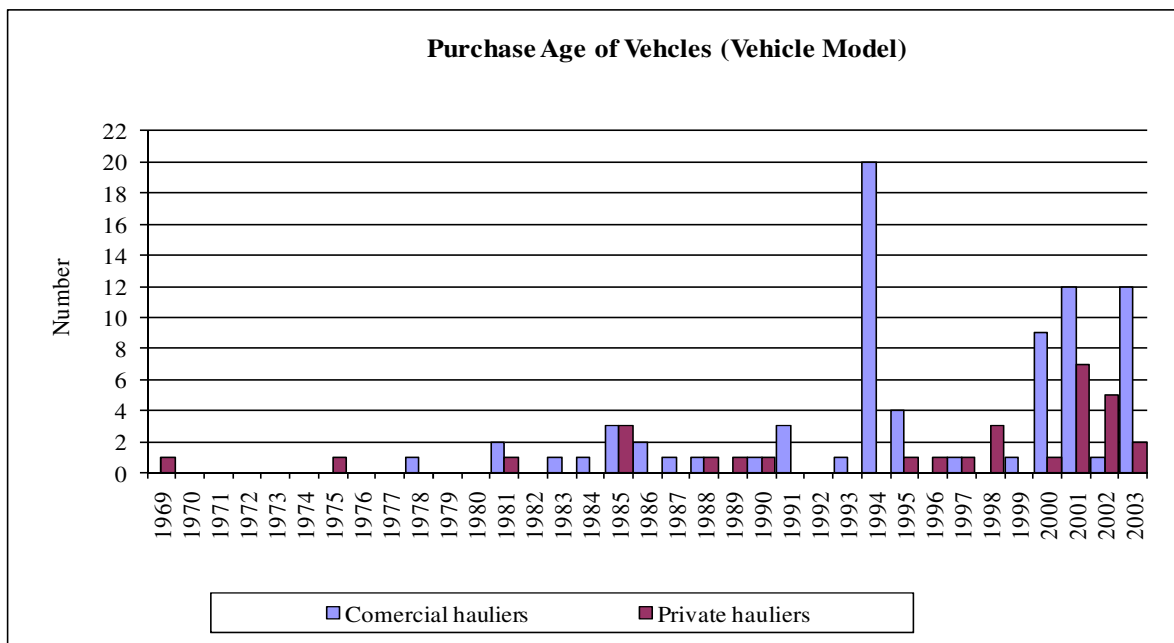


Figure 3.1 The number of vehicles purchased per year by both the commercial haulier and grower-cum-transporter vehicles in the Sezela mill area from 1969 to 2003.

Table 3.2 contains a summary of the number of vehicles in each of the six categories. It shows that a significant portion of the vehicles are of the commercial category, and approximately half are less than six years old. The tons transported per category shows some unexpected results. Commercial haulier vehicles in the less than six years old category transported an average of 5 384 tons per vehicle over the 2003 season, whereas the grower-cum-transporters with vehicles that were greater than 5 years old but less than ten years old transported 23 706 tons per vehicle per annum. In discussing the unexpected result with the cane supply department at Sezela, it was noted that the majority of the vehicles in the less than five years old category had been operated by a single new haulier who, in their opinion, had employed poor management and maintenance staff, and as a result are no longer in business.

Table 3.2 Categorisation of commercial hauliers and grower-cum-transporter groups according to number of vehicles, median age of vehicles, tons transported and ton weighted average lead distance.

	Commercial hauliers			Grower-cum-transporters		
	0-5 years	6-10 years	>10 years	0-5 years	6-10 years	>10 years
Number of vehicles	35	25	17	15	6	9
Median age (model)	2001	1994	1986	2001	1997	1985
Tons weighted average lead (km)	27.2	22.5	24.5	39.5	24.4	34.9
Tons transported (tons)	188 465	592 666	198 615	347 044	119 969	131 315
Average tons per vehicle (tons)	5385	23707	11683	23136	19995	14591

The tons weighted average leads varied significantly, particularly with regard to commercial hauliers who often service multiple growers and therefore have a range of lead distances, whereas grower-cum-transporters transport cane from a single farm and have a relatively constant lead. Indeed, this is the case in the less than six year category, where a single grower operates 11 vehicles from a single group of farms at a relatively long lead.

Figure 3.3 shows the total fixed and variable costs of transport for each of the six categories for 2003. The total cost of transport of the present system was therefore estimated conservatively at R68 million for the 2003 season. The relative fixed to variable cost ratios of the commercial hauliers and the grower-cum-transporters is clear. For grower-cum-transporters the ratio is of the order of 1:1, while a ratio of approximately 3:1 can be seen for the commercial hauliers. This can be accounted for in part by the poor performance of the less than five year old fleet, but can also be attributed to the fact that grower-cum-transporters have, or are perceived to have, significantly lower overhead costs. These anomalies in terms of utilisation and overheads per vehicle justify future research but falls outside the scope of this study.

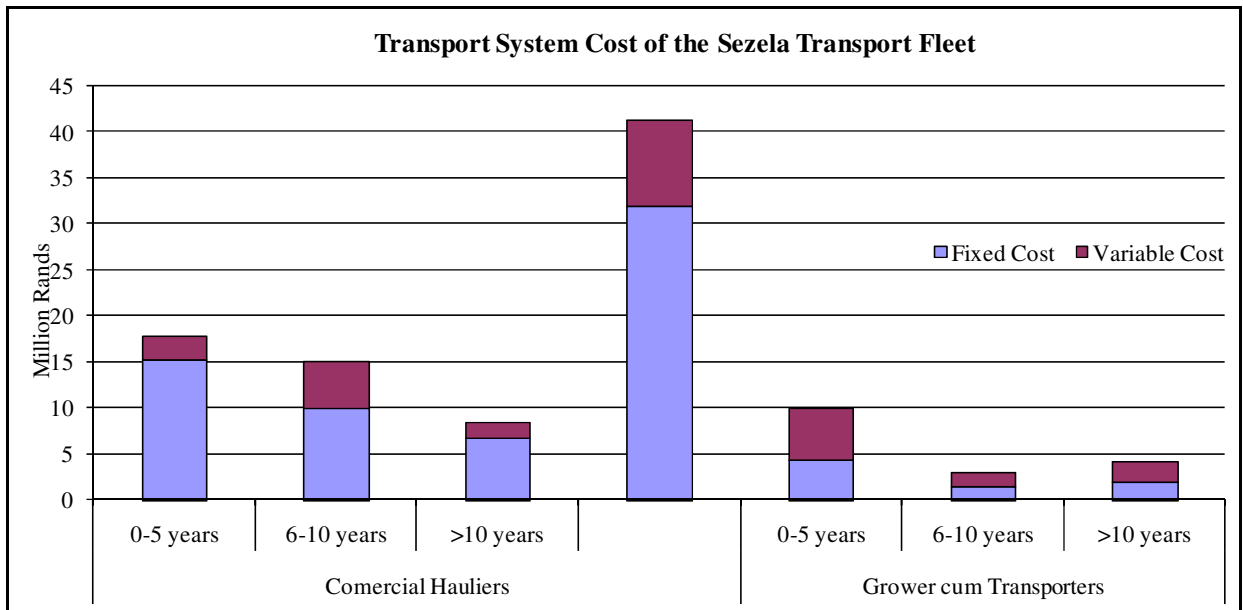


Figure 3.2 The total fixed and variable cost components of each of the six age categories of commercial and grower-cum-transporter vehicles.

3.5 Chapter Conclusions

To the best of the author's knowledge, this is the first study that attempts a relatively accurate quantification of the cost of operating a sugarcane transport system in South Africa. An indicator of vehicle under-utilisation and system over-fleeting is the relative tons transported per vehicle per season. The lowest and highest categories are 5 000 tons and 24 000 thousand tons transported per annum respectively. One case was recorded where an individual vehicle transported over 70 000 tons in one season. Relative to the industry benchmark established through the SLIP programme of over 35 000 tons transported per vehicle per annum, over-fleeting, and thus the cost of transport, is extremely high (Crickmay, 2003).

It is evident that, if cost savings are to be made, the fixed cost component of the transport fleet needs to be reduced and the utilisation of each vehicle increased. Therefore, fleet reduction serves as a primary indicator of cost saving and will be used for the remainder of this study as the quantifier of improved efficiency.

An brief investigation into this category of problems and the respective solutions is presented in the following literature review in Chapter 4 and 5.

4 VEHICLE ROUTING AND SCHEDULING

Vehicle Routing Problems (VRP) constitute an important and well-studied class of optimisation problems within Operations Research. Their importance relies on their theoretical and practical value, since a large number of applications are related to vehicle routing (Palmgren, 2001). VRP applications encompass diverse activities such as retail distribution (e.g. Harrison, 1979), school bus routing (e.g. Newton and Thomas, 1974; Bodin and Berman, 1979), mail and newspaper delivery (e.g. Golden *et al.*, 1977), municipal waste collection (e.g. Beltrami and Bodin, 1974; Tung and Pinnoi, 2000), timber transport (e.g. Rönnqvist, 2003), open pit mining vehicle routing and scheduling (e.g. White *et al.*, 1982), fuel oil delivery (e.g. Garvin *et al.*, 1957), orange harvesting (Caixeta-Filho, 2006) and airline and railway fleet routing and scheduling (e.g. Assad, 1980). Effective routing and scheduling of vehicles and crews can save government and industry large sums of money by increasing productivity, aiding long range planning, assisting in negotiations and controlling the financial impact of adverse weather conditions on vehicle utilisation (Bodin and Golden, 1981).

This chapter contains a review of the characteristics of vehicle routing and scheduling problems, including: problem constraints, objective functions, input data characteristics, classification criteria and problem solution techniques. A more detailed review of specific vehicle routing and scheduling problems and pertinent variants follows. This starts with the relatively simple Travelling Salesman Problem and proceeds to the VRP, and the complex Pickup and Delivery Problem.

4.1 Characteristics of routing and scheduling problems

VRP arise whenever a set of vehicles is available to serve a set of transportation requests (Cordone and Wolfler Calvo, 2001). Routing of vehicles can be defined as a sequence of pickup and/or delivery points, or nodes, which the vehicle must traverse, starting and ending at a depot node. A vehicle schedule is a sequence of pickup and/or delivery points together with an associated set of arrival and departure times. The vehicle must traverse the nodes in a specified order at designated times. When arrival times at nodes are fixed in advance the problem is known as a scheduling problem, and when the arrival times are unspecified the problem is purely a routing problem. In many applications, combined vehicle routing and scheduling problems arise from the existence of both time and node precedence restrictions (Bodin and Golden, 1981).

Routing and scheduling problems can be further broken down into arc based, node based or a combination of the two. In arc based routing and scheduling, a collection of arcs in a network have to be covered and some activity performed on that arc. Examples are street sweeping or snow removal. In node based routing and scheduling problems, a collection of origin/destination pairs of nodes are given, and at least one vehicle must travel from each origin to the corresponding destination. In the combined problem there exist specific nodes and arcs that need to be serviced. Examples of these are school bus routing and scheduling, and household refuse collection (e.g. Schrage, 1981).

In many real-world routing problems there exist elements of dynamicity, where the schedule must change in response to new or altered requests (Kilby *et al.*, 1998; Hvattum *et al.*, 2006). These real-time dynamic vehicle routing and dispatching problems have emerged as an intense area of research due to, amongst other reasons, the economic benefits that are realised by the increased efficiency of the logistic systems (Gendreau and Potvin, 1998; Bianchi, 2000).

The remainder of this chapter contains a discussion aimed at giving the reader a basic understanding of the constraints and objective functions, and the stochastic and deterministic input data imposed on the various routing and scheduling problems. A framework classification of the variants of the classical vehicle routing problem follows. This begins with the most simple, the Travelling Salesman Problem (TSP), and continues to the intricate and mathematically demanding Pickup and Delivery Problem (PDP) variants. Due to the inherent complexity of these optimisation problems a brief discussion of solution techniques, with examples, is also given.

4.1.1 Constraints Imposed on Vehicle Routing Problems

Each transportation request specifies one or more locations that have to be visited by the same vehicle. Various constraints exist to restrict the way in which they are to be visited. The most common, both in the literature and in practice, refer to capacity and time (Cordone and Wolfler Calvo, 2001). Golden *et al.* (1977) and Mitrovic-Minic (1998) provide summaries of the main constraints that have to be satisfied and relate to time windows, vehicles (types, numbers and capacities), depots (numbers, locations and production capacity), delivery points (demand requirements, service constraints on delivery time and load splitting), pairing and precedence of pickups and deliveries, and resources such as drivers. Precedence constraints restrict each pickup location that has to be visited prior to the corresponding delivery location. Pairing constraints restrict the set of optimal routes such that one vehicle completes both the pickup and the delivery of the load of one transportation request (Mitrovic-

Minic, 1998). Xu *et al.* (2003) go on to highlight compatibility constraints with respect to only certain vehicles being able to transport certain orders, and certain orders not being able to be transported with other orders. It is also mentioned in their paper that Department of Transport rules, with regard to maximum driving, working and trip time, must be followed.

4.1.2 Objective Functions

The objective of most routing and scheduling programs is to minimise the total cost of providing the service by minimising distribution costs and vehicle and depot acquisition costs (Golden *et al.*, 1977; Haksever *et al.*, 2000). Other objectives may include service minimisation, obtained by minimising total time to service customers, total distance travelled, customer inconvenience, or a weighted combination of time to service all customers and total customer inconvenience (Mitrovic-Minic, 1998). Savelsbergh and Sol (1995) expand on the objective function of minimising time by describing three subtly different time minimisation approaches. Firstly, to minimise route duration, which includes travel times, waiting times, loading and unloading times, and break times. Secondly, to minimise completion time, which is the time when the service at the last location is completed. Thirdly, to minimise travel time, which is the actual time spent travelling between different locations. Mitrovic-Minic (1998) and Ruiz *et al.* (2004) highlight that to minimise the number of vehicles serving the transportation requests is of economic importance to most operators. Equi *et al.* (1997) include storage cost minimisation when calculating the cost of product delivery.

4.1.3 Deterministic and Stochastic Input Data

As mentioned, static and dynamic versions of the VRP exist, for which both deterministic and stochastic data are possible inputs. A VRP is deterministic if all input data are known when designing vehicle routes, otherwise it is stochastic (Ghiani *et al.*, 2003).

A static problem can either be stochastic or deterministic. In deterministic and static VRPs all data are known in advance, and time is not taken explicitly into account. In stochastic and static VRPs vehicle routes are designed at the beginning of the planning horizon, before uncertain data become known. This problem occurs, for example, when traffic conditions are highly variable and the 'optimal' solution for the deterministic VRP may no longer be satisfactory (Ghiani *et al.*, 2003). A first-phase solution is often constructed using data available at the time, with corrections and alterations being made at a later stage when all random variables are known. The objective function to be minimised is

the first stage cost plus the recourse cost (Ghiani *et al.*, 2003). For further reading, Yang *et al.* (2000) give a summary survey of stochastic static problem formulation.

Dynamic VRPs can also be stochastic or deterministic. In deterministic dynamic problems, all data are known in advance and some elements of information depend on time. The Travelling Salesman Problem (TSP) with time-dependent travel times is an example. The salesperson has to find the shortest route passing through several cities only once, but travel times may vary throughout the day. Stochastic dynamic problems (real-time problems) are common and are the closest representation of real-world situations, where uncertain data are gradually revealed during the operational interval. Routes are not usually preconstructed; instead requests are dispatched to vehicles in an ongoing fashion as new data arrives. Events that lead to a plan modification can be of three types: the arrival of new requests, the arrival of a vehicle at a destination or the update of travel times (Ghiani *et al.*, 2003).

4.1.4 Classifying Routing and Scheduling Problems

The classification of routing and scheduling problems depends on certain characteristics of the service system. In the simplest case, a single vehicle services a set of nodes. The nodes may be visited in any order and in any direction. There are no precedence relationships, and there are no delivery time or capacity restrictions. Each node is visited only once and the route begins and ends at a depot node. This is typical of the TSP.

An extension of the TSP, which comes closer to accommodating more real-world problems (Golden *et al.*, 1977), is referred to as the Multiple Travelling Salesman Problem (m-TSP) and occurs when a fleet of vehicles must be routed from a single depot. The goal is to generate a set of routes, one for each vehicle. This problem has the characteristic that a node may be assigned to only one vehicle, but a vehicle will have more than one node assigned to it. The solution to this problem is to provide the sequence in which each vehicle is to visit its assigned nodes (Haksever *et al.*, 2000).

In addition, when the capacity of the vehicle is coupled with the varying demands at each node, the problem is known as a VRP (Palmgren, 2001; Ralphs *et al.*, 2003; Links, 2004).

If there are multiple transportation requests that specify the size of the load to be transported, the locations where goods are to be picked up (the origins) and where they are to be delivered (the destinations), along with the vehicle capacity restrictions and the requirement that each load is to be

carried by one vehicle only from origin to destination, the problem is known as a general Pickup and Delivery Problem (PDP). The PDP can be reduced to a VRP if all the origins or all the destinations are restricted to the depot (Savelsbergh and Sol, 1995).

If the pickup or delivery location has a time interval within which it should be visited, the problem is known as the Pickup and Delivery Problem with Time Windows (PDPTW). The time window specifies both the start and end time of the window. This time-restricted variant has been extensively researched, as it represents most commonly encountered PDP (Mitrovic-Minic, 1998).

Adaptations to the basic problems will be discussed in detail in Section 4.2.

4.1.5 An Overview of Solution Methods

An important issue in routing and scheduling involves the practical aspects of solving the aforementioned problems. Due to the intrinsic complexity of these problems, the use of mathematical program-based models and algorithms is needed when analysing and solving such problems to permit the realisation of cost reductions or profit improvement (Solomon and Desrosiers, 1988). Generally, solution techniques can be separated into exact methods, heuristic methods and more recently, metaheuristic methods (Ruiz *et al.*, 2004). A brief description of these methods, with examples follows.

Exact methods, also called optimal methods, are aimed at finding the optimal solution to the problem by implicit enumeration of all solution alternatives (Mitrovic-Minic, 1998). Exact methods have been effective in solving many TSP problems (e.g. Applegate *et al.*, 1998). Dynamic Programming, Lagrangean Relaxation and Column Generation are examples of exact methods used (Toth and Vigo, 2002).

As the size and complexity of the problem increases, it rapidly becomes too computationally expensive to solve optimally with an exact method. For example, consider the delivery of bundles of newspapers from a printing site to a number of drop-off points in a geographic area. This is a typical VRP. The drop-off points have different demands, and the vehicles have different capacities. Each vehicle in the fleet is assigned a route, beginning and ending at the printing site (depot). For a newspaper with only ten drop-off points there are 1024 possible routings, and for 50 drop-off points over one trillion routings. It is worth noting that real problems of this type involve over 1000 drop-off points (Links,

2004). The above problem has the characteristic of being combinatorial, which means that all the possible combinations of the decisions and variables must be explored to find a solution.

Fortunately, since the 1960s, heuristic solution techniques, or approximation algorithms, have been developed to explore specific parts of the search space, thus concentrating on those parts that appear to promise a probable improvement to the solution. This method reduces the time required to obtain a solution and yield satisfactory, if not optimal, solutions. Construction Algorithms, Insertion Algorithms and Route Improvement Heuristics are typical examples of methods used to find a solution within a reasonable time frame. (Wren, 1998; Haksever *et al.*, 2000; Hvattum *et al.*, 2006).

Heuristics which extend local search approaches that devise techniques which do not exploit only the problem characteristics, but also analogies with optimisation methods found in nature, are known as metaheuristics. These methods have the ability to escape from local minima, and continue towards better solutions. This approach improves on the classical heuristic methods at the expense of larger computing requirements. Ant Algorithms, Deterministic Annealing, Neural Networks, Genetic Algorithms, Simulated Annealing and Tabu Search are examples of metaheuristics (Toth and Vigo, 2002; Cordeau and Laporte, 2004).

4.2 Vehicle routing problems

The VRP plays a central role in physical distribution and logistics, and there are many VRP variants in the literature (Laporte, 1992). The following discussion will therefore cover only the most relevant published variants. The explanation will start with the simplest case, the TSP, followed by the VRP and PDP, and will end with that most representative of the real-world situation, i.e. dynamic vehicle routing.

4.2.1 Travelling Salesman Problem

The most basic VRP is the TSP, which can be stated as, “Given a finite number of ‘cities’ or nodes, together with the cost of travel between each pair of them, find the cheapest (or minimum distance travelled) way of visiting all the cities and return to the starting point.” (Palmgren, 2001). The travel cost of each of the visits is the same whether the route is in the opposite direction or not, and can therefore be described as symmetric. Figure 4.1 shows a geographically referenced set of nodes that

represent cities throughout Germany (a) and the USA (b), for which optimal routes were solved (Applegate *et al.*, 1998).

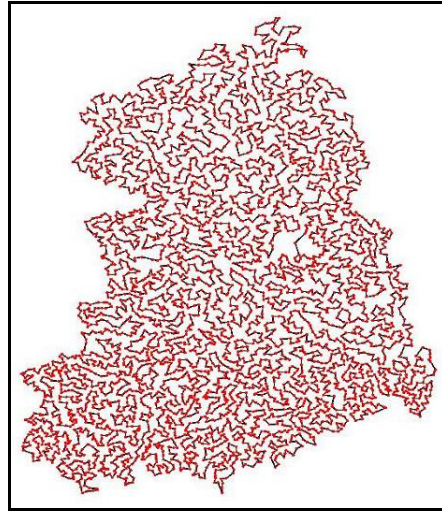


Figure 4.1 The optimal routes through 15 112 cities and towns throughout Germany (Applegate *et al.*, 1998)

4.2.1.1 A Brief History of the Travelling Salesman Problem

The TSP has been studied as a mathematical problem since the 1800s, originally by the Irish mathematician Sir William Rowan Hamilton, and the British mathematician Thomas Penyngton Kirkman (Vieira *et al.*, 2003). In the 1920s the mathematician and economist, Karl Menger, publicised the problem among his colleagues in Vienna, and in the 1930s at Princeton. During the 1940s, statisticians RJ Jessen and PC Mahalanobis studied the TSP in connection with agricultural applications (Applegate *et al.*, 1998). Bellmore and Nemhauser (1968) conducted a thorough survey on the progress of the TSP and can be consulted for further information.

4.2.1.2 Variants of the Travelling Salesman Problem

The TSP and its variants have been studied extensively and many variants exist although only those applicable to this review will be discussed. The Multiple Travelling Salesman Problem (m-TSP) is an important variant involving more than one vehicle, and has been discussed in Chapter 2. With the added complexity of allowable time windows, the problem is known as the Travelling Salesman

Problem with Time Windows (TSPTW). A generalisation, the m-TSPTW, deals with finding a set of optimal routes for a fleet of vehicles in order to service a set of locations, each with a specified time window (Mitrovic-Minic and Krishnamurti, 2002). The time windows stem from the fact that some customers impose service deadlines and earliest service time constraints. Two categories of time windows exist, these being hard and soft time windows. In the hard time window, if a vehicle arrives too early it will wait and due times cannot be violated. In contrast, in the soft time window category, constraints can be violated at a cost (Solomon and Desrosiers, 1988).

4.2.2 The Vehicle Routing Problem

The VRP can be seen as a merger of two well-known problems: the TSP and the bin-packing problem, which is determining how to put the most objects in the least number of fixed space bins. A typical VRP can be described as a fleet of vehicles with uniform capacity, a common depot, and several geographically referenced demand points or nodes (cities, schools, warehouses). The ‘problem’ arises in finding a set of routes, with overall minimum route cost, which will service all demands. The routes must be designed in such a way that each point is visited only once and by only one vehicle, all routes start and end at the same depot, and the total demands of all the points must not exceed the vehicle’s capacity (Braysy, 2001; Pereira *et al.*, 2002; Mestera, 2007).

The VRP problem was first introduced by Dantzig and Ramser (1959) which described the routing of a fleet of gasoline delivery trucks between a bulk terminal and a large number of service stations, with the objective of minimising total mileage. The VRP represents an area of extensive research and a detailed survey, containing around 700 references, was provided by Bodin and Golden (1981).

The VRP is used as the basic model for a large number of VRP variants (Larsen, 1999). The Vehicle Routing Problem with Time Windows (VRPTW) is one such generalisation, which involves the added complexity that every customer should be served within a given time window (Braysy, 2001; Mestera *et al.*, 2007; Doerner *et al.*, 2008). This problem occurs frequently in the real-world, when customers want to be serviced during certain operating hours, or when extra personnel are available. Restricted access during high traffic flow hours is another reason. The importance of the time window constraint results from the consequences of not arriving during the time window. In some cases this may cause only minor customer dissatisfaction, and in others may mean that the delivery cannot be made. It is also possible that, where the truck was loaded from the rear, none of the remaining loads can be delivered. As with the TSPTW, both soft and hard time windows exist, examples of which are bank

deliveries and the so-called dial-a-ride service, respectively (Solomon and Desrosiers, 1988). Dullaert (2001) notes that differences in customer flexibility, with respect to time of delivery, exist. Three categories of scheduling flexibility can be identified: short time periods (a few hours), daily flexibility (several hours), and customers who allow the carrier to choose the day of delivery. The first two can be modelled as VRPTW and the third as a Period Vehicle Routing Problem.

The Period Vehicle Routing Problem is a VRP where, over a chosen time horizon, the time of service is calculated to meet certain service requirements, such as a fixed number of visits. An example is the collection of 59 recycled paper containers using two vehicles, over a month-long planning horizon (Baptista *et al.*, 2002).

Vehicle routing with split deliveries is a relaxation of the VRP, as it allows customer demand to be split between several vehicles and each customer can be visited more than once. This is equivalent to removing the capacity constraint (e.g. Dror *et al.*, 1994; Belenguer *et al.*, 2000; Archetti *et al.*, 2003). Dror *et al.*, 1994, showed that this results in substantial savings, both in the total distance travelled and the number of vehicles used in the optimal solution.

Vehicle routing with full loads occurs in a variety of situations where vehicles must make a number of trips between pairs of specified cities and where, on each of these trips, they are fully loaded. Maximum route length, duration, capacity and time window constraints are still applied (Solomon and Desrosiers, 1988).

Brandao and Mercer (1997) introduce a variant of the VRP, the multi-trip vehicle routing and scheduling problem, which is regarded as a more realistic representation of the real-world. This problem is similar to the VRP, but has a larger number of constraints. In addition to time window and differing capacity constraints, vehicles can be hired if the company has insufficient capacity for the day, access to some customers is restricted to some vehicles, driver breaks and working hours are included, and unloading times are taken into account.

Goela and Gruhn (2008) describe the General Vehicle Routing Problem (GVRP) which is a combined load acceptance and generalised VRP. Among the real-life requirements are time window restrictions, a heterogeneous vehicle fleet with different travel times, travel costs and capacity, multi-dimensional capacity constraints, order/vehicle compatibility constraints, orders with multiple pickup, delivery and service locations, different start and end locations for vehicles, and route restrictions for vehicles.

A restriction of the VRP is studied by Gribkovskaia *et al.* (2002), where all delivery demands leave from the depot and all pickup demands are brought back to the depot. In a traditional VRP this can lead to poor utilisation of vehicle capacities, increased travel distances or a need for more vehicles. Where the constraint that each customer can be visited once only is relaxed, several different improved routing options are possible. One such option is the so-called Lasso-solution, where the first customers are visited twice. On the first visit only the delivery demands are performed, hence creating more free space in/on the vehicle. On the way back to the depot, the same customers are visited a second time to perform the pickup service.

(Okhrin and Richter, 2008) describe the use of a genetic algorithm to solve the classic VRP, but with real-time travel information through the use of mobile technologies. When compared against benchmarks, this strategy enabled them to improve the quality of the solution by an average of 1.5%.

Flisberga *et al.* (2009) describes an operational routing problem to decide the daily routes of logging trucks in forestry. This problem includes aspects such as pickup and delivery with split pickups, multiple products, time windows, several time periods, multiple depots, driver changes and a heterogeneous truck fleet. The solution is unique in that it uses a two-phase approach which transforms the problem into a standard vehicle routing problem with time windows.

4.2.3 The Pickup and Delivery Problem

The general Pickup and Delivery Problem (PDP) is a variant of the VRP which aims to find a set of optimal routes for a fleet of vehicles, in order to serve a set of transportation requests. Each vehicle within the fleet has a given capacity, a start location, and an end location. Each transportation request is characterised by the load, the load origin and the load destination. Therefore, the PDP aims to construct optimal routes to visit all pickup and delivery locations under precedence and pairing constraints (Mitrovic-Minic, 1998). This distinguishes it from the VRP where either only pickups, or only deliveries occur on a specific route. The two variants of the general PDP which best approximate real-world circumstances are the Pickup and Delivery Problem with Time Windows (PDPTW), and the Dynamic Pickup and Delivery Problem (DVRP).

4.2.3.1 The Pickup and Delivery Problem with Time Windows

The PDPTW variant of the general PDP constructs optimal routes, with the added constraint of time windows, and with the same properties of the VRPTW discussed in Section 4.2.2.1. Examples of practical problems that can be solved as PDPs are Dial-A-Ride Problems (DARPs), handicapped person transportation problems (HTPs) and courier company pickup and delivery problems (Mitrovic-Minic, 1998). The DARP is a transportation service which provides large numbers of passengers with a personalised service. It can be described as somewhere between a rigid bus system and a flexible taxi service (Stein, 1978).

Bodin (1990) and Xu *et al.* (2003) agree that many of the problems described in the literature oversimplify problems that occur in practice. Real-world problems usually include complications beyond the basic model. Xu *et al.* (2003) describe a practical pickup and delivery problem encountered in real-world logistics operations. The problem involves constraints such as multiple carriers and multiple vehicle types available to fulfil the transportation requests, each of which has multiple pickup and delivery time windows. Compatibility constraints specify orders that cannot be transported by a particular carrier, or vehicles that cannot carry particular loads. Order loading and unloading sequence constraints satisfy the precedence constraint that an order cannot be unloaded until orders that were loaded into the truck later have been unloaded. Driver work rules prescribed by the Department of Transport are also satisfied in this complex problem.

Mitrovic-Minic (1998) mention that some PDPs can, under certain conditions, be modelled as VRPs or even TSPs. The approach most pertinent to this dissertation is the full-load PDP that can be modelled as an m-TSPTW. The full-load PDP is a special case where each load has to be transported directly from the origin to the destination (Savelsbergh and Sol, 1995).

4.2.3.2 The Dynamic Pickup and Delivery Problem

The majority of VRPs are static and all data are known in advance. Real-time decision problems are, however, playing an increasingly important role in the economy as advances in communication and information technologies allow real-time information to be obtained and processed quickly (Seguin *et al.*, 1997; Mitrovic-Minic, 1998; Montemanni *et al.*, 2002). Among these, dynamic vehicle routing and dispatching solutions have emerged as intense areas of research (Psaraftis, 1995). In real-time fleet

management, vehicle routes are built in an ongoing fashion as vehicle locations, travel times and customer requests are updated over the planning horizon (Ghiani *et al.*, 2003; Cortés *et al.*, 2007).

In the Dynamic Vehicle Routing Problem (DVRP), new orders arrive after the vehicles have already left the depots and have begun executing their tours. The DVRP is an extension of the traditional VRPTW, where problem parameters change in real-time after vehicles have been commissioned (Zhu and Ong, 2000). Typically, some of the orders are known in advance and a first schedule is calculated for them. New orders are received during tour execution and immediately become eligible for consideration (Psaraftis, 1980; Montemanni *et al.*, 2002). Each time a new input to the problem is received, a corresponding modification to the schedule can be expected, producing a tentative optimal solution. This modification, for obvious reasons, cannot affect the portion of the route already completed, but will affect the remaining portion of the route (Psaraftis, 1980).

A complication occurs with continual reoptimisation, which conceivably may continually defer the service of any particular customer for an indefinite amount of time. Indefinite deferment of a customer's request can occur whenever a customer is continually assigned to the last position in the pickup and delivery sequence, as a result of their unfavourable geographic location with respect to the other customers. Therefore, any dynamic algorithm must incorporate a mechanism to prevent or at least discourage this possibility (Psaraftis, 1980).

Several problems must be solved in real-time. These include dynamic fleet management, vendor-managed distribution systems, couriers, rescue and repair service companies, dial-a-ride systems, emergency services, and taxi cab services. Dynamic fleet management is employed by large scale trucking operations which collect and deliver many shipments. Vendor-managed distribution systems estimate customers' inventory levels in such a way as to replenish them before they run out of stock, known as a 'just-in-time' (JIT) system. However, because demands are uncertain, there exists the possibility that a customer may run out of stock sooner than anticipated and need to be serviced urgently. Couriers collect local outbound parcels before sending them to a remote terminal to consolidate the loads before further shipment. Emergency, rescue and repair services include towing, ambulance, fire fighting and police services whose customers are, by nature, dynamic. Taxi services, too, have dynamic customer requests and, in both emergency and taxi services, relocation of temporarily idle vehicles to provide a more prompt service, becomes an issue (Ghiani *et al.*, 2003).

Psaraftis (1995) points out that dynamic vehicle routing problems have a number of peculiar features. Denied or deferred service, in some applications, is valid in various instances to avoid excessive delays, unacceptable costs or increased waiting time due to demand growing above a predetermined threshold.

The techniques to solve the dynamic problem are similar to the previously discussed problems, but here expediency is paramount. Sequential algorithms are such a technique. These can be divided into three main categories: simple procedures, classical insertion procedures and metaheuristics. Simple procedures function on a 'first come, first served' protocol or a nearest neighbour protocol. Classical insertion procedures include a rolling horizon and the double horizon protocol. Unfortunately, the above two procedures do not ensure good solutions. Metaheuristic procedures on the other hand, aim to find near-optimal solutions for large-scale problems. Parallel algorithms using metaheuristics are usually used when re-optimisation time of a route needs to be reduced (Ghiani *et al.*, 2003).

4.3 Chapter Conclusions

Within Operations Research, vehicle routing problems constitute an important and well-studied class of optimisation problems because of their theoretical and practical value.

VRPs arise wherever there exists a set of transportation requests and a fleet of vehicles to serve those requests. Many variants of the basic VRP exist. These are generally categorised by the service performed and by the predominant constraints imposed by the requestor or by the properties of the problem. These constraints restrict the way in which they are visited, but increase the quality of the solutions by more closely imitating reality. From the well documented, relatively simple TSP, through to the inherently complex PDPTW, the above statements are typically true.

While these increasingly complex solutions approximate reality more closely, they do so at the expense of solution time and the specific numeric quality of the solution. A solution can be obtained by optimising a number of functions under the aforementioned constraints. This often has the effect of minimising the overall cost of providing the service or of minimising some property of the service itself. Many solutions to the various vehicle routing problems and their variants exist, the choice of which depends on available solution time, solution accuracy, problem size and problem complexity.

From the above it is apparent that there is scope for improvement between research and real-life routing and scheduling applications. However, this gap is diminishing as more and more of the constraints describing real-world problems are included as a result of, amongst other things, the available computing power.

Dynamic Vehicle Routing would seem to be the best solution choice for a real-life transport operator as they can cope with variability with respect to supply, demand and vehicle performance on a real-time basis. However, a more skilled operator and a higher level of technology, with higher associated costs, are needed. Also, the risk of a transport system shut-down created by a system failure is higher, especially in the case of a centralised control system.

The routing and scheduling problems within operations research have been demonstrated to be a well researched but particularly broad field with many applications. Therefore, the following chapter contains a focused review of the specific agricultural haulage scheduling problem.

5 THE AGRICULTURAL HAULAGE SCHEDULING PROBLEM

Research and applications pertaining to the computerised scheduling of a heterogeneous truck haulage fleet to transport sugarcane from loading zone to mill, is limited. The problem, however, bears similarities to log truck scheduling, for which literature is available (e.g. Weintraub *et al.*, 1996).

This chapter contains a generic, relatively detailed description, encompassing both the timber and sugarcane vehicle scheduling problems, and includes case studies of both timber and sugarcane scheduling.

The objective of the Agricultural Haulage Scheduling Problem (AHSP) is to find a schedule for each truck in the fleet to transport a relatively low value product from the loading zone to the mill. This problem has many similarities to the standard Pickup and Delivery Problem with Time Windows (PDPTW) (Rönnqvist, 2003). Nevertheless, there is one major difference between the vehicle routing problems mentioned previously and the AHSP. In the PDPTW, the task is complete when the corresponding node has been visited. This is typically not the case in the AHSP, since a customer could be visited several times before the supply has been transported to the demand centre. For example, a truck may travel back and forth between a supply and demand point over the duration of the day before returning to the depot (Palmgren, 2001).

Consequently, the objective of the AHSP is to develop a set of minimum cost routes (Palmgren, 2001) so that:

- i. all customer demands are satisfied,
- ii. the supply at the zones (pickup nodes) is not exceeded,
- iii. each vehicle begins and ends its route at the corresponding depot node,
- iv. time windows at each node are adhered to,
- v. the capacity of the vehicle is not exceeded, and
- vi. the product is first picked up and then delivered (precedence).

Palmgren (2001) acknowledges that there are variants of the AHSP. The following points and their alternatives are all possible cases:

- i. Vehicles must be totally full before any delivery.
- ii. Vehicles should not mix different product assortments in one load.

- iii. Vehicles must always pick up the maximum possible load.
- iv. Vehicles must be empty after a visit to a drop-off node (mill).
- v. Vehicles must be empty at the start and end of each day.

Although vehicles are allowed to mix several assortments or visit different drop-off nodes in a row, the problem becomes considerably more complex, since the possible number of combinations increases dramatically. In reality it is most practical and realistic to completely unload at a single drop-off node and pickup a maximum of the same assortment at a supply zone (Palmgren, 2001).

5.1 Case Studies

Practical and efficient transportation planning is an important part of the agricultural product supply chain. Possibilities range from monthly flow planning to daily route planning and down to real-time dispatching, and each of these possibilities has advantages and disadvantages. For daily planning it is possible to find optimal routes, given that the data is available, but difficult to adapt to sudden changes, such as poor weather or truck breakdowns. For dispatch planning, it is possible to cope with reality, but harder to find high quality solutions. Dispatching also requires a high level of technology. Another aspect is whether to use a centralised or decentralised planning organisation. A centralised planning system reveals a potentially better combination of routes, whereas decentralised planning has the advantage of more customised planning (Eriksson and Rönnqvist, 2003).

Haulage of relatively low value product has been studied in several countries such as Chile, New Zealand, Finland and Holland. These studies have been mainly for the secondary transportation of timber, but there are instances in which both the mining and sugar industries have been studied (Palmgren, 2001). Pertinent industry examples of haulage truck planning systems. These are discussed in varying levels of detail, depending on the relevancy of the example to this study and the available literature.

5.1.1 Manual Real-Time Scheduling at Tongaat Sugar Ltd.

In 1957 consultants were tasked with introducing sugarcane vehicle scheduling into the Natal Tongaat Sugar Mills, to provide the necessary control procedures for the transport department. According to Dent (1973) the scheduling initiative failed for two reasons: (i) lack of accurate data on which to schedule, and (ii) the schedule was based on a pre-scheduled plan. The system did not cater for

unforeseen circumstances and therefore did not adequately reduce queuing in the millyard. It did, however, provide the momentum for a second successful scheduling initiative at Tongaat in the 1970/71 season. This was reasonably successful in eliminating the queuing effect in the millyard, provided no external influences, such as mill stoppages, were applied to the system (Dent, 1973).

Using a set of data recorded by studying the day-to-day operations of a sugarcane transport operation, such as trip times, loading times, offloading times and routine maintenance times that occurred on a regular basis, a simple vehicle scheduling board was constructed. A board with horizontal grooves, one for each vehicle in the fleet, these were incremented at five-minute intervals and accommodated 16 hours in total. A vertical cursor which could travel the length of the board was used as the indicator of time, while at the base of the board, a number of holes were drilled and pegs placed into the holes to indicate the desired rate of vehicle arrivals (Dent, 1973).

Chips the width of the vehicle groove were constructed for each loading point, with a length to indicate the cycle time for the vehicle to travel outbound, load and return loaded to the mill. As many loading sites were operating at any one time, and as they were generally at varying lead distances, it was possible to select trips for specific vehicles so that the fleet as a whole arrived in a staged fashion and could be processed at the mill crush rate. The queuing time was virtually eliminated, while the number of vehicles needed to transport cane decreased. Indeed, over the period 1967 to 1972 the number of vehicles transporting sugarcane was reduced from 34 to 28 (18% reduction), and the tons transported per vehicle per day increased by 9% (Dent, 1973).

It is important to monitor and benchmark the performance of the transport fleet against predetermined standard parameter, if a high level of efficiency is to be maintained. Up to the minute monitoring of payloads, ratio of kilometers covered to tons hauled, tons hauled per hour, and the monitoring of actual trip times against standard trip times are vital parameters to manage the day-to-day operations, and increase vehicle utilisation and productivity.

Dent (1973) explained how standardisation of vehicle type in the fleet simplified servicing and maintenance procedures that could therefore be performed more rapidly. He remarked that vehicle power was of little significance in the sugar industry, since relatively short lead distances were typical, and maximum speed was therefore often governed by road conditions.

5.1.2 FREDD

The New South Wales Sugar Milling Co-operative Limited has achieved substantial productivity gains in its cane supply operations, through using a real-time vehicle scheduling tool named FREDD to minimise operating expenses and maximise utilisation of capital. The scheduling initiative has evolved over almost three decades, since the change from manual to mechanical harvesting in the 1970s. The increase in efficiency in the harvesting of sugarcane has necessitated an increase in efficiency in the transport system (Dines *et al.*, 1999).

By 1992, the allocation of scheduled trips to vehicles to collect cane harvested infield and deliver it to the mill, had been automated to operate unmanned during the afternoon and night shifts. In 1994, with the addition of Global Positioning System (GPS) units on each vehicle, true real-time/ Just in Time (JIT) scheduling system could be achieved. Later, with radio telemetry links between harvesters in the field and the mill, and the addition of an automated weighbridge in 1996, the sending and receiving information about sugarcane consignments significantly increased levels of management and associated levels of efficiency (Dines, 1999).

The FREDD automatic traffic scheduling program is presently in operation at three New South Whales Sugar Mills and the Tableland Sugar Mill, where it schedules vehicles from the weighbridge to arrive JIT at sugar mills. The mills operate with no stockpiles. FREDD provides flexibility and has the capability to react to changes in crushing rate, payload and trip time which may vary due to fog, rain, holiday traffic, road works or the number of trucks available at any one time; it also allows for breakdowns (Dines, 1999).

The Harwood and Condong sugar mills operate at between 200 and 220 tons cane per hour, using only eight vehicles with an average lead distance of 19.5 km. They carry an average payload of 23.5 tons, and transport in excess of 100 000 tons of cane per six-month season (Dines, 2006). A reduction of 39% in the number of mill stops has occurred, with a 35% reduction in time, while the average lead distance has increased by 5% due to sugarcane area expansion.

5.1.3 The ASICAM Software

Since 1990 several firms in the Chilean forestry industry have used a computerised system named ASICAM, which helped increase the efficiency of the daily transport of timber by trucks. The

configuration allows for timber to be harvested from different stands (origins), with known supply quantity and variety, to destinations such as mills, ports and yards (destinations), each with its daily demand (Weintraub *et al.*, 1996).

Traditionally, log transport systems in Chile were inefficient and poorly organised. Schedulers used a magnetic board to determine adequate origin destination pairs, and performed truck scheduling manually by assigning sets of trucks to the routes and letting drivers decide on the schedules themselves. Loading and offloading were performed by crane operators on a 'first come, first served' basis and drivers competed to get more loaded trips. The lack of scheduling led to severe problems of congestion and under-utilisation of equipment. Loss and theft of timber occurred due to the poorly organised transportation system and the poorly organised downstream operation. Disruptions, such as breakdowns and bad weather, were often difficult to manage due to a lack of coordination (Weintraub *et al.*, 1996; Epstein *et al.*, 1999).

ASICAM, which is executed on a daily basis, uses as inputs to the program the supply of timber products at origins, demands at destinations, truck fleet and crane equipment characteristics, costs and times for the different trips, loading and offloading, plus an additional set of constraints describing the system. As outputs the system yields requirements for trucks and cranes, a schedule for each, and basic statistics to evaluate performance (Weintraub *et al.*, 1996).

Specific constraints that forest firms need to consider are: truck drivers and loader operators have a defined work schedule that includes a lunch break; trucks should arrive at destinations at uniform time intervals; to ensure contracts with truck owners are uniform, all trucks of the same type should earn similar quantities; trucks should start and end their shifts near driver home bases; and, in case of breakdowns, radios must be carried by drivers (Weintraub *et al.*, 1996).

The software objective was to develop a truck and loading/unloading schedule that will minimise idle time and minimise trip length while satisfying demand and supply, thus minimising the total cost of the transport system (Cossens, 1992).

ASICAM can be described as robust, which means it works well for all parties and situations. The system runs on a PC and takes a minimal amount of time to complete a schedule (typically a few seconds for a fleet of vehicles). The operator need not have a high level of technical knowledge, but

rather a good knowledge of the transportation system. Normally, three to four runs are required to evaluate several scenarios before choosing the best solution (Epstein *et al.*, 1999).

The implementation of the system provided significant benefits, both quantitative and qualitative. The quantitative improvements were measured in the numbers of trucks, numbers of cranes, operational costs, and total transportation costs. A more efficient assignment of trips led to shorter trips and less queuing time. As shown by the results Table 5.1, as productivity increased, fewer trucks were needed (Epstein *et al.*, 1999). Qualitative improvements included improved overall control with respect to organisation, maintenance and disruptions, and more regular deliveries to the demand nodes (Figure 5.1). This achieved smoother downstream operations, and an improved quality of life for the truck drivers, measured as the average working hours per day reduced from 14 to 10 (Weintraub *et al.*, 1996).

Table 5.1 The number of trucks required by four forest firms in Chile for hauling similar volumes of timber, before and after implementing ASICAM (Weintraub *et al.*, 1996)

	Before ASICAM	After ASICAM	Percentage reduction in no. of trucks
Bosques Arauco	156	120	23
Forestal Millalemu	80	50	38
Forestal Bio Bio	118	76	36
Forestal Rio Vergara	120	80	33

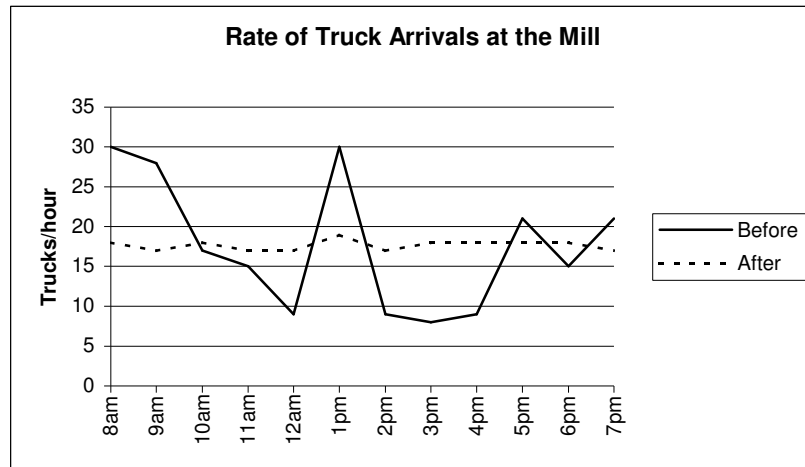


Figure 5.1 The more rateable supply at the mill before and after the implementation of ASICAM in Chile (after Weintraub *et al.*, 1996)

5.1.4 Other Examples of Truck Dispatch in Real-Time

Systems available today are mainly concerned with planning schedules on a daily basis. Rönqvist and Ryan (1995) described a real-time dispatch approach at one of the major forest companies in New Zealand. This system mitigated the problem of having to find correct estimates for the following day's supply, and the problem of uncertainties due to weather, delayed trucks, breakdowns or queues at either supply or demand locations was solved.

Here a complete daily schedule was not generated; rather the drivers contacted the control centre after the completion of a delivery that in turn generate one trip at a time for each truck. Thus solutions had to be generated quickly and, at the same time, be of satisfactory quality.

To cope with the two aspects of processing speed and quality of solution, the approach was to use two fast heuristic phases and an optimisation phase. This method provided a solution, on demand, at any time, and produced progressively better solutions as time progressed.

System constraints included capacity and truck configuration constraints, loading and offloading facilities, and time windows. The system operator needed to be experienced and the objective functions to be optimised had to include, but not be limited to, timber quality deterioration due to time, customer priorities, uniform distribution of work, ending shifts as close to depots as possible, and optimisation of the overall performance of the fleet.

The introduction of the truck dispatch system showed benefits for all parties involved. The forest companies benefited from lower transport costs, improved customer service and better control of the timber flow supply chain. Logging contractors benefited from fewer delays on skid sites, and from minimising excessive log stocks and loader interference. Truck and loader owners and drivers gained from a more equitable distribution of work.

Dispatching was a solution approach also used by Carlsson *et al.* (1998), who employed a three-phase heuristic procedure. The first phase generated trips and the following two phases found the minimum cost option and assigned a trip to each available truck respectively. When each trip was accomplished, the driver contacted the dispatcher to obtain details of the following trip, similar to the Rönnqvist and Ryan (1995) approach.

Although not implemented commercially, Murphy (2003) developed an integer linear programming truck route scheduling model that was tested at two New Zealand forest companies. One company indicated that truck fleet size could be reduced by 25 to 30%. The other company indicated that a reduction in fleet size of 50% was possible.

5.1.5 EPO and Other Special Cases of the Log Truck Scheduling Problem

Since 1993 a system called EPO has been in use in a large Finnish company, Enso-Gutzeit. This system deals with all stages of planning, ranging from strategic to operational. Inputs are collected online directly from the forests and one of the main outputs is a weekly schedule for each truck. The objectives are to minimise the total distance travelled, as well as the minimisation of empty driving. The annual savings created by using this system are estimated at several million US Dollars. This is achieved not only by an increase in efficiency, but also by an increase in up-to-date information on the overall process, from harvesting to sale of the product (Linnainmaa *et al.*, 1995). A similar system called SMART is used by a Swedish transport company, Skogsakarna Skogsakarna, which is located in the northern part of Sweden. It provides a vehicle schedule for one to several days and uses heuristics as a solution approach (Eriksson and Rönnqvist, 2003).

Carlsson and Rönnqvist (1998) identified the potential savings by using backhauling as a method of improving the efficiency of a transport operation. Backhauling occurs when a truck carries a load from a destination to the area of the origin of the first load. Large potential savings in direct costs, as well as a decrease in pollution, were identified through numerical results from case studies.

At Holmen Skog, a major Swedish forest company, a web-based transport planning tool named Akarweb has been in use since 2001. The transport work is carried out by a number of independent companies and organisations. The purpose of the system is to provide support to the transport managers and to allow for integrated planning between stakeholders (Eriksson and Rönnqvist, 2003).

5.2 Chapter Conclusions

Although studies into the transportation a relatively low value product from the field to the mill has not been widely published, examples of scheduling of vehicle fleets have been in operation since the 1970s in the timber and sugarcane industries. The AHSP has in fact many similarities to the PDPTW, one major difference being completion of the task after visiting the pickup node.

Instances of scheduling decision support tools described in this review are the ASICAM software used in the timber industry in Chile, the FREDD software used in sugarcane transport in Australia, the manual system of scheduling in sugarcane transport at Tongaat, and other scheduling solutions used within the Swedish timber industries.

For reasons of availability, local software expertise, capability to perform simulations and software cost, the ASICAM software was chosen as the only practical simulation tool for this scheduling study. It is a tool designed for timber, but has sufficient capability to provide meaningful results in a sugarcane study.

6 DATA COMPILATION AND SYSTEM CONFIGURATION

The objective of Chapter 6 is to describe the ASICAM configuration process enabling the model to accurately represent the actual business processes in Sezela of all logistical aspects including loading, transport and millyard systems.

The chapter goes on to document the procedure for the selection and preparation of the raw historical logistical data held within Laboratory Information Management System (LIMS) thereby ensuring that the simulations are performed using ASICAM simulations represents the day-to-day logistics in Sezela mill area. In addition the that is required to be filtering, cleaned and segmented prior to population of the ASICAM software, so that conservative scheduling simulations can be performed in reasonable time within the limitations of the software.

To follow in Chapter 7 is an investigation into the theoretical sensitivity of the transport system measured by daily tonnage delivered, total daily average queue time per vehicle, average vehicle working hours and average effective working hours, and the total sugarcane transport fleet size. This demonstrated the behaviour of the system in suboptimal fleeting conditions, which is the status quo at all South African sugar mills.

6.1 Information Sources for Simulations

I order to complete the ASICAM simulations, both a set of historical operational data needed to be compiled and a set of data that describes logistical business processes in Sezela (Table 6.1). Not of all information on each part of the supply chain necessary for ASICAM simulation is not held by any single organisation at Sezela. Information was therefore sourced from various organisations and industry experts as documented below.

Information pertaining to the millyard operations and the mill area was obtained from Sezela cane procurement (Simpson, 2004 and Tedder, 2004). This data included:

- Vehicle weigh-in and weigh-out durations,
- Millyard travel time,
- Offloading duration, and
- Trailer cleaning time.

Table 6.1 ASICAM model input requirements

Logistic Area	Data Requirement
Zone	Shift start
	Shift hours
	Sugarcane stock
	Loading time
Mill	Sugarcane demand
	Shift start
	Shift hours
	Unloading time
Truck	Shift start
	Shift hours
	Shift change
	Duration change
	Payload
Depot	Entrance time
	Exit time
Travel time	Loaded
	Unloaded

Information on different regional vehicle travel speeds and performance was obtained from local sugarcane grower and grower-cum-transporter (Cole, 2004).

Information regarding both infield and zone loading was provided by the mechanisation expert, from SASRI in Mount Edgecombe (Meyer (2004).

All information pertaining to quantities and origins of cane were found in the LIMS database captured mainly at the mill weighbridge. All data were date and time stamped, and along with a database of lead distances to each uniquely coded zone from which the cane originated.

Information stored within the LIMS database is sometimes erroneous and contains some delivery records which originate from infrequent deliverers/growers. Therefore, to provide reasonable amounts of accurate data in a reasonable time, data pertaining to small-scale growers and diversion cane was removed from the database. This was done because of the large number of individual small-scale farmers and their loading locations, as because of the number of different deliverers of diversion cane

(Union Cooperative, Eston and Noordsberg mill areas). This reduced the complexity of the scheduling simulations significantly (e.g. 164 large scale farmers vs. 2442 small scale farmers). Therefore, only cane delivered from large-scale growers (including the MCP), which used Sezela as their home mill, were simulated. Figure 6.1 shows the sugarcane origins on a percentage basis. Sezela large-scale growers produced approximately 79.4% of the total tonnage that entered the Sezela mill in the 2003/04 milling season. This is equivalent to 1 598 344 tons, or $\pm 55,000$ deliveries, at approximately one vehicle every six minutes.

6.2 The Selection Procedure for the Simulation Week

Due to simulation time constraints, it was decided to choose a single, but most representative week, within the 2003/04 Sezela milling season and to simulate a scheduled scenario using the ASICAM software. The supply of sugarcane from all the delivery locations in Sezela can be found on the LIMS database. The data include a date and time, grower, zone origin and mass for each delivery. Thus, on each of the seven days of the simulation the supply could be reconstructed.

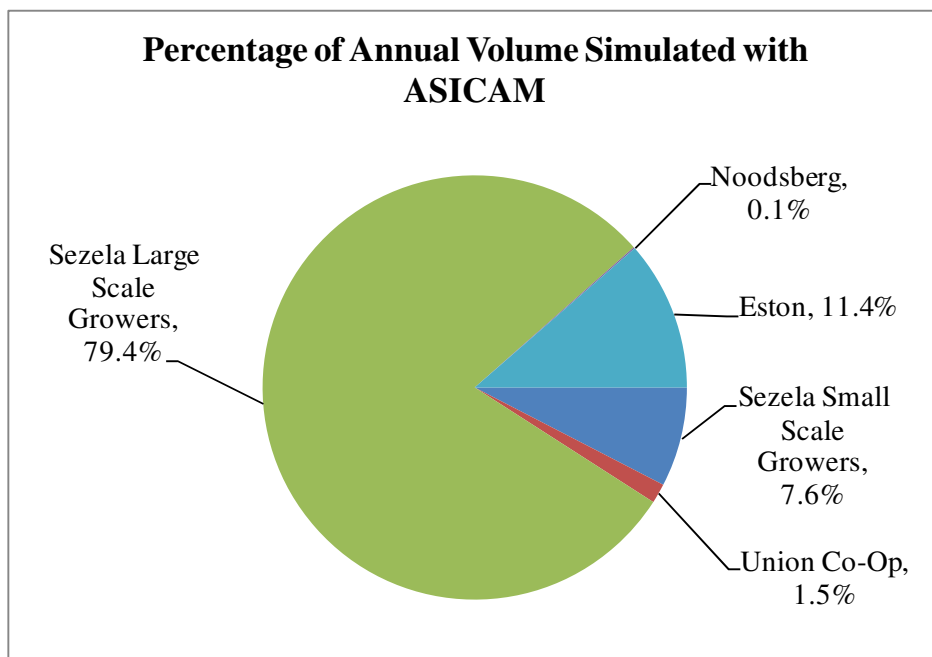


Figure 6.1 Origins of cane delivered into Sezela mill showing percentage simulated with ASICAM.

All weekly deliveries to the Sezela mill area are different with respect to loads per farm. Farm level and not grower level was selected to increase the accuracy of the calculation, as certain growers may own multiple farms. Excessive cane burnt during run-away fires, or rapidly harvested during severe frosts, are two reasons for growers to deviate significantly from their agreed Daily Rateable Delivery (DRD) allocation. It was important to select the week that best represented the norm (or the week with the fewest anomalies), so that the scheduling simulations would be as representative as possible. The most representative week was selected by calculating the two-dimensional euclidean distance on growers' farm delivery pattern quantifiers, as shown below.

Initially, a matrix of the number of deliveries per grower farm, per day, for every day of the 2003/04 milling season, was created using the following notation standard:

$$DG_{i,w,d} = (\text{count of daily loads})_{w,d} \quad (6.1)$$

where:

- $DG_{i,w,d}$: daily number of deliveries per grower farm per day,
- i : unique grower farm code (100707A, 100708B ...),
- w : milling week number (1, 2, 3, 4 ... 32), and
- d : week day (Monday, Tuesday Sunday).

From this matrix the mean number of loads per week day and per milling week per farm was calculated using the equation:

$$ML_{w,d} = \frac{1}{n} \sum_{i=1}^n (DG_{i,w,d}) \quad (6.2)$$

where:

- $ML_{w,d}$: mean number of loads per week day (d) per milling week (w) per farm, and
- n : number of farms delivering on a particular day during the 2003/04 milling season.

Because farms typically deliver a spread of number of loads around their DRD quota for various operational reasons, the standard deviation of the number of loads per grower per day was also calculated as:

$$SL_{w,d} = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (DG_{i,w,d} - ML_{w,d})^2} \quad (6.3)$$

where:

$SL_{w,d}$ = standard deviation of loads per week day per milling week per farm.

From this matrix of means and standard deviations, the median of the daily mean loads and the median of the daily standard deviation of the loads, was recorded. Together with the means and standard deviations calculated in Equations 6.2 and 6.3, the two-dimensional euclidean distances for each week in the milling season could be calculated using the following equation:

$$\delta_{w,d} = \sqrt{(ML_{w,d} - \overline{ML}_d)^2 + (SL_{w,d} - \overline{SL}_d)^2} \quad (6.4)$$

where:

$\delta_{w,d}$ = the two-dimensional euclidean distance,
 \overline{ML}_d = median of the mean number of loads per day per farm, and
 \overline{SL}_d = median of the standard deviation of loads per day per farm.

For each week, the daily euclidean distance calculated in Equation 6.4 was summed for all seven days of the week to give the total euclidean distance for each week, as shown in Equation 6.5.

$$\delta_w = \sum_{d=Monday}^{Sunday} \delta_{w,d} \quad (6.5)$$

Where:

δ_w = total weekly euclidean distance.

The week with the fewest anomalies within the 2003/04 milling season is therefore the week with the minimum total weekly euclidean distance and is calculated by Equation 6.6:

$$\text{Week with the fewest anomalies} = \min(\delta_1, \delta_2, \delta_3, \dots, \delta_{32}) \tag{6.6}$$

Using Equation 6.6, Week 22 was selected as the week with the most normal volumes and fewest delivery deviations during the 2003/04 milling season.

Figure 6.2 depicts the distribution of the euclidean distances for all of the crushing weeks in the 2003/04 season. The relatively flat profile of the Euclidean distance for approximately 80% of the weeks of the season emphasises the validity of Week 22’s selection as representative week within the season.

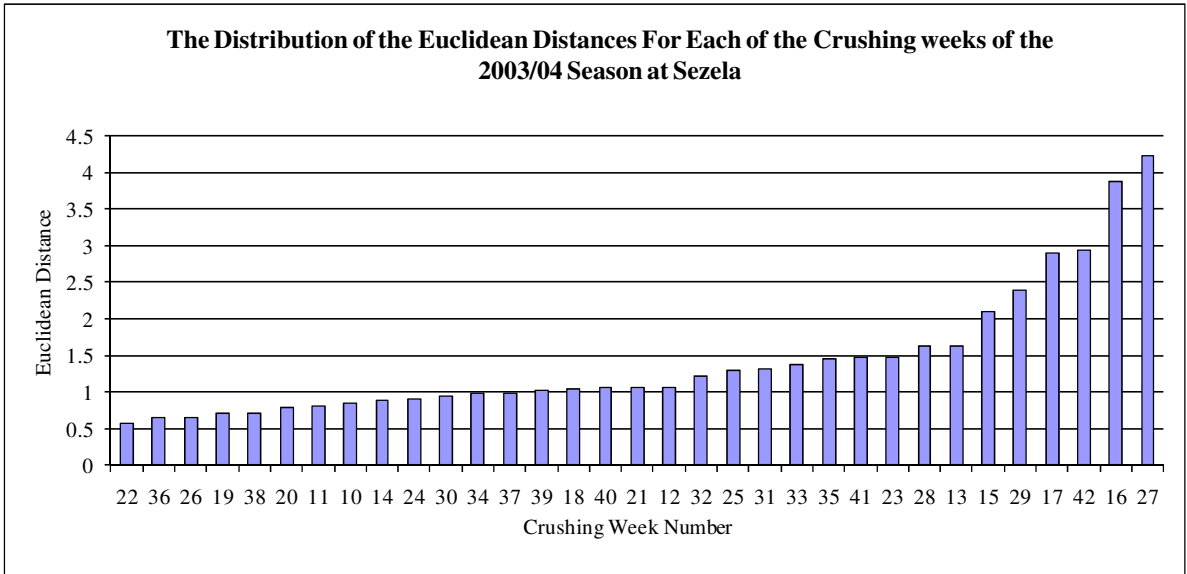


Figure 6.2 The distribution of the euclidean distances for each of the crushing weeks in the 2003/04 season at Sezela.

As mentioned previously, the LIMS data pertaining to Week 22 was partially incomplete with respect to the origins of all the sugarcane loads. This is because the grower code is the only mandatory information required on the delivery note. The remaining information is optional for the driver/grower/clerk/loader operator to complete on the delivery note. Therefore, a manual data infilling procedure was followed as described below to complete the data set:

- i. Rank all the farm codes in Week 22 (each grower is issued with a unique code for each farm).
- ii. Group all zone codes within each week day.
- iii. If a zone code is missing from a delivery entry, and the deliveries before and after the delivery in question have an identical zone code, then automatically infill the same zone code.
- iv. If the zones before and after are not the same then infill the zone code with the larger lead distance to be conservative.

6.3 Daily Equitable System Division Procedure

Although used operationally in the Chilean and South African timber industries, the ASICAM scheduling software has two limitations that are pertinent to this simulation study. First, a maximum period of 24 hours can be simulated at a time, and secondly, the software can accommodate a maximum of 39 grower/farm zones. Since a whole week was required for the scheduling study, and an average of approximately 95 large-scale and MCP growers delivered sugarcane per day, the following solution was decided upon. Three copies of ASICAM software were executed independently and in parallel each day, each run simulated an equitable third of the supply (only two runs were needed for Sunday, because it is a low delivery day). This was an acceptable solution as, at present, three offloading facilities exist at the mill. These are the east spiller, west spiller and dummy spiller, and each one could therefore be used and could operate independently in the three equitable daily divisions. It was assumed that the weighbridge and the cleaning bay had sufficient capacity to process the arrivals from each of the three equitable divisions.

An equitable procedure was followed to divide the daily supply into three sets. It should be noted that, on any given farm on any particular day, there is often more than one zone that is used for loading, e.g. when one field has been loaded and the vehicles move on to the next. The lead distances from these zones to the mill are different, although they are on a single farm. For this reason, each zone was treated independently to increase simulation accuracy. The following procedure was followed:

1. A matrix of each zone's total daily delivery tonnage and lead distance to the mill was generated. The number of loads was calculated by dividing the total daily tonnage by the average payload and rounding to the nearest whole payload (for more information, see Section 6.4.2).
2. From the lead distance, the inbound and outbound times for each zone was calculated using the vehicle speed as described in Section 6.4.4 and Equation 6.7 below.

$$T = \frac{D}{S} \quad (6.7)$$

where:

- T = calculated inbound or outbound time (minutes),
- D = distance from zone to mill (km), and
- S = average speed, either inbound or outbound (km/h).

3. Along with the loading time, weighing time, offloading time, cleaning time and inbound and outbound time, the cycle time was calculated using Equation 6.8 (for descriptions of how each of the terms of Equation 6.8 were calculated, see Section 6.4).

$$C = L + IT + WT + O + CT + OT \quad (6.8)$$

where:

- C = cycle time (minutes),
- L = the time to load a vehicle on zone (minutes),
- IT = the time taken for the vehicle to travel loaded from zone to mill (minutes),
- WT = the time to weigh the vehicle loaded and empty (minutes),
- O = the time to offload the vehicle of the sugarcane (minutes),
- CT = the time to clean the vehicle of any sugarcane not removed during the offloading process (minutes), and
- OT = the time taken for the vehicle to travel unladen from mill to zone (minutes).

4. Each zone's cycle time was then multiplied by the rounded tonnage delivered to produce a weight indicator

$$y = Z \times C \quad (6.9)$$

where:

- y = weight indicator (ton.min), and
- Z = zone tonnage (tons).

These indicators were ranked in descending order and divided into three equitable sets by placing each third entry into one of three sets of independent spiller groups.

In addition, within each of the independent spiller groups, an ASICAM software heuristic limitation became apparent and that needed to be accounted for. The software had a limitation in that a vehicle was sent to a zone only when the previous vehicle had returned to the mill. This limitation was checked and it was found that in certain cases the tonnage delivered on a particular day exceeded the capacity of a single vehicle operating in this fashion on the zone.

A second procedure was followed and a second indicator was calculated to show whether the above scenario existed and in such cases the zones were split accordingly.

6.4 ASICAM Inputs

For ASICAM to schedule vehicles, sets of information needed to be inputted into the software to describe the Sezela transport system. With this description of the transport system within ASICAM, different and independent instances of ASICAM were executed to represent different days (Monday to Sunday) of Week 22, 2003 and to schedule the three different spillers. This equated to 20 simulations, three per Monday to Saturday and an additional two on Sunday. A description of each of the required inputs mentioned above follows.

6.4.1 Offloading Time

As described in Section 2.4, four offloading facilities exist at Sezela mill: bundle offloading, east spiller, west spiller and the dummy spiller. As discussed, the bundle deliveries are being phased out and constitute only a small percentage of Sezela's DRD, and therefore only the other three offloading facilities were considered in this study. Bundle sugarcane was therefore considered as spiller cane.

For the purpose of this study, all three spillers were assumed to function at the same rate to supply the mill demand of 450 tons per hour. To the author's knowledge, studies detailing the physical offload time have not been done in recent years, therefore two approaches were followed to obtain realistic and appropriate time estimates.

Firstly, the cane supply manager at Sezela, Mr Allan Simpson, performed a short duration time and motion study, and concluded that the time taken to offload the largest double interlink cane trailer was between 10 and 15 minutes. The second approach was to calculate backwards from the mill crushing

capacity of approximately 70 000 tons per week, and to calculate the maximum offload time. As can be seen in Table 6.1, under the Full Capacity column, the weekly tonnage of approximately 70 000 tons per week is divided by six and a half working days to obtain the daily operating capacity. This is then divided by its operating hours of 24 hours per day, to obtain the daily crush rate of approximately 450 tons per hour. If it is assumed that the three spillers are operating simultaneously, the offload capacity of each is approximately 150 tons per hour. The median truck configuration in the Sezela mill area is a 31 ton payload cane interlink, which equates to 4.82 offloads per hour. Thus, the time to offload a double interlink trailer is 12.44 minutes, which was rounded to 13 minutes as ASICAM does not accept fractions of a minute.

Table 6.2 Determination of offloading times for the ASICAM scheduling simulations.

	Full capacity	80% capacity
Tons per week (t)	70000	56000
Tons per day (t)	10769	8615
Tons per hour (t)	449	359
Spillers operating	3	2.4
Tons per spiller per hour	150	150
Offloads per hour	4.82	4.82
Spiller time (min)	12.44	12.44

Under the simulation scenario, accounting for 80% of the mill supply (diversions and small-scale sugarcane excluded) of 56 000 tons per week, a similar procedure can be followed and is shown in the 80% capacity column of Table 6.1. It can be seen that if all three spillers continue to offload at the same rate of 12.44 minutes, 20% of the time is available to offload the excluded 20% of the mill supply not scheduled by ASICAM.

6.4.2 Cane Transport Vehicles

ASICAM has provision for three levels of vehicle setup which are vital in describing agricultural transport systems, and it has the facility to include various products. First, the *type* of truck, which allows for the description of differing payload-carrying abilities for different vehicle configurations. For the purposes of this study, a single commodity (sugarcane) is assumed, therefore all the trucks in the simulation are designated as the same type. Division of cane loaded infield and cane loaded on the zone was considered, but due to a lack of information regarding these loading techniques the idea was abandoned.

Second, the *class* of vehicle, which allows the user to limit a truck or groups of trucks to certain supply points. Season contracts between certain growers and hauliers are an example of this. Contracts, such as these are common at Sezela, but were set to be all of one type in order to simulate a homogeneous fleet, and it was therefore assumed that all vehicles could service all zones. Furthermore, the gains seen by allowing all vehicles to have access to all supply points was of interest to the relevant parties.

Thirdly, ASICAM has provision for a description of every vehicle and its operating parameters. These include naming codes, working hours, shift change time and duration, and class and type of truck. The payload quantity chosen as the representative payload for the vehicles in the simulation was done by analysing the vehicle information in the LIMS database. Of the approximately 300 vehicles registered to enter the mill, 75% were the 31 ton Interlink. This was therefore a representative choice of vehicle configuration and payload.

Although a uniform payload of 31 tons was selected, deviations were present in practically every delivery, because it is impossible to load a vehicle with an exact tonnage every time, even with sophisticated load measuring devices. This is due to the variable density of both the individual sugarcane sticks and the bulk of loaded sugarcane. Age, variety and burn-to-crush delay are all factors that affect the density of sugarcane. Therefore, the total daily supply from each delivery zone was rounded to the nearest whole payload. To check that no significant error was produced by the rounding procedure, the total daily delivered tonnage was checked against the new total rounded tonnage. On every day the change in tonnage was satisfactorily small.

6.4.3 Loading Time

The time to load 31 tons into a vehicle at a zone was entered to be 50 minutes. This was calculated as the average time for infield vehicle loading by a three-wheel loader and, on a zone, for loading by a crane (Meyer, 2004).

6.4.4 Travel Times

ASICAM is a time-based program, meaning that the lead distance to each zone must be converted to a lead time. Therefore, a representative inbound loaded, and outbound empty vehicle speed was selected. This was coupled with the lead distance information, to calculate the inbound and outbound lead times using Equation 6.7 described in Section 6.3.

After meetings with experienced transporters in the Sezela area, it was decided to use three representative inbound and outbound speed sets, one to each of three relatively similar geographic/terrain areas within the Sezela mill supply area. The three areas were: (i) the relatively flat coastal region, (ii) the steep inland region and (iii) the mainly gravel road hinterland region. A local sugarcane grower and haulier, was consulted about the transport speeds to the three areas. He transports sugarcane from these areas on a regular basis, and records average speeds using his vehicle on-board computers (Cole, 2004). From his records, speeds for the coastal, hinterland and inland areas were assumed as shown in Table 6.2.

Table 6.3 Representative speeds to each of the three homogeneous areas in the Sezela supply area for both inbound (loaded) and outbound (empty) trips.

	Inbound (km.h ⁻¹)	Outbound (km.h ⁻¹)
Coastal	52	60
Hinterland	25	40
Inland	51	51

The vehicles used were relatively large truck-tractors of approximately 380 kW, which allowed for good uphill speeds. They were fitted with intarders which allowed faster downhill speeds. The coastal area had the highest speed both inbound and outbound. This was due to the relatively flat terrain. The inland area (Highflats area) had the second fastest speeds, with both inbound and outbound speeds being the same due to long ascents and descents. Lastly, the hinterland area had the lowest speeds, due to the poor road surfaces and the existence of many short, steep climbs and descents.

The ASICAM program has no facility for the inclusion of millyard activities in the offloading time component. Therefore, time for weighing in and weighing out was added to the inbound and outbound legs, respectively. Time was also added to the outbound leg to account for the time taken to clean the trailers of any loose cane not offloaded in the spilling process (Table 6.3).

Table 6.4 Average millyard times for vehicles at Sezela (Simpson, 2004).

	Added to inbound time	Added to outbound time
Weighing in	4 minutes	-
Weighing out	-	3:30 minutes
Trailer cleaning	-	5 minutes

6.4.5 Cane Transport Vehicle Depot

Any vehicle used to transport any commodity, whether it be commuters, high value break bulk or sugarcane will operate from a depot. This depot is where refuelling and maintenance occur, where shift changes are most likely to take place, and where the necessary administration is often located. For the purposes of the simulation, a depot 10 minutes from the mill, from which all the vehicles operated, was assumed. This coincided approximately with the current Unitrans depot on the access road to the mill.

Two additional times are needed for ASICAM to complete a schedule for the fleet. These are the time to each of the zones from the depot, and the time from the mill to the depot. These times simulate the first trip of the day which starts from the depot, and the last trip of the day from the mill, after offloading the last load for the shift.

6.5 Optimisation Procedure

Although the ASICAM scheduling software is an effective scheduling tool, it does not optimise the fleet requirement to transport the cane from the zone to the mill. Rather, the number of vehicles despatched on a particular day is determined by the user, and ASICAM shares the workload equitably between the vehicles. Therefore, the process followed was to repeatedly run ASICAM fully configured, for each equitable spiller division, on each day, and to vary the number of vehicles, while monitoring whether the mill demand was being fulfilled. This process continued until the demand was not fulfilled, when it was assumed that the number of vehicles had been optimised. In some instances the mill demand could not be supplied by a small fraction of the supply. In these instances the optimisation procedure ceased when the maximum supply was delivered to the mill.

6.6 Transport System Sensitivity to Fleet Size

An investigation into the sensitivity of the tonnage delivered, queue time, vehicle working hours and effective working hours, as well as the total sugarcane transport fleet size, was completed for each of the three equitable fleet divisions, to demonstrate the behaviour of the system in sub-optimal fleet conditions. Tuesday was selected as the day most representative of a normal day in Sezela, as Monday, Friday, Saturday and Sunday have differing logistical arrangements. It was also of interest to this review to investigate the magnitude and trend of the effect of introducing insufficient and excessive

vehicles into the system. The situation of excessive vehicles was of specific interest, as over-fleeting is commonplace at all South African sugar mills.

The tonnage delivered is an indicator of the minimum or optimal requirement. Below this threshold, the transport systems capability to deliver all the sugarcane is insufficient, while above the same threshold would indicate excessive vehicles operating in the system, creating an over-fleeting situation.

The total daily average queue time per vehicle in each of the three equitable divisions is an indicator of the inefficiency caused by increasing the number of vehicles above the optimal requirement. Below this threshold is irrelevant to this study, as the primary objective of delivering the required tonnage to the mill is not satisfied. Above the threshold is of particular interest as again it quantifies the effect of over-fleeting on the system in terms of additional queuing time. The total average daily queuing time can be divided by the average number of trips per vehicle per day to give an indicator of the average queuing time per vehicle per trip, but should be viewed with caution as the queuing times recorded on an individual basis are significantly variable.

The total daily average working hours per vehicle is an indicator of the availability of the vehicles. As the fleet size increases for the given supply, the tons transported per vehicle per day decrease, as do the hours of operation. The effect of fixed shift change times can to an extent be seen by the magnitude of the difference between the hours worked and total 24 hours. As the time of day nears shift change time, the ASICAM software will park a vehicle if it cannot be sent out on an entire cycle and return empty to the depot before shift change time. Again, a fleet size below the optimal is of little relevance to this study, but the effect of over-fleeting is of particular interest.

The effective working hours are defined as the working hours described above, less the shift change duration (user-defined in ASICAM), less the total daily average queuing time. This time is an indicator of the utilisation of the vehicles, as it is the time during which income generating tasks of loading and transporting sugarcane are being performed.

In all cases the number of trucks operating in the ASICAM software was varied manually over a reasonable range, and the tonnage not delivered, the total average daily queue time per vehicle, the working and effective working hours per vehicle per day recorded accordingly.

6.7 Model Validation and Verification

ASICAM validation was completed by observing the model results relative to the current logistical environment and to manually verify samples of the outputted data to be within expected and reasonable ranges.

Model verification of the simulated results vs. real world actual results was not considered practical as it was not possible to identify an example of this type of research approach against which to compare results. In addition the approach follows an Operation Research optimisation approach and should not be confused against the real world as it does not currently exist.

Lastly, no documented sensitivity studies for ASICAM were available as the model is one used only in the commercial environment and not in the academic environment.

6.8 Chapter Conclusions

This chapter described the data compilation procedures used so that the ASICAM scheduling tool could be used to conservatively simulate the present transport system, under the scenario of a central scheduler. This simulation provides a valuable benchmark against which to investigate a range of transport system scenarios that can be simulated by varying the input parameters. A description of each of the scenarios simulated will be discussed in the following chapter.

7 INVESTIGATORY SCENARIOS SIMULATED

When a benchmark simulation of the 2003/04 Sezela transport system had been completed and was operating within satisfactory tolerances, ‘what if?’ scenarios could be evaluated and quantified using ASICAM. Presumably any scenario regarding any of the inputs described in the previous chapter could be studied. Input parameter sensitivities to be simulated and decided upon according to the sugar industry’s interest were (Lyne, 2004; Simpson, 2004; Crickmay 2004):

1. Differing loading times,
2. Differing offloading times,
3. Changing vehicle speed by changing the truck-tractor engine power and braking ability, and
4. Increasing the payload carrying ability of the vehicles.

Tuesday of Week 22 (*viz.* 22 July 2003) was selected as an appropriate day to perform the scenario simulations. Monday, Friday, Saturday and Sunday normally have different logistical arrangements as a result of grower-miller arrangements, labour issues and maintenance schedules.

This chapter describes each of the above four scenarios, and the range over which each scenario specific input was varied. All of the scenarios chosen and their associated ranges exist in limited numbers in South Africa and in other countries, and are therefore significant to the South African sugar industry’s decision makers. Costing of the payload scenario performed is reported and enables a direct economic comparison to be made between the benchmark and payload scenarios.

7.1 Loading Time Variation

The loading time of a vehicle constitutes a significant fraction of the cycle time. Typical loading times vary between 40 minutes and one hour where a zone crane and three-wheeled loader are used, respectively (Meyer, 2004). These are currently the two most popular methods of loading in South Africa. Other sugarcane loading equipment is in the research and development phase and is being used only to a limited extent. Trailer management strategies are also being developed that can significantly improve loading times. Examples are a high capacity modified excavator, which can load a 31 ton payload in under 20 minutes, and the UVS Dovea dolly system that operates two sets of trailers shuttled between a single truck-tractor, with an effective load time of under 10 minutes (Crickmay, 2004).

It has long been recognised that a decrease in load time, and therefore cycle time, will benefit the transport system, but the extent of the decrease is relatively unknown. This scenario investigation was aimed at quantifying, in terms of fleet requirements, the benefits of adopting strategies that will decrease loading times.

Using the benchmark scenario as a platform, the loading times from all the zones were varied from 100 minutes to 10 minutes, at 10 minute decrements. All other ASICAM inputs were kept constant so that a comparison between other further scenarios could be made.

7.2 Offloading Time Variation

The offloading system choice at Sezela, the associated offload time, and the effect on the transport system, is currently a controversial issue (Crickmay,2004 and Simpson, 2004). This scenario quantified the effect of the offload system choice, with its associated offloading time, by simulating and scheduling the Sezela transport system using ASICAM, and calculating the required number of sugarcane transport vehicles. The scenario investigates decreasing the offload time from the present 13 minutes to five minutes, at approximately two minute decrements.

Because the mill has a fixed crush capacity of approximately 450 tons per hour, no increase in trucks offloaded per hour is possible, although they can be physically offloaded in a shorter period. Therefore, the benefit of decreased offloading time would be seen only in that the truck could be routed earlier to its following loading point, thereby reducing its effective outbound time.

Using the aforementioned benchmark scenario as a platform, each outbound (empty) travel time to every loading zone was reduced by a total of eight minutes, at two minute decrements, thereby simulating a reduction in offloading time. As mentioned in Section 7.1, all other parameters were kept constant for purposes of comparison.

7.3 Truck Tractor Power and Braking Ability

For a given payload and lead distance, the higher the power rating of the truck-tractor, the shorter the time to haul the load due its higher power-to-weight ratio and associated higher speed potential within safe and legal parameters. As described in Section 2.3.2, the downhill speed and therefore the travel

time, is a function of the safe braking ability of the haulage vehicle. Making use of a retarder or intarder can have a significant effect on the allowable safe downhill speed, thus reducing the travel time.

For the purpose of this scenario, two different truck-tractor powers were simulated. A relatively large 380 kW Mercedes Benz Actros 3348 fitted with an intarder, as in the benchmark simulation, and an older Mercedes Benz 2637 with no additional braking systems were used. Again a local grower and transporter, who operates both categories of truck-tractors, was consulted and provided information included in Table 7.1, which shows averages from recorded data pertaining to the three homogeneous areas of coastal, hinterland and inland (Cole, 2004).

Table 7.1 Speeds to the homogeneous regions in the Sezela supply area for both 380 kW and 280 kW vehicles, inbound and outbound.

	Inbound (km.h⁻¹)	Outbound (km.h⁻¹)
380 kW, Intarder fitted as standard		
<i>Coastal</i>	52	60
<i>Hinterland</i>	25	40
<i>Inland</i>	51	51
280 kW, no additional braking system		
<i>Coastal</i>	45	50
<i>Hinterland</i>	25	28
<i>Inland</i>	32	36

7.4 Payload Increases

A typical interlink configuration vehicle carrying sugarcane is limited by South African law to carry a Maximum Permissible Combination Mass (MPCM) of 56 tons. The MPCM is the total of the payload mass plus the vehicle tare mass. Therefore, to increase the payload carrying ability, the tare mass of the vehicle must be decreased. This is achieved through re-engineering, making use of lighter materials and more efficient trailer design(s), or in some cases, a change in the vehicle configuration itself. Such is the case in the timber industry, which uses aluminium rigid-and-drawbar configurations designed using technology from Sweden (Armstrong, 2004)

As a demonstration of this principle and philosophy, Figure 7.1 shows the evolution of timber transport vehicles over a 10-year period. Payloads were legally increased from 28 to 42 tons over the period 1992 to 2002.

The scenarios chosen to simulate realistic ‘what if?’ vehicle payloads were:

1. 31 ton payload, benchmark sugarcane Interlink used extensively in Sezela (see Figure 7.1),
2. 35 ton payload, rigid-and-drawbar cane trailer used fairly frequently in other mill areas in South Africa (see Figure 7.2),
3. 38 ton payload, rigid-and-drawbar cane trailer with the spiller chains removed, emulating a Brazilian method of offloading (Figure 7.3).
4. 44 ton payload, Performance Based Standard (PBS) trailer configuration based on the Australian non-prescriptive system of vehicle design (Nordengen *et al.*, 2008).

The 31 ton Interlink truck-tractor and trailer combination, as discussed in Section 4.4.4, is the most common configuration in the Sezela mill area (Figure 7.1) and is readily available from trailer manufacturers. It is used as the benchmark scenario against which improvements in payloads were compared.



Figure 7.1 A typical sugarcane truck-tractor and interlink trailer combination.

The 35 ton rigid-and-drawbar configuration is also currently available and has a payload benefit of approximately four tons, while remaining compatible with the current spiller offloading facilities. It is used fairly frequently in mill areas in the Mpumalanga and northern KwaZulu-Natal regions (Figure 7.2).



Figure 7.2 A typical sugarcane rigid-and-drawbar combination.

The 38 ton payload vehicle was chosen to emulate a Brazilian system of offloading, where the trailer design allows offloading staff to feed cables beneath the payload and sling the sugarcane from the trailer. The stresses imposed during the offloading process are significantly reduced, allowing for a lighter trailer design. In addition, the spiller bar and spiller chains are part of the mill's offloading mechanism (Figure 7.3) and not part of the vehicle itself, again lowering the tare weight of the vehicle and allowing for greater legal payloads.



Figure 7.3 A typical Brazilian sugarcane vehicle (left) showing the spaces provided for feeding the offloading cables with the cables inserted ready for offloading, together with the spiller mechanism (right) to which the cables are temporarily attached to offload the sugarcane.

The current fleet of haulage vehicles in South Africa (including the three combinations/designs discussed previously) complies with a set of prescriptive regulations which specify a number of parameters, such as the vehicle's dimensions and its configuration. However, these regulations do not

address the vehicle's dynamic performance, such as its tracking ability, its roll-over threshold and its behaviour when a sudden directional change is made. In addition, legislation on vehicle loading focuses on axle and axle unit loadings, maximum permissible vehicle and combination mass, and the so called 'bridge formula'. While the current regulations address a range of safety issues, there are some aspects of heavy vehicle safety performance that are not adequately controlled by these regulations (Nordengen *et al.*, 2008).

In contrast to the prescriptive regulations are Performance Based Standards (PBS) vehicles which are deemed vital in improving productivity and safety in the transport industry, which in turn is vital for the country's competitiveness in international markets. The objectives of the PBS philosophy (Nordengen *et al.*, 2008) are to utilise technology to:

- reduce road damage,
- improve safety,
- increase payloads, and
- reduce costs.

The benefit of using the sophisticated PBS numeric modelling technique is that the design approach is not bound by the accepted prescriptive regulations, although the redesigned vehicle will still conform with road infrastructure and safety conservation principles. As an example, PBS-designed vehicles will be able to safely carry heavier loads by increasing overall vehicle length, with no adverse effects on the road surface other than normal deterioration. This will have a positive effect on the productivity and safety record of the transport industry (Nordengen *et al.*, 2008).

To simulate the improved payload scenarios, certain ASICAM input parameters needed to be modified. Table 7.2 summarises changes to the offloading, loading and inbound times for each increased payload scenario. First, a 35 ton payload was based on a rigid-and-drawbar type configuration, and this was assumed to reduce tare mass by 4 tons, but actually increased the offloading time from 13 to 15 minutes and loading time from 50 to 56 minutes. This was calculated on the basis of proportion to the linear increase in payload. Secondly, a 38 ton payload was based on a Brazilian system after removing all spiller chains. Offloading time, however, was assumed to increase to 16 minutes and loading time to 61 minutes. Thirdly, the PBS vehicle design was assumed (PBS, data courtesy of Mr Andrew Crickmay of Crickmay and Associates). This vehicle was allowed a 44 ton payload and gross mass of 61.5 tons, but was assumed legal, based on successful safety and performance evaluations as per PBS.

Offloading time was increased to 18 minutes to compensate for the mill’s maximum potential crush rate of 450 tons per hour. Loading time was increased to 71 minutes and inbound travel time was increased on the assumption that a truck-tractor with engine power similar to the one hauling in the other payload scenarios would be used. This would therefore have a lower power to weight ratio. This reduction in ratio was assumed to decrease the inbound time by the same proportion as the GCM increase. No outbound time increase was assumed, since the power-to-weight ratio of the empty vehicle would be sufficiently high in both the case of the interlink and the PBS vehicle.

Table 7.2 System properties that were changed to simulate and investigate higher vehicle payloads using the ASICAM software.

Property	31 t (benchmark)	35 t (rigid-&-Drawbar)	38 t (Brazil)	44 t (PBS)
Offload time (min)	13	15	16	18
Inbound time increase (%)	N/A	N/A	N/A	9.7
Load time (min)	50	56	61	71

Since new payload scenarios were being investigated, the number of loads per zone needed to be adjusted to ensure that all zone supply was divisible by the respective improved payload. It was, however, ensured that the total sugarcane supplied on any given day remained relatively constant, and that the distribution of supply, on a ton by kilometre basis, remained balanced to ensure that the system remained representative of the Sezela system. The change in the total tons per zone was checked manually to be less than 50% of the new payload.

In terms of the costs associated with each configuration, the interlink trailer was deemed to cost the same as the rigid-and-drawbar configurations. The same was assumed for the Brazilian-type trailers. In the case of the PBS vehicle the trailer was assumed to cost significantly more, and an increase in price of 20% was assumed as this type of vehicle is not yet commercially available on the South African market.

7.5 Chapter Summary

Using the benchmark ASICAM simulation as a reference, scenarios of interest to the sugarcane industry could be conservatively studied and quantified by simulation. Tuesdays would always be used as a reference. However, when studying a particular scenario, it was important that all other parameters

be kept constant so that direct and meaningful comparisons could be made. The following chapter documents the results pertaining to these scenarios, including costings to convert each set of ASICAM outputs to monetary terms.

8 RESULTS

Initially ASICAM was configured and used to produce a benchmark set of results using the data set that best described the current environment at Sezela. This benchmark system demonstrated the benefit of moving towards a central scheduling controller, using a generic fleet of vehicles that could visit all possible pickup points. In addition, the benchmark can be used as a base against which all the subsequent scenarios of further logistics could be compared.

The results are structured firstly to provide insight into the sensitivity of the total tonnage delivered, individual queue time per delivery, total daily vehicle working hours and effective working hours, by varying the total sugarcane transport fleet size. The objective is to demonstrate the logistics system behaviour in suboptimal (excess) fleet conditions. Secondly, the benefits of improving loading time, offloading time, vehicle speed and payloads are shown in an attempt to quantify the benefits of each.

Accompanying the benchmark and payload investigatory scenarios is a set of vehicle costings. These convert the scheduling output figures of fleet size and efficiency into monetary terms and thus quantify the benefits. Information is provided on which decisions pertaining to changing relevant systems can be based. For an explanation of the methods for the benchmark and scenario scheduling simulations, see Chapters 5 and 6. For an explanation of the costing procedure, see Chapter 3.

No costings pertaining to loading and offloading times and vehicle speed scenarios accompany the investigations, as many crude assumptions would have to be made as to the costs of improving these values, e.g. capital for offloading and loading equipment, and these could distort the results.

8.1 Benchmark System Simulations

The pertinent information from the ASICAM software is summarised in Table 8.1 for each of the divisions, Monday to Sunday for the Week 22, 2003. Reading the table from left to right, the week day and the division is detailed with the sum of the total demand (made equal to the supply) for the 24 hour period captured from the LIMS database. The 'number of trucks' column details the required fleet for each of the system divisions, when ASICAM is used to schedule the vehicles. This column should be viewed with reference to the column headed 'trucks used at present' which describes the number of different vehicles that passed over the weighbridge and was captured on the LIMS system on the

particular day. It can be seen that the fleet ranges from 52 per day to a maximum of 82 per day during this particular week. It should be noted that, at present, the number of vehicles used on any particular day would exclude any vehicles not active in the system (such as breakdowns, those in for maintenance or those that exclusively transport cane that forms part of the diversions and/or small scale grower cane). If the same LIMS data are investigated with respect to the number of different vehicles crossing over the weighbridge during the week-long period, 95 different vehicles are recorded, and if the same query is performed for the 2003 season, 107 different vehicles can be identified.

In percentage terms, if 41 vehicles is taken as the reference (the maximum fleet requirement which can be seen on Saturday), a reduction of approximately 50% in the vehicles required daily can be seen to transport the equivalent tonnage, over the same leads from the same zones. Furthermore, in the case of the entire week and the whole season, reductions of 56% and 76% respectively, are evident. Due to the reduced total fleet, the total daily average queue time per vehicle is shown; this corresponds to approximately 10 min per vehicle per trip, giving a mill turnaround time of approximately 35.5 minutes, if weighing time, yard travel time, cleaning time and offloading time are included. Relative to the average mill turnaround time for the 2003/04 season of 116 minutes, there is an improvement of 80.5 minutes.

The working hours per day and the effective working hours are shown, as are the loads simulated not to be delivered by the vehicles into the mill with respect to the supply gathered off LIMS. This was due to the coarseness of the supply network, combined with the zone number limitation of ASICAM, and cannot be eliminated no matter how many vehicles are introduced into the system. It should, however, be viewed with reference to the number of loads transported for the day, and therefore only constitutes a relatively small tonnage.

Figure 8.1 summarises the data pertaining to the present daily system fleetings, and the system requirement, under a central scheduling control, where it was assumed that the complexity of vehicles dedicated to specific growers or groups of growers was removed (the results would be further improved if the 'only day' and 'only night' growers changed to a 24 hour loading strategy).

Table 8.1 A summary of the ASICAM output for Week 22.

Week day	System division	Mill demand (tons)	Number of loads	Number of trucks	Trucks used at present	Total daily average queue time (hh:mm)	Average effective working hours (hh:mm)	Working hours (hh:mm)	Loads not received
Monday	1	1984	64	11	63	00:52	17:20	18:41	0
	2	2139	69	9		01:39	18:29	20:39	0
	3	2015	65	10		00:53	17:05	19:14	0
	Total	6138	198	30		01:08	17:38	19:31	0
Tuesday	1	2697	87	13	74	01:56	19:00	21:26	0
	2	2635	85	10		02:03	19:56	22:29	0
	3	2480	80	12		01:03	18:03	20:13	0
	Total	7812	252	35		01:40	18:59	21:22	0
Wednesday	1	2759	89	14	82	01:35	18:00	20:05	0
	2	2604	84	12		01:15	17:39	19:24	0
	3	2852	92	14		02:00	17:43	20:13	1
	Total	8215	265	40		01:36	17:47	19:54	1
Thursday	1	2883	93	14	77	01:44	20:02	18:06	1
	2	2728	88	12		01:36	21:35	19:29	0
	3	2542	82	12		00:54	20:38	19:14	0
	Total	8153	263	38		01:24	20:45	18:56	1
Friday	1	2666	86	13	75	01:44	18:48	21:02	0
	2	2728	88	13		01:45	19:01	21:16	0
	3	2604	84	13		02:18	17:31	20:18	0
	Total	7998	258	39		01:55	18:26	20:52	0
Saturday	1	2728	88	11	70	01:34	19:38	21:42	0
	2	2728	88	16		02:52	15:14	18:36	0
	3	2635	85	14		02:25	15:47	18:42	1
	Total	8091	261	41		02:17	16:53	19:40	1
Sunday	1	1674	54	9	52	01:15	17:56	19:04	0
	2	2356	76	12		05:47	15:41	21:58	3
	Total	4030	130	21		03:31	16:48	20:31	3

The results in Figure 8.1 also demonstrates the inconsistent sugarcane delivery pattern in terms of tons delivered per day, even in the most normal week in the 2003/04 season, *viz.* Week 22. As a result, the hauliers supply fleet for the maximum probable tonnage demand and therefore are significantly over-fleeted for the remainder. In the author's opinion, this imbalance in tonnage delivered per day is one of the more fundamental problems facing the industry, the reasons for which need to be investigated further. It would seem plausible that under a system of central control and with a generic fleet, not only could the reasons for the under-supply be better managed at a tactical and strategic level, but so too could the operational management of the problem. There is also a growing 'master-servant' relationship between grower and haulier, which is a result of the industry Rörich Commission of 1984, where the miller no longer bears the responsibility of transporting the sugarcane to the mill. The

commercial hauliers are at the mercy of poorer and more variable transporting conditions to avoid losing contracts with growers. Conditions such as significantly variable and excessive loading times, poor on-farm road conditions, poorly maintained and insufficiently staffed loading equipment, sub-optimal individual grower loading windows and variable supply of cane on a day-to-day basis, are commonplace in all mill areas across South Africa.

It must be noted that significant education about the operation of the system, and the involvement and responsibility of all parties, would be needed prior to the commencement of the scheduling project. The level of discipline amongst the role players would need to be high, especially under the static daily ASICAM scheduled plan, as the sensitivity of the schedule to changes in the assumed times (loading time, offloading time, cleaning time and travel times) could be significant. Indeed, if scheduling were to be employed in the South African sugar industry, a dynamic form of scheduling is vital for significant efficiency increases to be realised to account for the inherent variability (labour issues, mechanical failures, mill crush rate variability and variable weather conditions) common within the sugarcane supply chain.

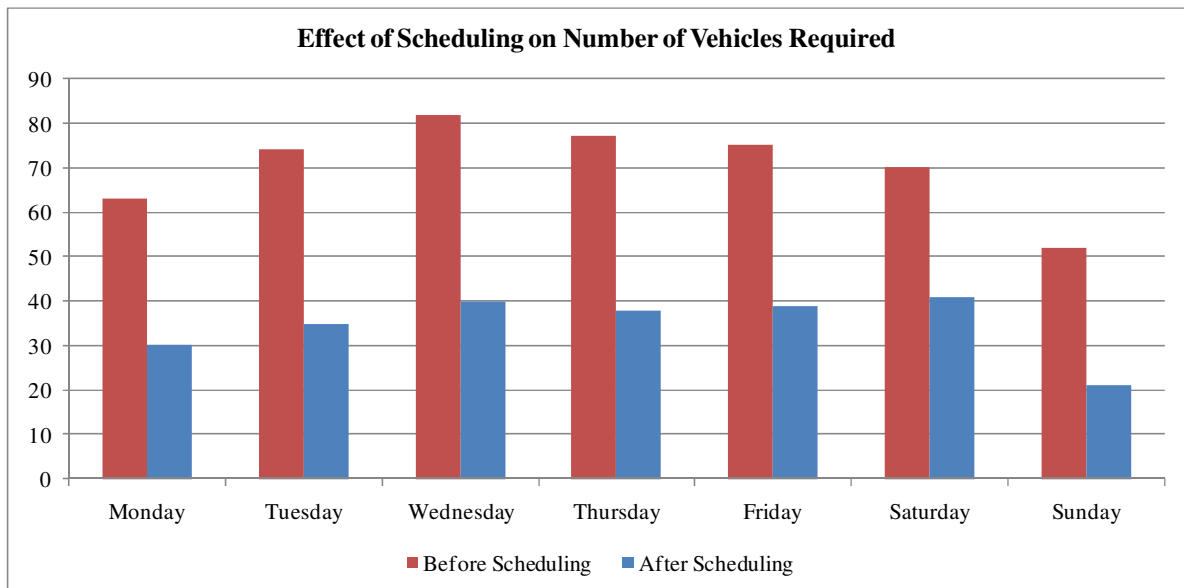


Figure 8.1 The actual number of different vehicles used per day, and the number required when a central scheduling system is simulated.

A second benefit of a scheduling solution would be to unify the presently fragmented supply chain of individual growers, individual hauliers and miller. By presenting a non-contentious solution, with

benefit to all parties, scheduling can provide a means to achieve increased efficiencies which are impossible for individuals to achieve in a fragmented system.

8.1.1 Fleet Size Sensitivity Analysis

An investigation into the sensitivity of the system to the fleet size was performed to document the behaviour under less than optimal conditions, as discussed in Section 6.6.

Figure 8.2 demonstrates the scenario of how sugarcane is not delivered into the sugar mill when too few vehicles operate within the system. Each of the three lines in Figure 8.2 represents one of the three equitable segments and shows a relatively linear trend (approximately 200 tons is not delivered for every vehicle removed from the segment) as the number of trucks are decreased. As the number of vehicles is increased beyond optimum (shown when the tons sugarcane not delivered is equal to zero) no effect on the tonnage not delivered can be seen.

With reference to Table 8.1, where more than 70 vehicles were operating on Tuesday, Week 22, 2003, it can be seen that this historical scenario position would be to the far right of the x-axis, indicating significant over-fleeting.

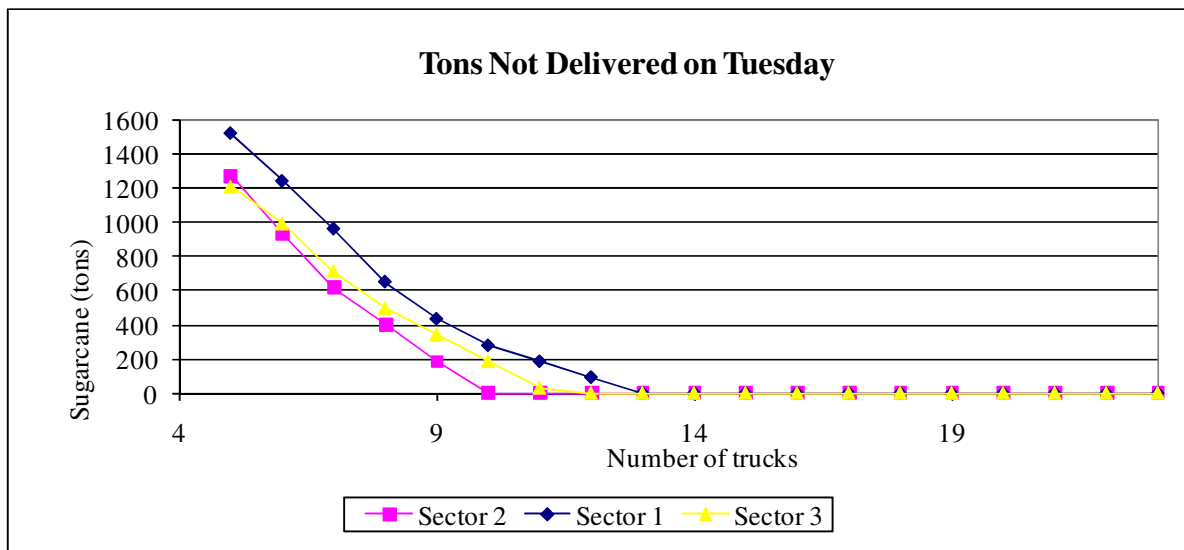


Figure 8.2 The quantity of cane not delivered to Sezela sugar mill as the fleet size varied on Tuesday, Week 22, 2003.

Figure 8.3 shows the average working hours and average effective working hours of the three equitable segments on the simulated Tuesday. Both the working and effective hours are at a maximum where less than the optimum number of trucks are operated, but decrease as the utilisation of each individual truck decreases. The difference between the working and effective working hours indicates the increase in queue time as more vehicles are introduced into the system.

With reference to Figure 8.4, the increase in queue time with an increase in fleet size confirms the above, and shows how over-fleeting above the optimum has the effect of cluttering up the system and increasing delays for all parties.

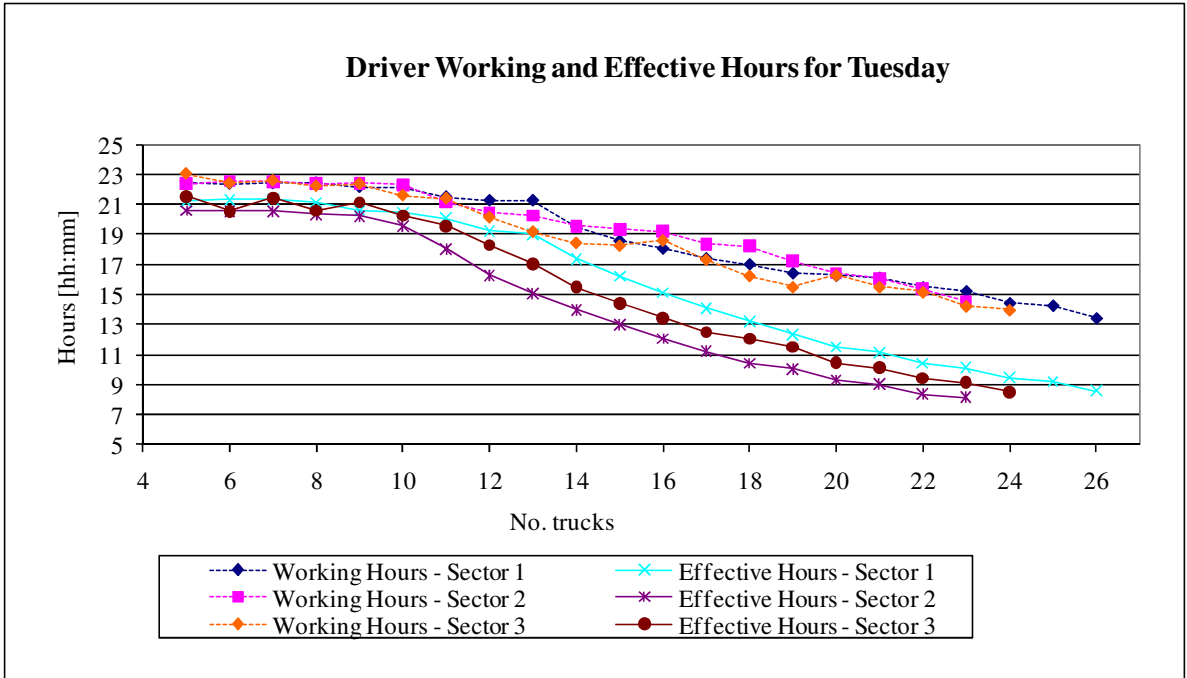


Figure 8.3 The average Working Hours and Effective Working hours per vehicle per day for the three segments at the mill, for various fleet sizes.

The increase in queue time (Figure 8.4) is due to the fact that the mill has a relatively fixed crushing rate and thus offloading rate. Therefore, in the scenario where more than the optimal number of trucks are operated in the system, they will wait in the queue to offload. This is despite the ASICAM software selecting trips at a rate equal to the crushing rate, in a sequence so as to arrive Just-In-Time at the back of the queue.

To a lesser degree the relative difference in queue time between the three equitable segments demonstrates the sensitivity of transport systems to specific groupings of input parameters as, although the divisions were balanced on a tons kilometre basis, significant queue time variability still exists. This can be seen in the rough shape of the graphs which show how particular combinations of fleet supply and lead distance can have profound effects on the efficiency, and ultimately the cost, of the system. In a system where the complexity is significantly increased by haulier-grower relationships and truck-type grower relationships, the problem will only be exacerbated further.

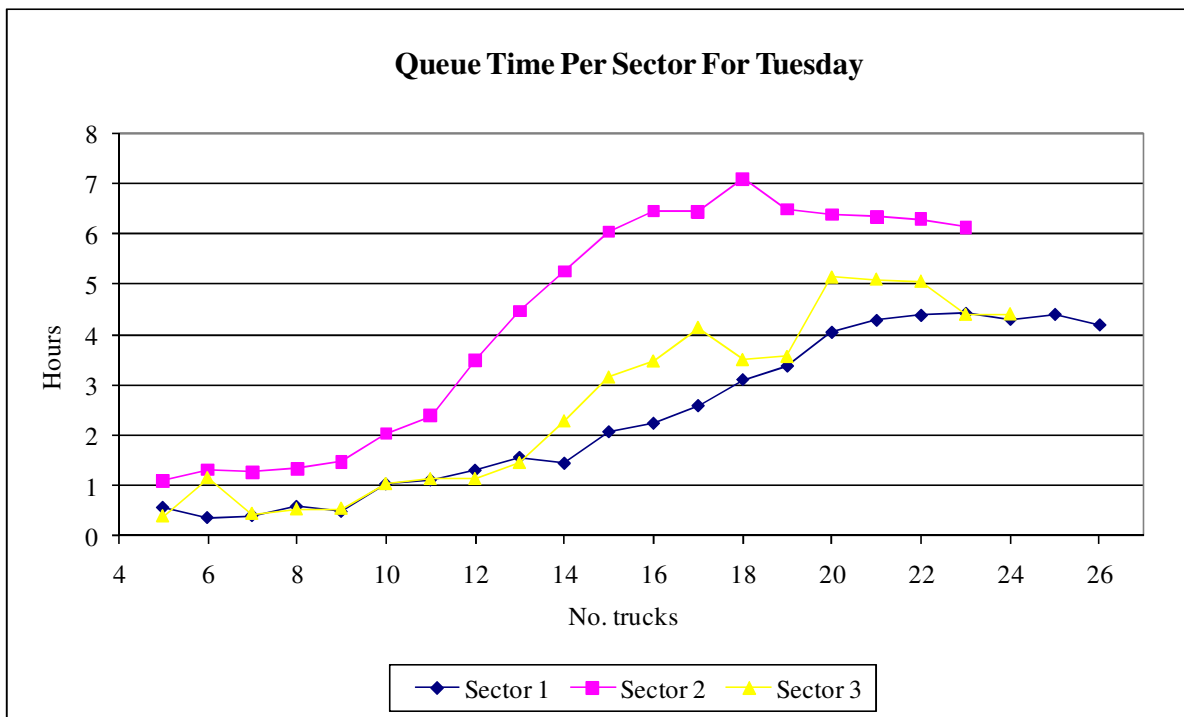


Figure 8.4 The average total daily queue time per vehicle as the fleet size is varied in each the three equitable segments.

8.1.2 Costing of the System

The maximum number of vehicles used were simulated on a Saturday, with 41 vehicles needed to transport the given supply. Table 8.2 is a summary of the estimated cost of the scheduled sugarcane transport fleet using the inputs as discussed in Chapter 3. The costs have been broken down into fixed and variable costs as well as profit. The results have been shown in R/km, R/ton and R/vehicle.

Table 8.2 The estimated cost components of the benchmark system in terms of R/km, R/ton and R/vehicle.

	R/km	R/ton	R/vehicle/ annum
Fixed	7.09	13.50	526224
Variable	4.25	8.10	315638
Profit	2.47	4.69	183000
Total	13.82	26.29	1024862

Therefore, the total cost of the entire fleet of 41 vehicles, as simulated by ASICAM using a central scheduling controller, is R42 million.

This represents a significant saving of approximately R16 million for the Sezela transport and grower community, relative to the present cost of transport estimated conservatively in Chapter 3 at R68 million. Indeed, if the sugarcane supply was more balanced on a day-by-day basis, the saving could be further increased.

8.2 Investigatory Scenarios

As described in Chapter 7, four sensitivity analysis scenarios were investigated: (i) loading time variation, (ii) offloading time variation, (iii) truck tractor power and braking ability variation and (iv) payload increase. These scenarios were designed to quantify the effect of a change in parameters, thereby helping to identify the areas on which the industry should focus to achieve the largest improvements over and above that seen through central control.

In each scenario only the parameter of interest was changed, and all other variables kept constant, so that relevant comparisons could be made. In the case of payloads, the total supply tonnage was kept constant, but the tonnages off specific zones were altered slightly to adjust for the increased payload. Loading and offloading times were also adjusted in proportion to the increased payload. The adjustment procedure can be found in Chapter 6.4.

8.2.1 Loading Time Investigation

This scenario was aimed at providing a relationship between fleet size and loading time, by varying the loading time from 60 minutes to 10 minutes, at 10 minute decrements. The ASICAM software was run and fleet size was thus optimised.

The loading time and minimised fleet size is shown in Figure 8.5. It should be noted that the loading time can only be increased to a certain level for the cane to still be delivered to the mill. Beyond that point the cycle time increases to a degree where the tonnage cannot be completely moved during the day. Figure 8.5 only shows values where the entire demand is supplied. A linear regression was fitted to the portion of the sectors where demand was supplied to describe the trend between loading time and fleet size. All three equitable divisions' gradients were then averaged to give a relationship between loading time and fleet requirement, i.e. on average for every 3.9 minutes reduction in loading time, the required fleet decreased by one vehicle. Minor differences can be seen between the sections which demonstrates the random nature of the system.

The loading time was calculated as the most sensitive of all the parameters studied in the investigatory scenarios. From the author's experience, it is the one component of the sugarcane supply chain which is often treated with little concern. Indeed, it is the interface between the grower and the haulier, who often operate in different shift windows, which affects the loading time. Growers operate predominantly during the day, while commercial hauliers operate for 24 hours per day.

It is therefore not only the selection of loading equipment which determines the loading time, but also the day to day management on the loading zone which is extremely important. With such a significant effect on the fleet requirements, and therefore the level of transport rates charged to the grower, it would be worth focussing on this area.

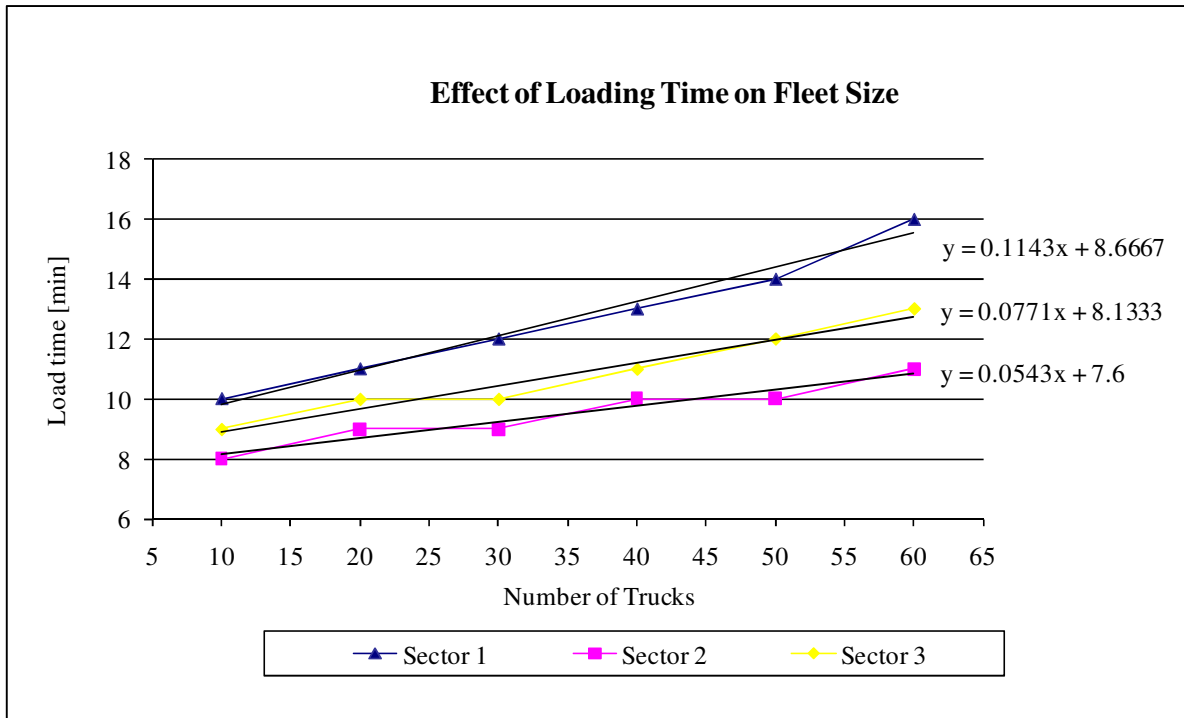


Figure 8.5 The change in fleet size as the loading time is varied for each of the three equitable segments.

8.2.2 Off Loading Time Investigation

The offloading time at the spiller, keeping the other yard times constant, was varied from the present 13 minutes down to 5 minutes. As described in Chapter 7.2, since the mill has a fixed crush rate, and therefore a fixed number off offloading opportunities per hour, given a constant payload of 31 tons, a decrease in offloading time reduces only the outbound time.

The offloading time and the effect on the optimised fleet size are shown in Figure 8.6. There is relatively little change in the required fleet size with a reduction in loading time. This is due to the fact that the percentage reduction in cycle time is relatively small and therefore has little effect on the total fleet requirement. The raw ASICAM outputs show a small decrease in working hours per vehicle, but this is not sufficient to remove an entire vehicle from the system.

Although the study did not quantify an increase in offloading time, the effects were marked, since significant amounts of sugarcane would not be delivered because there would be insufficient time to

offload all the loads for the day. Therefore, strategies such as the Brazilian offloading style (Section 7.4) in which chains are fed under the load at the spiller offloader, should be fed through pre-spilling.

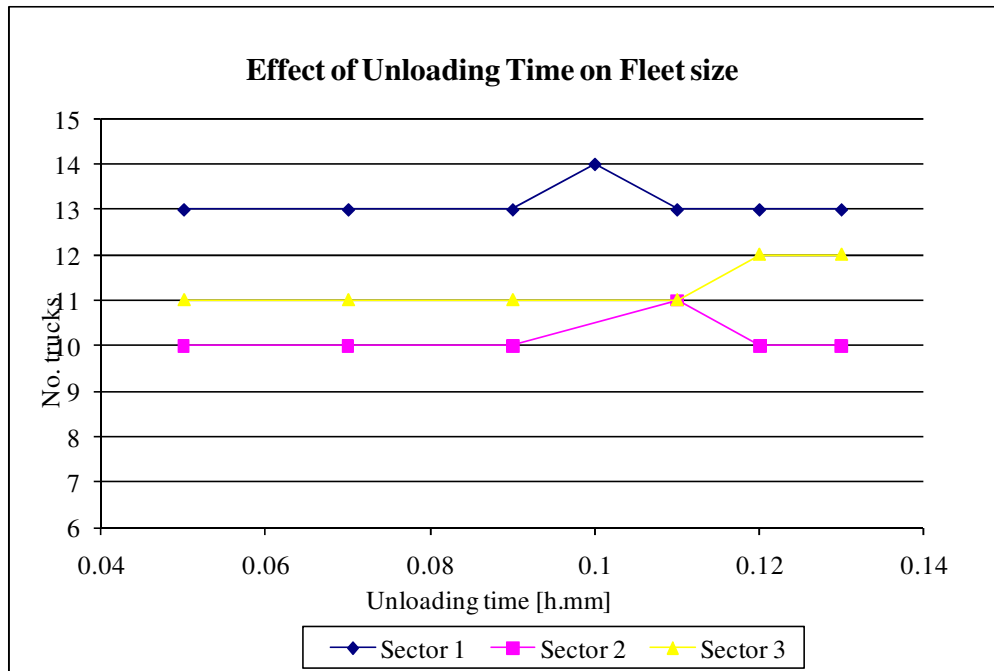


Figure 8.6 The fleet size in each of the three equitable segments as the offloading time was varied.

8.2.3 Truck Tractor Power and Braking Sophistication Investigation

Power and braking sophistication, described in Chapter 7.3, allow for faster speeds both uphill and downhill, respectively. Faster speeds decrease the cycle time for each load, although limitations are imposed by road conditions and by road traffic authority regulations governing maximum allowable speeds.

The effect of a decrease in engine power from 380 to 255 kW increases the optimised fleet size requirement by six vehicles, as shown in Figure 8.7. This fleet increase is significant, and is due mainly to the large proportion of steep terrain in the Sezela mill area.

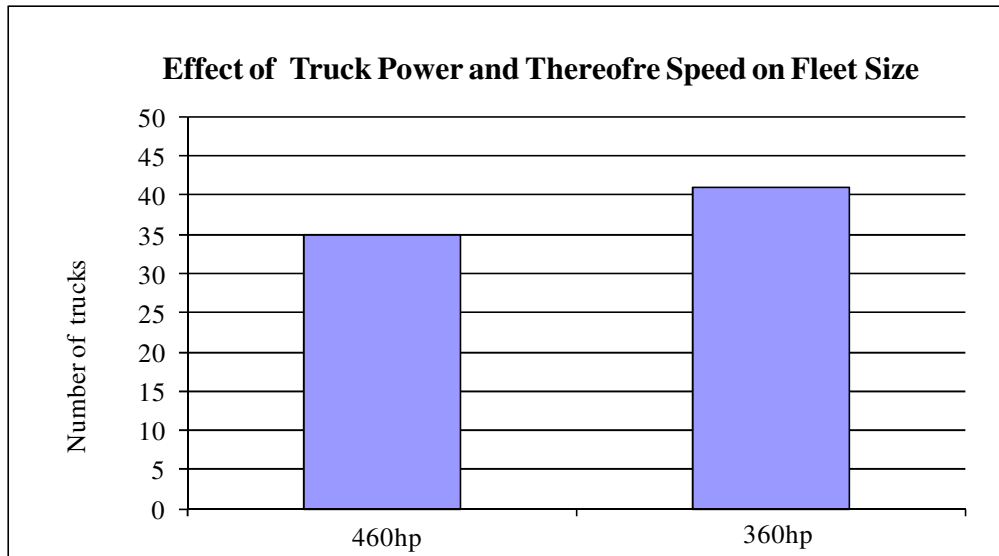


Figure 8.7 The change in fleet size as the power and braking system and thus speed of the vehicles is changed.

At present, a large percentage of the commercial hauliers, for reasons other than vehicle speed, operate vehicles of 255 kW type. In the relatively harsh environment of sugarcane haulage, the relatively simple mechanical nature of older vehicles makes them attractive to hauliers who operate, and provide their own mechanical maintenance support to the vehicles. Indeed, in the present environment of significant mill turnaround time, a delay of approximately two hours and loading zone delays, the effect of the power increase, and therefore reduced loaded and empty trip time, is negated.

Another reason for the use of older vehicles is their low utilisation (of the order of 35 000 km per annum relative to long-haul type trucks which travel in excess of 100 000 km per annum). Not only do the vehicles have a longer average life span, but commercial hauliers cannot afford the capital expense of purchasing a new fleet in the inefficient environment that presently typifies the Sezela supply chain.

8.2.4 Payload Investigation

As discussed in Section 7.4, four payload scenarios, were simulated using the ASICAM software to the optimised fleet size. Each scenario represented a legitimate strategy with regard to payload increase.

8.2.4.1 Payload Scheduling Outputs

With reference to Figure 8.8, a reduction in fleet size can be seen with an increase in payload. A minimum fleet size of 35, 31 ton payload trucks was required to transport the Tuesday supply to the mill as a simulated benchmark scenario. For a payload of 35 tons, which is typical of a rigid-and-drawbar configuration used extensively in the northern regions of South Africa and Swaziland, the required fleet size dropped by 9%, to 32 trucks. With an increase in payload to 38 tons, the required fleet was not simulated to reduce any further. This can be attributed to the heuristic nature of the software, and the nature of the supply quantities and lead combination. Indeed, when the raw outputs from ASICAM are further analysed it can be seen that, in the case of the 35 ton payload, the average hours worked per vehicle was low with exceptionally low average queue times, whereas in the case of the 38 ton payload the working hours were relatively longer and the queue times were significantly higher, demonstrating the efficient 35 ton payload system and the less efficient 38 ton system.

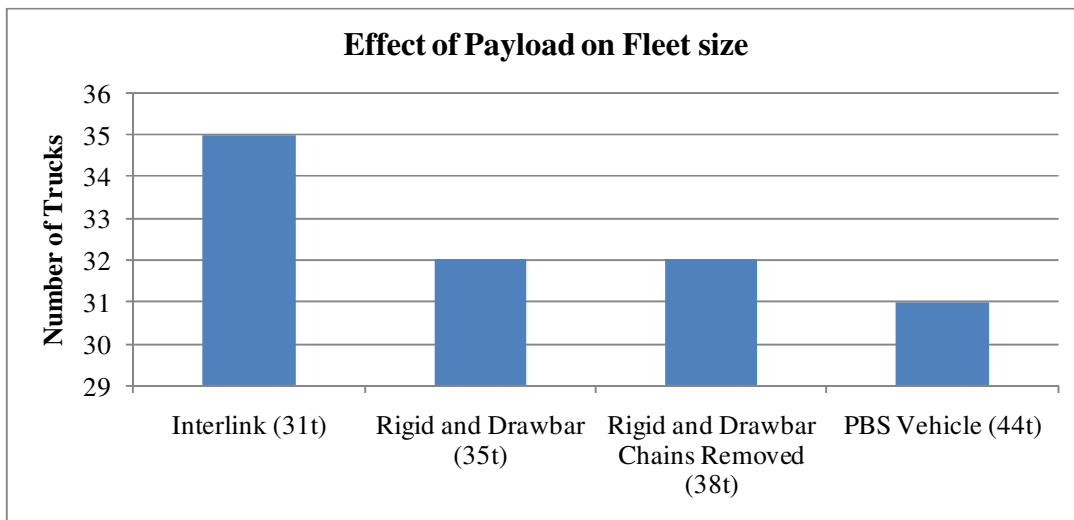


Figure 8.8 The fleet size requirement as the payload is varied.

By increasing the payload even further to 44 tons the fleet required to transport the supply was reduced by 11% from the original 31 ton Interlink combination to 31 vehicles.

Figure 8.9 shows the benefit of increased payload in terms of tons transported per vehicle per day for the decreasing fleet requirement. The gradient of the trend line fitted to the data indicates that, for every ton increase in payload, approximately 7.4 tons extra cane is transported per vehicle per day.

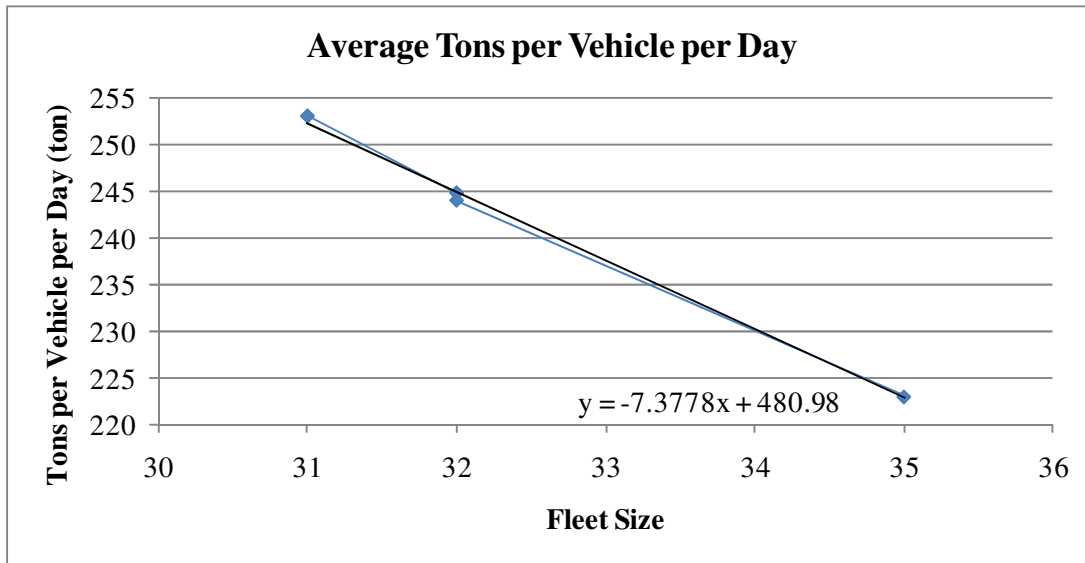


Figure 8.9 The relationship between payload and tons per vehicle per day.

8.2.4.2 Payload Costing

The cost saving associated with increased payload and reduced fleet, is detailed in Table 8.3. The fixed cost per vehicle remains relatively constant for the 31, 35 and 38 ton payloads. This is because, although the 31 ton configuration is more expensive, the fleet requirement is higher, and therefore the dilution of the overhead costs is greater. The higher fixed cost of the 44 ton payload vehicle is due to the expensive nature of the newer trailer.

The variable cost per vehicle in Table 8.3 is seen to decrease with the decreased number of kilometres travelled per vehicle, due to the increased payload. Remarkably, the total cost per vehicle, which is a summation of the fixed and variable cost components, remains relatively constant over all the payload scenarios and the systems saving is therefore in the reduced fleet requirement shown in Figure 8.10.

Table 8.3 The approximate costs per vehicle for the four different payload scenarios investigated.

	Payload (tons)			
	31	35	38	44
Number of simulated vehicles	35	32	32	31
Fixed cost per vehicle	R710 000	R709 000	R709 000	R760 000
Variable cost per vehicle	R402 000	R391 000	R364 000	R344 000
Total cost per vehicle	R1 112 000	R1 100 000	R1 073 000	R1 104 000

The savings associated with an increase in payload suggest that increasing payload to 35 tons would produce a saving of approximately R3.7 million across the fleet, while the other scenarios constitute only relatively small savings. It is questionable whether it would be worthwhile investing in this higher payload technology, were the whole system to adopt the increased payloads under a central scheduling scenario.

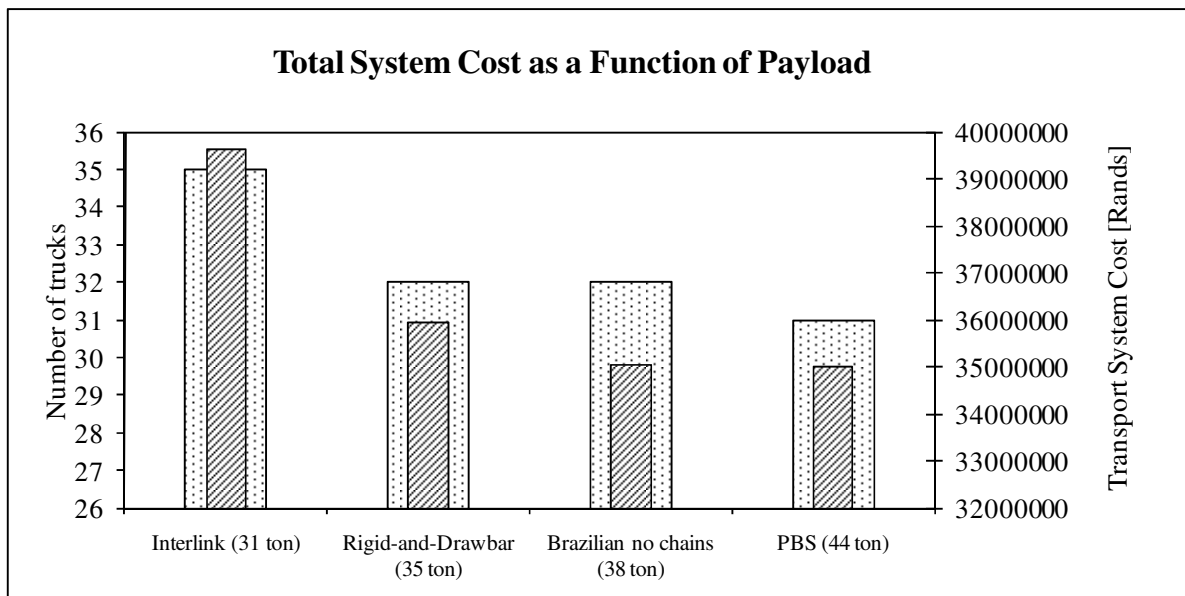


Figure 8.10 The total system cost against payload showing relative fleet size.

At the longer lead distances, the savings associated with an increase in payload are more pronounced. Significant caution should be adopted when choosing this approach, because the majority of lead distances at any South African sugar mill are relatively short and the complexity of introducing specific high payload carrying ability vehicles, dedicated to a few long lead distances, may not have the desired positive effect of reducing costs. There could be a negative impact on the rateability of the arrivals to the mill, on the ability to operate the minimum fleet and on cost reduction.

Another consideration when increasing payload is the ability of the vehicle configuration to perform other haulage work during the off-crop. Due to their specialised design, rigid-and-drawbars typically cannot be used for other operations, while the truck-tractors from interlink configurations can haul other trailers. The choice of configuration and associated payload, is therefore also a function of management's ability to secure regular off-crop work. The reduced efficiency, caused by the lower payload, may be trivial relative to the inability to perform off-crop work.

9 DISCUSSION AND CONCLUSIONS

Approximately 2 500 registered growers deliver sugarcane to the Sezela sugar mill, which is one of the largest mills in the South African sugar industry. Due to a lack of coordination between the individual hauliers, and between the growers, miller and the hauliers, significant delays are incurred within the transport cycle, as each individual haulier attempts to deliver to a single mill, which can only process the vehicles at a relatively constant rate.

It becomes apparent that the only way to minimise delays, and thus increase the cost effectiveness of the transport system, is for a single controller, using a sophisticated scheduling, to schedule and effectively manage loading and delivery patterns for each haulier.

The present cost of sugarcane transport is relatively high, and is logically due to the excessive number of vehicles being used to transport the given tonnage, each with a set of high fixed costs. Relative to the industry benchmark of over 35 000 tons transported per vehicle per annum, the over-fleeting, and therefore the cost of transport, is extremely high at Sezela. The present cost of transport was estimated conservatively at R68 million per annum if the costs of both commercial hauliers and grower-cum-transporters are included.

Vehicle routing problems arise whenever a set of transportation requests are made and a fleet of vehicles to serve those requests. There are many variants of the basic Vehicle Routing Problem. These are generally categorised by the service performed, by the predominant constraint imposed by the requestor, or by the properties of the problem. These constraints restrict the way in which they are visited, but increase the quality of the solutions by more closely imitating reality. From the very well studied, relatively simple Travelling Salesman Problem, through to the inherently complex Pickup and Delivery Problem with Time Windows, the above statement is typically true.

While these increasingly complex solutions approximate reality more closely, they do so at the expense of solution time and the specific numeric quality of the solution. Obtaining a solution is performed by optimising a number of functions under the aforementioned constraints. This has, most often, either the effect of minimising the overall cost of providing the service or minimising some property of the service itself. Although many solutions to the various vehicle routing problems and their variants exist, the choice depends on available solution time required, solution accuracy, problem size and problem complexity.

Although the problem of transporting a relatively low value product from infield to mills is seemingly not well researched, instances of the Agricultural Scheduling Problem have been in operation since as early as the 1970s in timber and sugarcane transport systems in Chile and Australia, respectively. Instances of scheduling software that have been described in this review are the ASICAM software used in the timber industry in Chile, the FREDD software used in sugarcane transport in Australia, the manual system of scheduling in sugarcane transport at Tongaat, and a group of similar scheduling solutions used within the Swedish timber industries, all of which have been extremely successful.

Using the Laboratory Information Management Systems (LIMS) 2003/04 Sezela database, the ASICAM scheduling tool was used to conservatively simulate the transport system under the scenario of a central scheduler. Scheduling simulations show that a daily fleet reduction of approximately 50% per day is possible, with an associated cost saving to the system of R16 million per annum. This excludes the saving that would be realised by unifying the fragmented supply chain which presently operates in a relatively autonomous environment.

Real-time vehicle scheduling, as it is more commonly known, would seem to be the best solution choice for a real-life transport company as it can cope with the inherent variability with respect to supply, demand and vehicle performance on a real-time basis. However, a more skilled operator, operating the system 24 hours per day with a higher level of technology and associated costs are needed. Also, the risk of a transport system shutdown created by a system failure would seem to be higher, although easily catered for, especially in the case of a centralised control system.

The sensitivity of the scheduled system to tonnage delivered, the average working hours and effective working hours per vehicle per day, and the average queuing time per vehicle per day, was simulated. This confirmed that over-fleeting has a significant detrimental effect on the transport system. Utilisation per vehicle decreases due to the increased number of vehicles in the system transporting the same total tonnage. The extra vehicles also have a cluttering effect which increases the average queuing time and decreases each vehicle's effective working hours.

Using the above simulation as a platform, scenarios of loading time variation, offloading time reduction, vehicle speed decrease and three increased payload scenarios were quantified both in terms of fleet requirement and, in payload scenarios, in monetary terms. The simulations confirmed that the

Sezela transport system is especially sensitive, due to the short leads distances, to loading and offloading time changes.

Loading time was identified as the area where the greatest additional savings could be made. Simulated results indicate that for every 3.9 minutes reduction in loading time, the fleet requirement would reduce by one vehicle. Offloading time reduction did not have a significant effect on the fleet requirement due to the relative small change in terminal time. However, it is concluded that caution should be shown not to increase the offloading time beyond the present time of 13 minutes without changing the payload. The reduction in vehicle engine power and braking ability, and therefore overall speed, had the effect of increasing the required fleet by 17%, but, for reasons of high capital expenditure, this is not a realistic short-term solution but should be phased in as new fleet is incorporated into the system. Payload increase, from a 31 ton Interlink, to a 35 ton rigid-and-drawbar, a 38 ton Brazilian configuration and a 44 ton Performance Based Standards (PBS) System, showed that a total fleet reduction of 11% was possible if increased from 31t to 44t. In addition, the simulations showed that for each ton increase in payload, an associated 7.2 tons extra are transported per vehicle per day. This translates into an extra cost saving of approximately 12% relative to the benchmark scheduled solution. In view of the relative savings of each of the payload scenarios, it would be advantageous to operate vehicles of the 35 ton payload, where the greatest savings were seen. The ability to perform alternate off-crop work should also be a consideration when selecting a vehicle configuration.

As an unexpected outcome of this study is the significant negative effect of the transport complexity where certain vehicles are able to service only certain growers cannot be underestimated and is, in the author's opinion, responsible for much of the inefficiency currently present within the supply chain. This phenomenon is of particular importance during periods when supply chain anomalies occur e.g. loader breakdowns, labour issues, traffic congestion, and road/zone conditions, which are relatively commonplace in the sugarcane operational environment. In contrast to the historic methods that specify transport equipment for specific applications, a generic type of transport that can perform satisfactorily well under all supply chain conditions and constraints should be investigated carefully from a supply chain point of view. The current modern sugarcane industry, with its social, political and environmental challenges, needs a transport system that will accommodate many different loading environments/conditions, and it may therefore be prudent for transport to revert to zone-type loading only. This will allow growers to use whatever infield equipment and systems they need or choose to operate, so that they can exploit agronomically sound practices such as controlled traffic and low compaction tyres. A generic road transport system will haul sugarcane efficiently from the zone to the

mill. When coupled with the challenge of inclement weather that has a significant effect on the ability to extract cane from the fields, in-field loading should be eliminated.

In the operational environment and to cope with the natural variability within the sugarcane supply chain, the effect of sugarcane stock on farms is very apparent; this in terms of the quantity, timing and consistency of sugarcane availability. This is not to say that large amounts of stock should be carried, but rather that some stock if used effectively allows to the supply chain to continue to operate efficiently even in times where unforeseen issues do occur. Interestingly, a typical sugarcane supply chain in South Africa does indeed carry excessively large amounts of stock (both on farm and at the mill), but it would seem apparent that this stock is not effective due to poor communication about this stock, the negative effects of transport complexity necessitating more stock needing to be carried as well as the effect of excessively poor supply chain discipline and performance.

Although stock is a very necessary element of an efficient supply chain, the stock should be held at the most effective and lowest cost point in the chain. In addition, stock needs to be managed very carefully in an ongoing fashion otherwise the stock that was used to give the supply chain the agility to be efficient instead gets used up automatically due to general supply chain inefficiency and the highly undesirable downward spiral scenario where the use of stock is used only to counter supply chain inefficiency, which then necessitates more stock, therefore needs to be managed carefully.

Subsequent to the Rorich Commission of 1984 that took the responsibility for transport from the miller and made the grower community responsible, there has been a distinct and steady fragmentation of the supply chain with an associated and undeniable increase in inefficiency. A strong recommendation of this project would be therefore to change the decision making structures relating to supply chain decisions and remove the individual's ability to make supply chain level decisions. Instead a single entity should actively manage, be responsible for and, importantly, pay for transport. Given the current structures in existence within the industry, potentially the Mill Group Board or possibly Miller would be ideally positioned to take back the responsibility of transport and to allow for the extraction of the potential efficiency gains.

Although extremely powerful and vital to the project success, it is extremely unlikely that software alone would be sufficient to realise the potential cost savings simulated in this study. Rather, an extremely dependent set of three project components namely: the technology (software and enabling hardware), quality staff and change management process would be needed.

The technology would include appropriate software that would schedule vehicles but also hardware such as vehicle on-board computers, GPS, PCs, printers, automation equipment etc. would be necessary.

To effectively operate the software and actively manage the supply chain management and operational staff would be necessary. The quality of these individuals would need to be of the highest possible calibre and would need to be not only technically capable, but also have sufficient available capacity to complete a very challenging task and also very importantly have the authority to make the necessary decisions for the good of the supply chain. Indeed if the highly efficient Australian road transport industry is taken as a benchmark, the Supply Chain Manager is second in charge only to the highest level of authority in the mill, the Mill Manager.

The implementation of a scheduling solution would result in large amounts of valuable data that if managed in the effectively, will provide previously unknown information on the supply chain processes and supply chain performance. Indeed, the whole supply chain has been operating relatively uncontrolled and measured with little accountability. The central coordination provided by scheduling and the reporting on the smallest detail will aid the management in both better understanding the issues and exposing areas of weakness and opportunity. This said, this information alone will not guarantee improvement and would need to acted upon by the Supply Chain Manager as part of a change management process and that it would be the changes themselves that would liberate the cost savings.

In conclusion, appropriate scheduling solutions are available and the potential savings to be made in terms of fleet reduction and reduced costs are significant if the transport system was to be scheduled from a central centre and if all vehicles could visit all growers to load sugarcane removing the current logistical complexity. If the system was to also adopt strategies of improved loading, offloading, vehicle technologies and payloads, the savings, including those that would be realised due to the unifying of the present fragmented supply chain, would definitely increase the competitiveness and the sustainability of the South African sugar industry.

10 RECOMMENDATIONS FOR FUTURE RESEARCH

The following would increase the accuracy of the results and enhance the usefulness of the tool in this application:

- i. To including the complexity created by zone and in-field loading as part of the solution,
- ii. Including the complexity of individual haulier/grower contracts,
- iii. Accounting for the effects of variable individual grower supply (daily and in real-time),
- iv. Accounting for the hourly milling performance changes,
- v. Including the effects of stochastic payloads,
- vi. Accounting for the effects of variable travel times,
- vii. Including the effects of specific grower loading time windows,
- viii. Including a heterogeneous fleet in the simulation.
- ix. Considering the variance in the data which may include overarching optimisation such as the Tour Guide Linear Program.

In addition, two further studies areas are recommended that are not transport modelling related:

- i. A study into the amendment of the Sugar Act to allow a single entity to both manage and pay for transport,
- ii. A study into whether the common practice of infield loading is in fact a viable option when viewed from a supply chain and not individual grower perspective. This study would be enhanced if performed using long term weather data and the impacts of this weather on all supply chain operations.

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