AN INVESTIGATION INTO SUGARCANE VEHICLE LOADING WITH RESPECT TO INFLUENCES ON OVERALL TRANSPORT EFFICIENCY

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ABSTRACT

The South African sugar industry ranks eleventh in size out of 200 sugar-producing countries; and continuous advancement is essential to ensure that this industry remains competitive. The transfer system from field to mill, includes sugarcane being moved, loaded, transloaded and off-loaded and amounts to more than 25 % of the total production cost of sugarcane, hence small adjustments can have significant economic benefits. Payload variability is a current problem making the loading operation a leverage point for improvement. As a consequence of poor management and the under-utilisation of equipment, loading has been identified as an inefficient and costly operation. Studies have shown that technology and management can contribute to improved loading accuracy.

This study aimed to evaluate loading characteristics in an attempt to develop guidelines for loading. Whole-stick loose sugarcane, which is loaded with grab-loaders, is common practice in South Africa and this study aims to improve this loading system. This was achieved by reviewing transfer systems worldwide and synthesising the sugarcane characteristics that drive the designs and the management of equipment and systems within the transfer system. The sugarcane characteristics include the sugarcane bulk density, the length, the diameter and other variety characteristics *e.g.* the degree of lodging. Other factors, such as the preparation method for loading, the harvesting method and the topography, also have a marked influence on the efficiency of the transfer system.

An assessment of typical South African loading practices was undertaken to establish beneficial practices and current operating rules. These factors included the way in which the sugarcane was presented prior to loading, as well as the techniques adopted for loading. The results were used to generate practical recommendations for the improvement of the loading component in order to make the transfer system more efficient. An efficient system comprises a balance of high quality operations with respect to safety, accurate loading, reduced cycle time, optimal fuel usage, reduced roadside losses, reduced sugarcane damage and increased off-loading efficiencies. An investigation into consignment characteristics was also carried out to identify the

factors that need to be considered during the loading operation. These factors included the sugarcane bulk density, the degree of sugarcane alignment and the design characteristics of various vehicles. A set of practical guidelines were created from this study.

SYMBOLS

m	Mass of sugarcane	kg
β	Vehicle load index	ratio
γ	Consignment payload	kg
γ'	Vehicle design payload	kg
ρ_b	Sugarcane bulk density	$kg.m^{-3}$
ρ_b'	Design bulk density	$kg.m^{-3}$
% UL	Percentage under-load	%
v	Volume of sugarcane consignment	m^3
v'	Design volume of a vehicle	m^3
A	Approximate surface area of sugarcane per trailer	m^2
l	Length of the sugarcane load profile within each trailer	m
L	Length of a trailer	m
φ	Undulation ratio	l/L
I	Interlink vehicle	
R	Rigid drawbar vehicle	
T	Tri-axle vehicle	
B	Bolster type trailer	
F	Frame type trailer	
C	Cleaning score	
D	Discharge rating	

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1. INTRODUCTION

Sugar from sugarcane is a commodity which impacts on many economies including South Africa. The sugar industry in South Africa faces many challenges, which need to be addressed in order to remain competitive (Lyne, 2007a). Profitability in the international sugar industry has been strained by increasing agricultural input costs, with one of the main factors being transport costs (McWhinney, 1983; Meyer, 2005b; Meyer, 2006; Milan *et al.,* 2006; Gomez *et al.,* 2010). This component accounts for approximately 20 – 25 % of the total cost of sugarcane production in South Africa, which equates to R 750 million per annum (Meyer, 2004; Lyne, 2007b; Giles *et al.*, 2008). Harris *et al.* (2010) illustrated that the sugarcane input costs are rapidly rising compared to the relatively stable income generated.

Sugarcane in South African is mainly grown in the rural regions of KwaZulu-Natal and Mpumalanga which had an annual production increase from 500 000 tons in 1950 to ± 21 million tons in 2000 (Meyer, 2002; Isaacs, 2003 and Giles, 2009). This indicates that sugarcane production has rapidly increased. The average lead distance is 25.4 km with an average payload of 25.1 tons. The transport component is undertaken by 470 hauliers using more than 1400 vehicles and delivering at 14 mills. All these vehicles differ with respect to their management, design and capabilities. The South African sugar industry is large and ranks 11th amongst the 200 sugar producing countries in the world which are managed by 6 companies (Source: The Sugar Directory Season 2009/10).

The sugarcane transfer system comprises sugarcane being moved, loaded, transloaded and off-loaded, which amounts to more than 25 % of the total production cost of sugarcane, hence small improvements can have significant economic benefits. An improvement in the transfer system can be achieved by the modification of various components within the system. Load cells on transporting units offer a means of achieving accurate loads, however the initial capital costs and the increased management requirements often make it less utilised (Lagrange *et al.,* 2008, Giles *et al.,* 2009). Weighing devices can be mounted onto loading equipment, such as grab-loaders and cranes, to improve loading accuracies, however, these devices become unreliable when used under inclined conditions (Lagrange *et al.*, 2008; Giles *et al.*, 2009). Weighing pads were found to be affordable and reliable with 1 % accuracy error (Meyer *et al.*, 2001).

The aim of any sugarcane transport system is to ensure delivery from the field to the mill within a minimum time-frame and at a minimal cost (Stutterheim, 2006). There is room for improvement in the loading and off-loading components in the sugar industry (Meyer, 2004; Meyer, 2005a; Meyer, 2005b). Steward and Fischer (1983) reported that insufficient training and supervision of the loader operators results in inaccurate loading and hence high transport costs. Overloading of vehicles results in road damage, tyre damage, increased maintenance costs, fines and can also compromise road safety (Cole *et al.*, 2006; Lagrange *et al.*, 2008; Giles *et al.*, 2009). Significant economic losses and increased productions costs for additional trips, are the result of under-loaded consignments (Meyer, 2004; Cole *et al.*, 2006; Lagrange *et al.*, 2008).

There have been many strategies in place to minimise the degree of over-loading which include; PBS and RTMS and these seem to have increased the severity of under-loading (Bezuidenhout, 2010), hence the emphasis in this study is placed on the under-loading of sugarcane vehicles. On average, vehicles are 13 % under-loaded and approximately every 8th consignment is unnecessary. In this document, transport *efficiency* was assumed to be influenced by factors such as the optimal utilisation of equipment, maximum payloads, short turn-around times and optimal fuel usage. In addition an *effective* system comprises high quality operations with regard to safety, reductions in roadside losses of sugarcane and effective off-loading with respect to spilling and cleaning requirements. This can be achieved by considering the sugarcane’s length, bulk density and diameter, along with other factors, such as the equipment specifications and the field and loading zone conditions (Lee, 1978; Carter-Brown, 1980; de Beer, 1982; Cowling, 2008a; Cowling, 2008b).

By generating a set of practical guidelines the training of loader operators can result in more efficient operations in terms of equipment performance and sugarcane quality (Bentley, 1956; Barlett, 1974; Neethling, 1982; Steward and Fischer, 1983; Meyer *et al.*, 2001; Stutterheim, 2006; Lagrange *et al.*, 2008; Giles, 2009; Giles *et* *al.,* 2009). This study was directed towards more accurate vehicle loading in an attempt to help address the degree of under-loading. One main problem was hypothesised to be a large variation in the sugarcane bulk density (ρ_b). It was found that this varied per consignment and is dependent on various factors ranging from management to equipment specifications.

The aim of this study was to compile a set of practical standards and guidelines for loading sugarcane with grab-loaders in order to improve the transfer system of the South African sugar industry in terms of efficiency and effectiveness (Section 5.2). Specific objectives include the following:

(a) to conduct a literature review of the transfer system to gain an understanding of the system and to establish sugarcane characteristics which influence the efficiencies of the transfer system (Chapter 2),

(b) to assess typical loading operations used in South African in order to identify beneficial practices and operating rules (Chapter 3 and 4),

(c) to examine the characteristics of vehicle consignments, in terms of sugarcane properties and the vehicle's design, in order to identify important factors that need to be considered during the loading operation (Chapter 3 and 4), and

(d) to identify other areas of concern for future research (Chapter 5).

Variety refers to the type of sugarcane as per its biological and physical make-up. A review of the sugarcane variety was not within the scope of the study, since the guidelines are to be general and for the overall improvement of the loading of sugarcane in South Africa. The loading zone design and orientation was also found to impact on the efficiency of the loading operation; however this was not evaluated in-depth as it did not fall within the scope of this study.

2. A REVIEW OF WHOLE-STICK SUGARCANE TRANSFER SYSTEMS IN CONJUNCTION WITH THE INFLUENCING PROPERTIES

This chapter consists of a literature review of the transfer processes in the sugar industry on an international scale in order to ascertain the factors that influence the designs and the management of equipment and systems. The advantages and disadvantages of these systems are presented and discussed in a South African context. The transfer system incorporates the movement of sugarcane from the harvested field to off-loading at the mill. This, therefore, includes the loading, transport, off-loading, as well as possible transloading processes.

2.1 Overview of Sugarcane Transfer Systems

The components of the transfer system are interrelated and each aspect has an influence on the overall efficiency. South Africa on average harvests 20 million tons of sugarcane annually (Meyer and Fenwick, 2003). The harvesting techniques used impacts on the loading method adopted. There are two main harvesting techniques used in South Africa, (a) cut and stack and (b) cut and windrow (Meyer and Fenwick, 2003). Sugarcane is loaded in loose form or in bundles. Bundling is a process whereby sugarcane stacks are secured by chains. Gordon (1978) and Carter-Brown (1980) argue that the loading operation is more effective for bundled sugarcane, compared to the operation of sugarcane in loose form from windrows, since it results in less spillage and a reduction in the quantity of extraneous matter, such as soil particles within the load. However, the most common existing system in South Africa comprises sugarcane being windrowed, followed by loading with a grab-loader (Statham, 1990; Meyer *et al.*, 2001). The creation of the windrows has an impact on the effectiveness of the loading operation, where neater and denser windrows result in increased payloads (Carter-Brown, 1980; Boast, 1985). Spalding (1992) found that it was advantageous to separate the cut and stack harvesting operation, into two individual processes (*i.e.* cut only and stack only). The result was a 54 % increase in labour productivity and a 62 % improvement in the in-field self-loading operations due to stack sizes being more consistent.

Sugarcane transport systems comprise of (a) direct and (b) indirect systems (Meyer, 1997; Meyer *et al.,* 2001; Tshawuka and Ellis, 2001; Stutterheim, 2006). The direct system involves the direct loading of sugarcane in-field onto transport units for delivery to the mill (Cowling 2008a); however, this system may cause soil damage which is more severe under wet field conditions. Indirect systems include a transloading component and involve the transportation of sugarcane to a loading zone or depot, from which the sugarcane is later transferred onto road units.

Barnes (1999) summaries the various types of transport systems in South Africa, namely:

(a) directly to the mill in bundles;

(b) directly to the mill in loose form;

(c) sugarcane transported to transloading zones in bundles by tractor-trailer units, then transloaded onto Hilo-type vehicles and transported to the mill, and

(d) sugarcane transported to transloading zones in loose form by bin or basket trailer units, then transloaded onto Hilo-type vehicles and transported to the mill.

Points (a) and (b) above are known as direct systems, while (c) and (d) involve transloading and are termed indirect systems.

Factors such as long lead distances, the infrastructure available, topography and the farmer's management preference influence the system adopted (Steward, 1955; Lee, 1978; Libunao, 1978; Carter-Brown, 1980; de Beer, 1982; Meyer *et al.,* 2001; Stutterheim, 2006; Cowling, 2008a). The disadvantage of indirect systems include; (a) the additional cost incurred through double handling, (b) the reduction in sugarcane quantity and quality and (c) extended duration of the operations (Jacquin *et al.,* 1996; Hughan, 1998; Meyer *et al.,* 2001). The equipment used for transloading comprise of grab-loaders, cranes and slewing loaders. Meyer (2001b and 2002) describes a ‘roll-on roll-off’ system which simplifies the transloading operation. This system involves the loading of sugarcane into spiller bins which are placed onto a ‘roll-on roll-off structure’. This allows for the bins to be manually moved onto transport vehicles, as shown in Figure 2.1. The system is not widely adopted in South Africa.

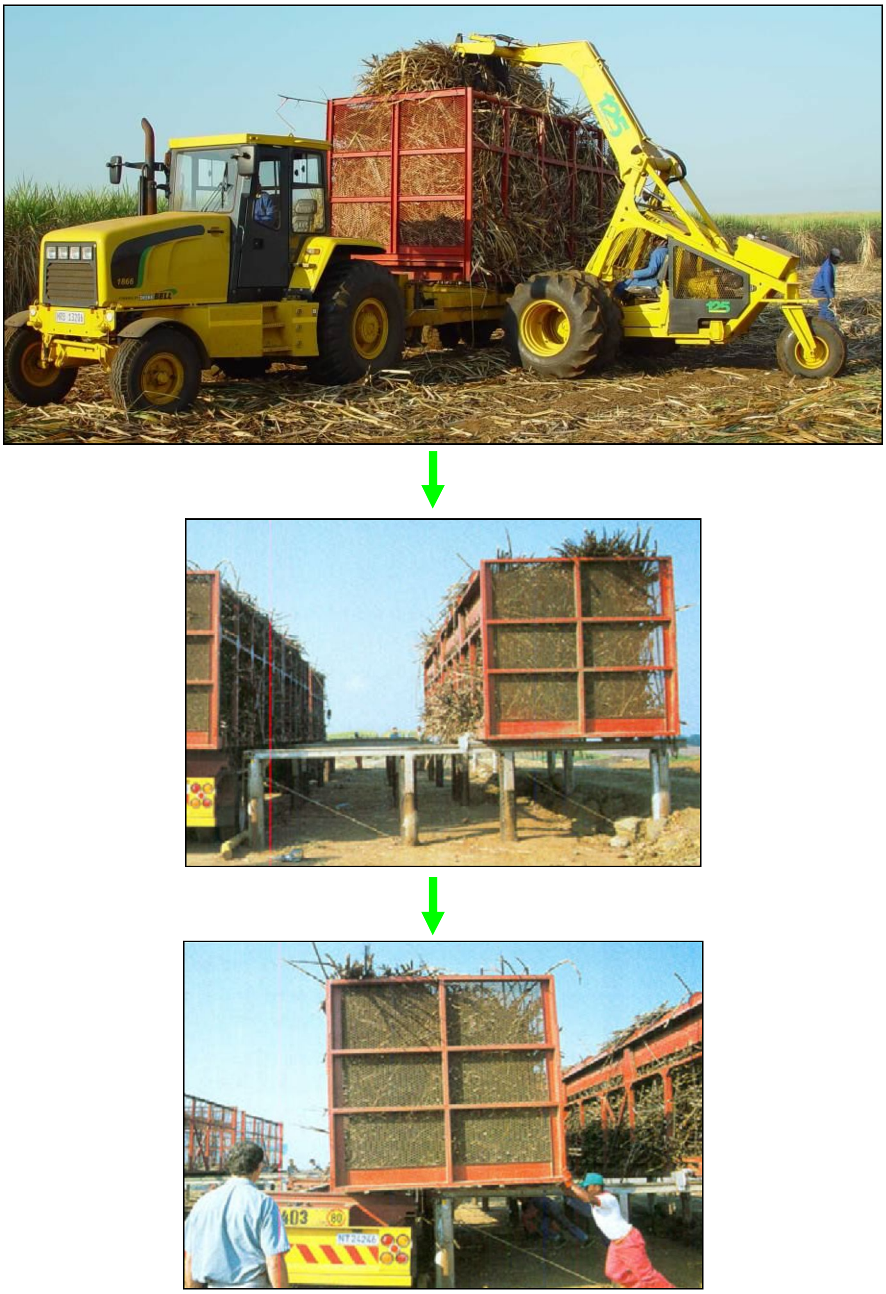


Figure 2.1 Roll-on, roll-off system (from Meyer, 2001b; Meyer, 2002)

The aim of sugarcane transport is to ensure a constant supply of sugarcane to the mill (Milan *et al.*, 2006). Prior to 1984, sugarcane transport costs in South Africa were top-sliced from the sugar industry proceeds and thus there was less concern for the actual costs of transporting sugarcane (Statham, 1990). The farmers did not consider transport as a production cost. There has been a shift towards the creation of more efficient transport systems which is driven by economic viability (Statham, 1990). An understanding of the interactions within the sugarcane transportation system is essential in order to allow for efficient and effective management (Libunao, 1978).

Transport can be divided into primary and secondary components, where tractors form the primary components and trucks form the secondary transport (Stutterheim, 2006). There are two main modes of sugarcane transport in South Africa, namely, rail and road (*cf.* Section 2.1.2). The various methods and usage within South Africa are shown in Table 2.1 (Davis and Archary, 2006; Cowling, 2008a). Transport systems are modified in relation to the mill's receiving-facilities (Meyer *et al.*, 2001).

Table 2.1 The proportion of sugarcane moved by different types of transport in South Africa (after Davis and Archary, 2006)

Transport type	**Quantity (%)**
Rail and tram	6.2
Articulated trucks	52.0
Rigid chassis	21.2
Tractor driven	20.6

Before 1993, few advances were made in the designs of haulage units in order to reduce sugarcane losses while the vehicles are in transit (Bezuidenhout, 1993). The cost incurred for sugarcane transport is one of the largest components within many sugar industries, amounting to 12 % in South Africa, as illustrated by Figure 2.2 (Meyer, 2006; Stutterheim, 2006; Lagrange *et al.*, 2008). This value, however does not offer a true reflection of the magnitude of the sugarcane transport costs, since the cost of transport forms part of each other category specified within the pie chart, excluding chemicals and fertilizer. Hence the actual value of this component is the largest expense for sugarcane production.

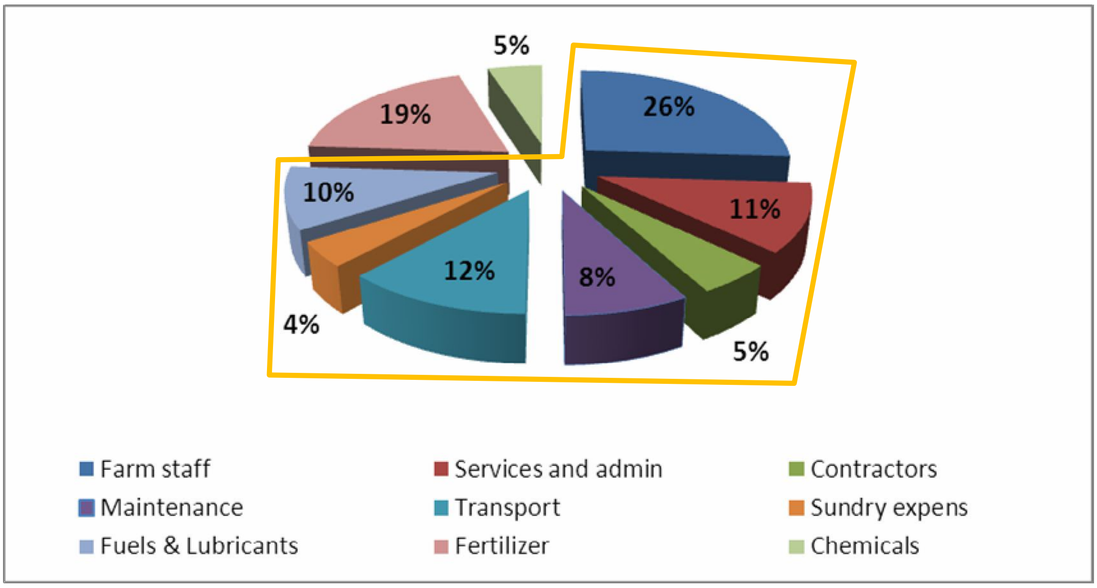


Figure 2.2 Production cost breakdown of sugarcane in the South Africa (Source: Canegrowers, 2008/09)

Loading is performed in a sugarcane field and /or on a transloading zone. Geddes *et al.* (1998) and Meyer (2001a) elaborate on the factors that affect sugarcane loading, which include among others:

(a) the characteristics of the windrows (width, neatness),

(b) the features of sugarcane (lodged *vs.* straight, variety),

(c) the type of loader, and

(d) the harvesting method (burnt or green).

de Beer *et al.* (1989) state that unburnt sugarcane results in reduced payloads. Loading depends on whether the transport process is direct or indirect. In addition, the type of haulage vehicle affects the type and efficiency of the loading operation (Hughan, 1998; Cowling, 2008a; Giles *et al.*, 2009). The method adopted varies in relation to distance from the mill, the infrastructure and topography (Lee, 1978; Carter-Brown, 1980; de Beer, 1982; Cowling, 2008a). These factors influence the system (*i.e.* direct or indirect) being adopted as well as the type of equipment utilised. In some instances, for the loading of bundled sugarcane, the larger bundles are loaded first and then the smaller bundles are added, with the aim of attaining the correct payload (Cole *et al.*, 2006; Lagrange *et al.*, 2008). The three main sugarcane loading methods adopted are; (a) manual, (b) loading by crane and (c) grab-loader operations.

Off-loading can occur at the mill or at an intermediate point of the transfer system, such as a stockpile or a transloading zone. Sugarcane is spilled onto the floor of the mill-yard, serving as a stockpile buffer, or onto a feeder table for direct entry into the mill (Stutterheim, 2006). According to Cowling (2008a and 2008b) there are various factors that influence the efficiency of the off-loading process. These include the method of loading, the type of sugarcane (green *vs.* burnt) and the length of the sugarcane. In addition, the type of haulage vehicle used, affects the selection of the off-loading operation (Cowling, 2008a). The off-loading systems used within the sugar industry include spillers, gantries and mechanised tippers (Kedian, 1979).

2.1.1 Loading methods

Until 1998 50 % of the global loading operations, were done by manual means (de Beer and Purchase, 1998). The various methods of manual loading include carrying the sugarcane on the hips, head, back or shoulders, which could result in spinal injury or musculo-skeletal strain (Nag and Nag, 2004). In the Philippines, the loaders carry approximately 10 stalks of sugarcane up ramps which are at an angle of up to 45°. Six loaders can load a 12 t truck within three hours (Hughan, 1996). Figure 2.3 illustrates a loader, loading sugarcane with the use of a ramp. A favoured method involves containers being placed on the ground, thus making the container more accessible and reducing the safety issues (Hughan, 1998) since the use of ascending inclined surfaces can be dangerous, especially in wet conditions.

Figure 2.3 Worker manually loading sugarcane onto a truck

Manual loading usually results in the cleanest sugarcane, in terms of trash and ash content (Libunao, 1978; Meyer and Worlock, 1979; Neethling, 1982; Meyer *et al.*, 2001; Abdel-Mawla, 2010). Abreu *et al.* (1980) deduced that the quantity of sugarcane that was manually loaded is influenced by the sugarcane variety, the cultivation conditions (degree of lodging and crop age) and the skill levels of the labourers. Manual loading has been carried out in the Philippines, South Africa, Zimbabwe, Jamaica and Swaziland (Lee, 1978; Bredin and Murton, 1991; Richard *et al.*, 1996; Hughan, 1998; Meyer *et al.*, 2001), but has been drastically reduced over recent years. This decrease is due to the increasing labour costs and the large risk of human injury (Bartlett, 1963; Bartlett, 1974; de Beer, 1982; Hughan, 1996).

If labour is readily accessible and inexpensive, manual loading would be economically viable (de Beer, 1982). Hughan (1996) believes that steps should be taken to mechanise this component. Manual loading has been replaced by grab-loaders in many countries such as India, Egypt, South Africa and Puerto Rico (Partridge, 1965; de Beer, 1982; Richard *et al.*, 1996; Nag and Nag, 2004; Abdel-Mawla, 2010).

Cranes are used extensively in the sugarcane industry and are often used at transloading zones (Ashe 1979; Stutterheim, 2006). Types of cranes include gantry or derrick cranes, which can be stationery or mobile (Bentley, 1956; Libunao, 1978; Meyer *et al.*, 2001). Sugarcane bundles are secured by chains, which are picked up by the cranes. The sugarcane is then released from the chains into transporting units.

A mobile derrick crane lifting a sugarcane bundle, secured with chains is shown in Figure 2.4.

Figure 2.4 Bundled sugarcane being loaded by a mobile derrick crane at a transloading zone

In the Philippines, empty containers are left in the field for loading and once loaded, are lifted by a self-loading hydraulic crane onto the trucks (Hughan, 1996). In South Africa, bundles of sugarcane weighing 3 – 5 t are created in loose sugarcane form. The loading operation in South Africa entails, loading by mobile cranes of the larger bundles first followed by the smaller bundles to attain payload (Bartlett, 1974; Worrall and Meyer, 1991; Cowling, 2008a). Carter-Brown (1980) and Spalding (1992) argue that the elimination of the chains will allow for an increase in the efficiency and safety of this system.

Grab-loaders (*cf*. Figures 2.5 – 2.7) are hydraulically-operated machines which are used widely in the sugar industry (Ashe, 1979; Carter-Brown, 1980). There are different types of grab-loaders which include; non-slewing, slewing and push-pile grab-loaders. Experiments undertaken by Nour and Allam (1989) and Abdel-Mawla (2010) revealed that this type of loader offered good manoeuvrability and the use of this system, compared to manual loading, results in a significant increase in productivity. This is the most common type of loading used in South Africa, Egypt, Swaziland, Jamaica, the Philippines and Guyana (Abrahamson, 1949; Lee, 1978; Richard *et al.*, 1996; Hughan, 1998; Meyer, *et al.*, 2001; Tshawuka and Ellis, 2001; Davis, *et al.*, 2005; Abdel-Mawla, 2010).

The use of the grab-loader was found to improve the utilisation of transport vehicles (Lagrange *et al.*, 2008). Carter-Brown (1980) found that different types of grab-loaders are used for varying topographies. In the steeper coastal areas, three-wheeled grab-loaders are used to load sugarcane, while in the flatter areas, push-pile grab-loaders are used (Carter-Brown, 1980). These are shown in Figure 2.5 and Figure 2.6, respectively. A new machine which is being used more widely, is the excavator with a grab attachment, which is illustrated in Figures 2.7. These machines replace cranes at loading zones and eliminate the need for chains (Bartlett, 1974; Carter-Brown, 1980).

Figure 2.5 Three-wheel non-slewing grab-loader loading loose sugarcane at a transloading zone

Figure 2.6 Push-pile slewing grab-loader loading loose windrowed sugarcane in-field

Figure 2.7 Excavator with a grab attachment loading sugarcane in-field

The method of sugarcane loading adopted varies in relation to (a) circumstances, which may include the type of sugarcane *i.e.* burnt *vs.* trash, topography, positioning of the truck in relation to the sugarcane pile and (b) the sugarcane preparation *i.e.* windrows *vs.* unaligned sugarcane. Some trailer designs allow for the grab-loaders to compact the loads through slots on the side of the trailer (Statham, 1990). This machine can be quickly and easily transferred to other transloading zones and may be used to load sugarcane directly into road transport units if field conditions are favourable (Bartlett, 1963; 1974).

Spalding (1992) found that the use of a grab-loader machine reduced labour requirements by 75 % and increased the payloads. Gordon (1978) found that small changes to supervision techniques of the loading operation can result in the system being significantly improved. Operators require training in order to ensure the maximum payloads and minimal collection of soil (Neethling, 1982; Meyer, 2004).

2.1.2 Transport systems

McWhinney (1983) and Meyer *et al.* (2001) reviewed the various transport methods used internationally, ranging from animal-drawn vehicles to large road trucks. In Guyana, sugarcane transport is *via* a canal system by barges (Davis *et al.*, 2005). The form of transport employed in the Philippines includes bull-carts for in-field transport and trucks for transfer to the mill (Libunao, 1978; Hughan, 1998). Hughan (1998) added that this system was ideal during wet conditions. The initial mode of transport in Puerto Rico was by ox and cart, which was replaced by simple tractor-trailers in the 1940's (Partridge, 1965). In Zimbabwe, sugarcane is transported directly to the mill in tractor/self-loading trailer combinations or through a transloading zone (Meyer *et al.,* 2001). In Cuba, sugarcane is transported in two ways: (a) directly - with road swing bolsters and (b) indirectly - by road vehicles to a transloading zone and then by rail carriages to the mill (Milan *et al.*, 2006). The main methods of sugarcane transport in the United States of America are by rail and large trailers (Cowling, 2008a). The main mode of transporting sugarcane in Brazil is by road haulage (Cowling, 2008a). The systems in Australia include rail or articulated self-propelled tractor/trailer combinations and rigid self-propelled units (Geddes *et al.,* 1998). There is a trend towards road transportation with the use of higher payload vehicles with a capacity ranging between 24 – 35 tons (Barnes, 1999). Systems are also becoming more mechanised due to high labour costs.

As a result of the rising prices of fuel, rail transport is sometimes favoured (Milan *et al.,* 2006). In the Philippines, 20 % of sugarcane is transported by rail cars on trailers that are transferred onto the rail system at a siding. However, there has been a gradual shift towards road transport (Libunao, 1978; Hughan, 1998). The majority of sugarcane in Australia is transported to the mill by narrow-gauge rail, which is also slowly being replaced by articulated road vehicles (McWhinney, 1983; Meyer *et al.,* 2001; Cowling, 2008a). In Cuba rail system functions on a 24-hour basis, hence allowing for the transport of sugarcane at night when road transport is halted (Milan *et al.,* 2006). Jacquin *et al.* (1996) found that the incorporation of night transport resulted in a cost reduction of 31 %. There are only two mills in South Africa that have sugarcane delivered by rail. The Felixton Mill uses standard rail, while the Umfolozi Mill has a narrow-gauge tram-line system, shown in Figure 2.8. Rail has not been favoured due to the high initial capital investment cost, the high maintenance costs, the time required for loading and the higher level of management required due to many loading operations occurring simultaneously (Steward, 1955; Meyer *et al.,* 2001).

Figure 2.8 Tram-line system at the Umfolozi Mill

There has been a shift towards the use of road transportation for sugarcane as opposed to rail systems, as it is often found to be the more economical (Hughan, 1998). The transport of sugarcane in South Africa is carried out by various road systems; with the main types including, (a) tractor-trailer combinations (b) interlink and (c) rigid drawbar spiller trailers (Bezuidenhout, 1993; Davis and Archary, 2006; Cowling, 2008a; b; Giles *et al.*, 2008; Giles *et al.*, 2009; Roberts *et al.*, 2009). This distribution is illustrated in Figure 2.9. The tractor-trailer, interlink, rigid drawbar and tri-axle haulage units are illustrated in Figure 2.10.

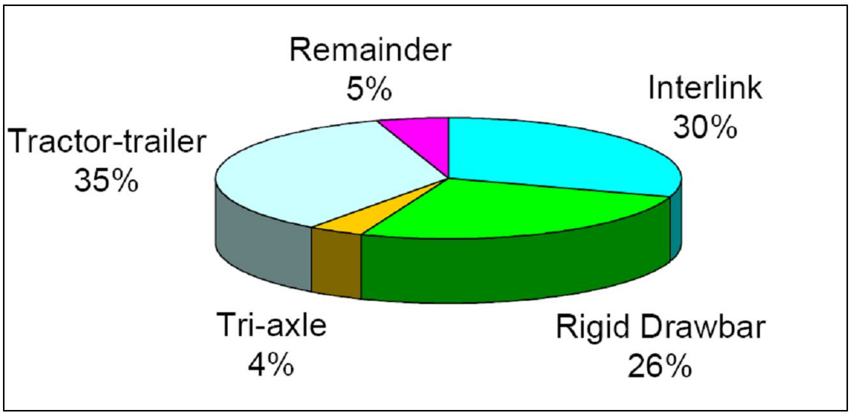


Figure 2.9 Fleet distribution of transport vehicles within the South African sugar industry in 2008 (Giles *et al.*, 2009)

Roberts *et al.* (2009) carried out an economic analysis comparing different road vehicles and found the tri-axle to be the most cost-effective option. Yet, it is the least common vehicle used within the industry. Roberts *et al.* (2009) concluded that interlinks are the most expensive vehicles to maintain, even at high payloads. Despite this, these vehicles are used widely within the sugar industry and this can be attributed to their high volume capacity and their compatibility with lodged and low density sugarcane (Geddes *et al.*, 1998; Roberts *et al.*, 2009). In addition interlinks are well configured for the off-loading facility (Cowling, 2008a).

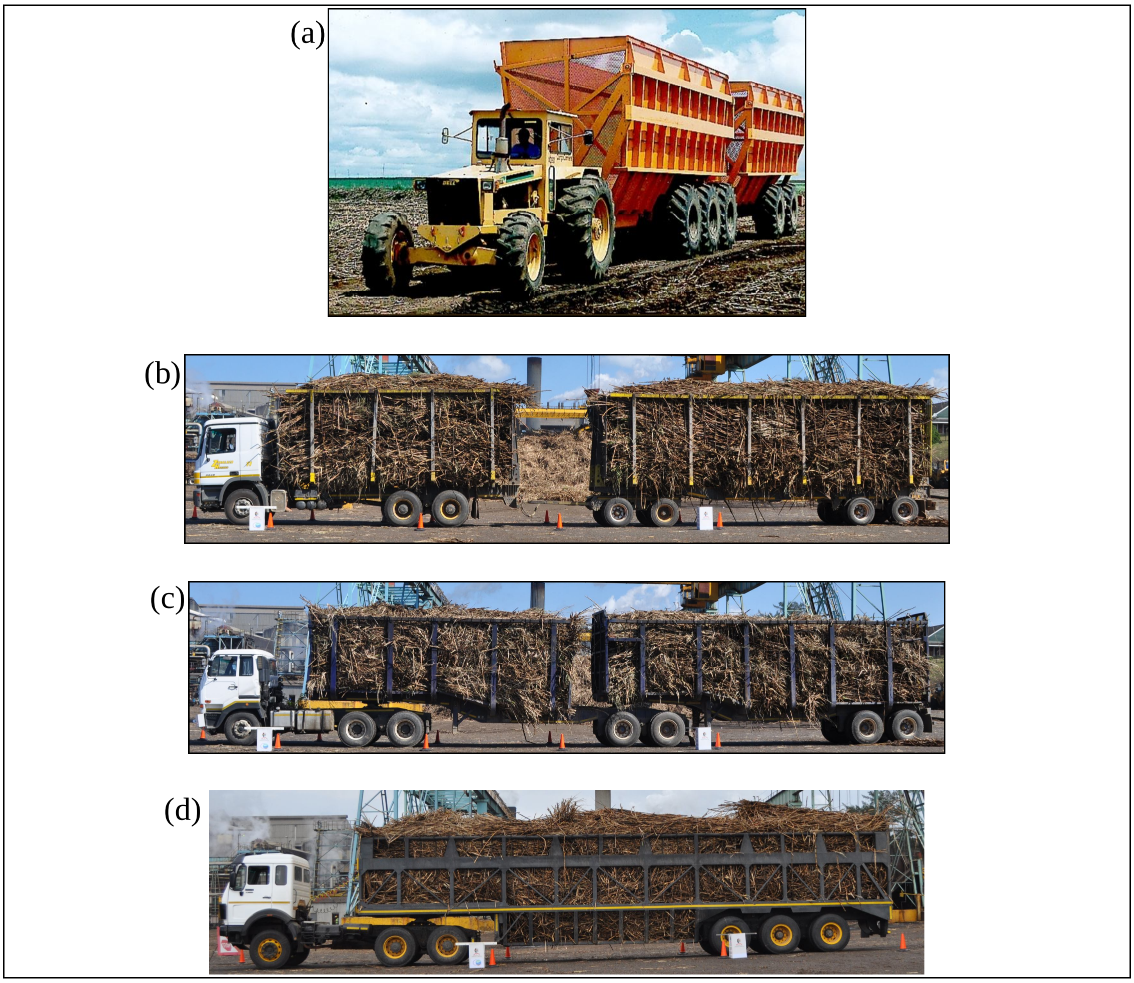


Figure 2.10 The most common transporting unit types within the South African sugar industry (a) Tractor-trailer (b) Rigid drawbar, (c) Interlink and (d) Tri-axle

Vehicle designs offer constraints relating to the axle distribution, as well as the volume and mass aspects of the sugarcane load (Bezuidenhout, 2010). Bezuidenhout

(2010) states that due to the design of the sugarcane vehicles, a flat bed load will not meet optimal payload requirements. The haulage vehicles are designed for different types of sugarcane bulk densities, as later discussed in Chapter 4 of this study. Each vehicle has its own design specifications, which comprises a design payload (γ' in kg) and design volume (v' in m^3) and the ratio of these specifications gives the design bulk density (ρ_b' in $kg.m^{-3}$) for each vehicle. The ideal sugarcane vehicles are those designed for a bulk density of 350 kg/m^3 while designs of higher densities indicate poor designs. One way to increase payloads is to reduce the tare-mass of the transport units (Meyer, 2002; Roberts *et al.*, 2009). Geddes *et al.* (1998) formulated a vehicle load index to assess the efficiency of a transport system (*cf.* Equation 2.1). Nevertheless this is just an indicator, as Geddes *et al.* (1998) admit that there are many factors that affect the transportation of sugarcane.

$$\beta = \frac{\gamma}{m} \qquad \text{(2.1)}$$

Where: β = Vehicle load index

γ = Vehicle payload [kg]

m = Gross mass [kg]

de Beer *et al.* (1993) stated that for an efficient transport system, the payload to tare weight ratio should be at least 1.5:1. Cowling (2008a) calculated the vehicle load index as per Equation 2.1 for different vehicles currently used in South Africa (*cf.* Table 2.2).

Table 2.2 Vehicle load index for vehicles used to transport sugarcane in South Africa (after Cowling, 2008a)

Vehicle Type	**Vehicle load index**
Rigid Drawbar	1.95
Tandem/Tandem Interlink	1.46

The design of transport vehicles is affected by the off-loading facilities, as well as economical factors (McWhinney, 1983; Meyer *et al.*, 2001). Designs for sugarcane trailers should ideally offer (a) more capacity for delivery than that currently available, (b) a lower centre of gravity to increase stability and (c) a reduction in operational costs (Bentley, 1956; McWhinney, 1983; Koppen *et al.*, 1998). Domex is a new type of steel which has a better strength-to-mass ratio (Cowling, 2008a). This is now being used for the construction of trailer units to allow for reduced tare-mass and hence increased payload capacities (Bezuidenhout, 1993; Geddes *et al.*, 1998; Koppen *et al.*, 1998; O'Reilly, 1999; Cowling, 2008a; Roberts *et al.*, 2009). The absence and/or presence of a base and the type of tailboards form part of the newer trailer designs. The different types of tailboards are illustrated in Figure 2.11.

Figure 2.11 The different types of tailboards of sugarcane transport units in South Africa, closed, semi-closed and open (meshed)

Bezuidenhout (1993) argues that the chain system results in losses in revenue since the mass of the chains reduce the allowable payload and sometimes results in inefficient spilling, which, in turn, increases the time taken to clean the trailer after off-loading. Bezuidenhout (1993) explored the concept of utilising nylon straps with the Hilo-type trailer, as opposed to chains. Essentially this could lead to increased payloads and a reduction in protruding sugarcane and roadside spillage. Figure 2.12 (a), (b) and (c) demonstrate trailers with chains, belts and ropes, respectively. In some cases of chain and rope systems there can be extensive roadside losses and spillage during off-loading, as illustrated in Figures 2.13 (a) and (b), respectively. This can be avoided through better loading techniques. The trade-off with the belt system is an increased ash content within the load (Bezuidenhout, 1993). The implications for replacing the chains with belts were not ascertained due to complications within the experiments carried out by Bezuidenhout (1993).

Figure 2.12 Various designs of trailers used to transport sugarcane, *viz.* (a) trailers with chains (b) trailers with belts in place of the chains and (c) trailers with ropes

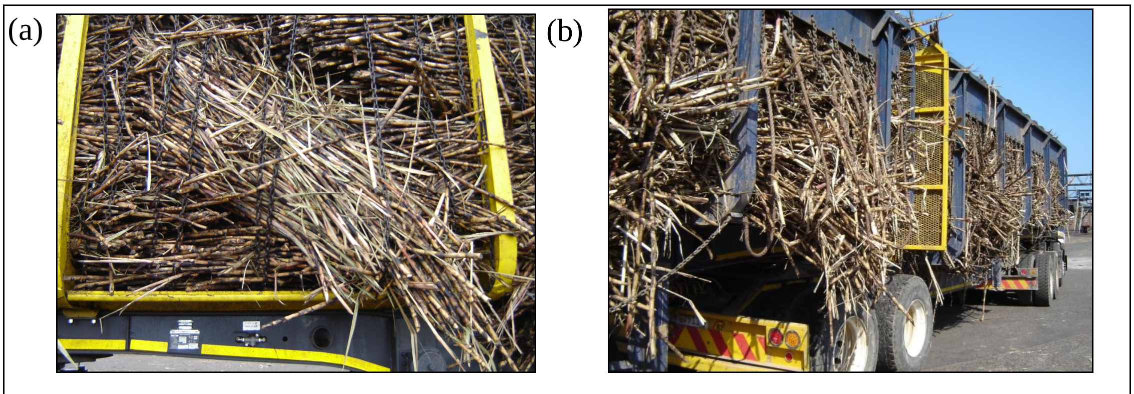


Figure 2.13 Illustrations of potential sugarcane spillages based on trailer designs, *viz.* (a) chains and (b) ropes

A study by Cowling (2008a; 2008b) compared two types of transport vehicle trailers, *viz.* the bolster and the frame type. It was found that the bolster type trailer requires less effort for off-loading, compared to the frame type. This was as a result of the increased friction between the sugarcane and the rigid frame of the frame type trailer, while the curved shape of the bolsters complemented the spilling operation and presented a reduced contact area between the trailer and the sugarcane (Cowling, 2008a; Cowling, 2008b). The two types of transport trailers are shown Figure 2.14.

(a) (b)

Figure 2.14 (a) A frame-type trailer and (b) a bolster-type trailer

2.1.3 Off-loading mechanisms

Cranes are used extensively in the sugarcane off-loading process (Libunao, 1978; Ashe, 1979; Meyer *et al.*, 2001). Bundled and loose sugarcane may be off-loaded by bridge cranes with a grab attachment or overhead gantries (Bentley, 1956; Kedian, 1979; Meyer *et al.*, 2001; Tshawuka and Ellis, 2001; Watson *et al.*, 2008). In the Philippines, rail cars are carried and moved around by cranes (Hughan, 1998), while in Australia, containers are transferred by a fully-automotive crane-type machine (Koppen *et al.*, 1998). As an alternative, some mills use hysters (Abrahamson, 1949; Bartlett, 1974). This system is relatively expensive due to high maintenance and labour requirements, making it a less attractive system. It has been phased out due to the extremely high costs.

Mechanised off-loading includes two methods, namely, off-loading by means of the (a) chain-spiller system and (b) by hydraulic tipping equipment. Bredin and Murton (1991) found that off-loading efficiencies can be improved by off-loading two trailers at once. The chain-spilling system is employed in Cuba, South Africa, the Philippines and Swaziland (Bentley, 1956; Bartlett, 1974; Abreu *et al.*, 1980; Statham, 1990; Hughan, 1998; Meyer *et al.*, 2001; Tshawuka and Ellis, 2001; Stutterheim, 2006; Cowling, 2008a). The chain-spiller system requires specialised trailers, Hilo spillers or semi-trailer rigs (Kedian, 1979; Statham, 1990; Stutterheim, 2006; Cowling, 2008a). The trailers are designed around the constraint dimensions of the off-loading equipment (Bredin and Murton, 1991; Statham, 1990). Generally this method is employed for loose sugarcane (Watson *et al.*, 2008). A schematic illustrating this spilling operation is shown in Figure 2.15. Hilo-type trailers consist of chains under the sugarcane load attached at both sides of the trailer, as shown by A and B in Figure 2.16. The chains form a net within the trailer which assists in the removal of the sugarcane. On side A (*cf.* Figure 2.16) of the trailer a large metal bar is present. This is called a spiller bar and is used for the attachment of a special crane which is raised until the sugarcane is ejected from the trailer (Bentley, 1956; Bartlett, 1974; Statham, 1990).

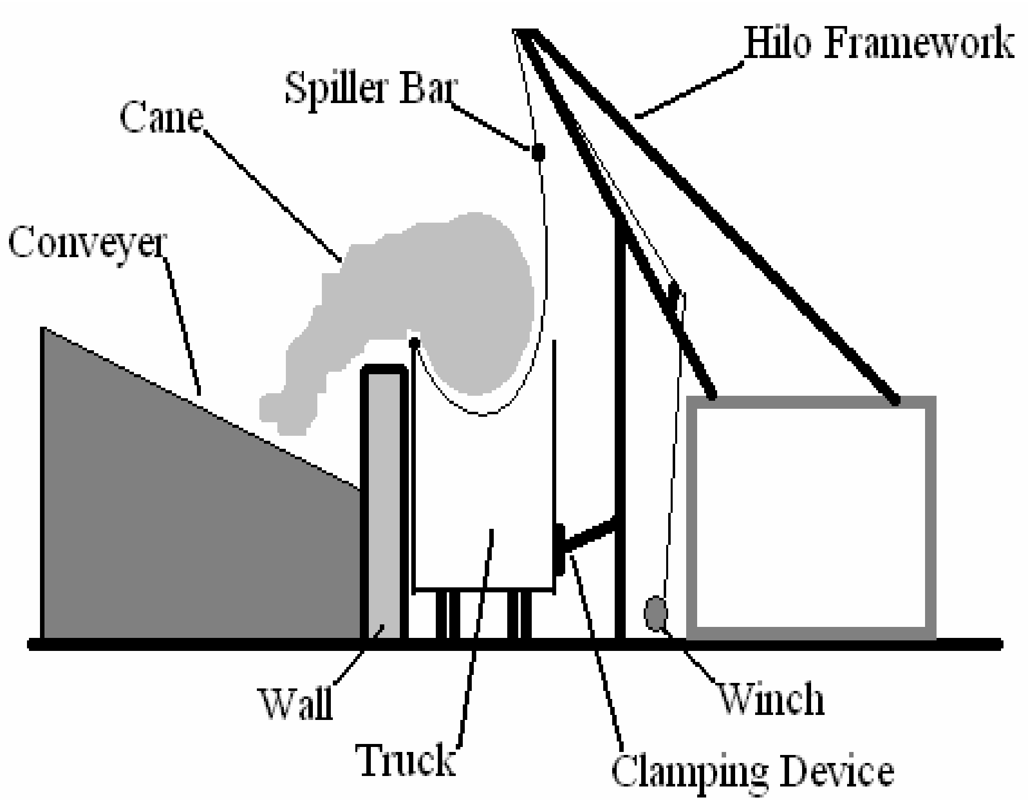


Figure 2.15 Schematic of an off-loading chain-spiller system (Cowling, 2008a)

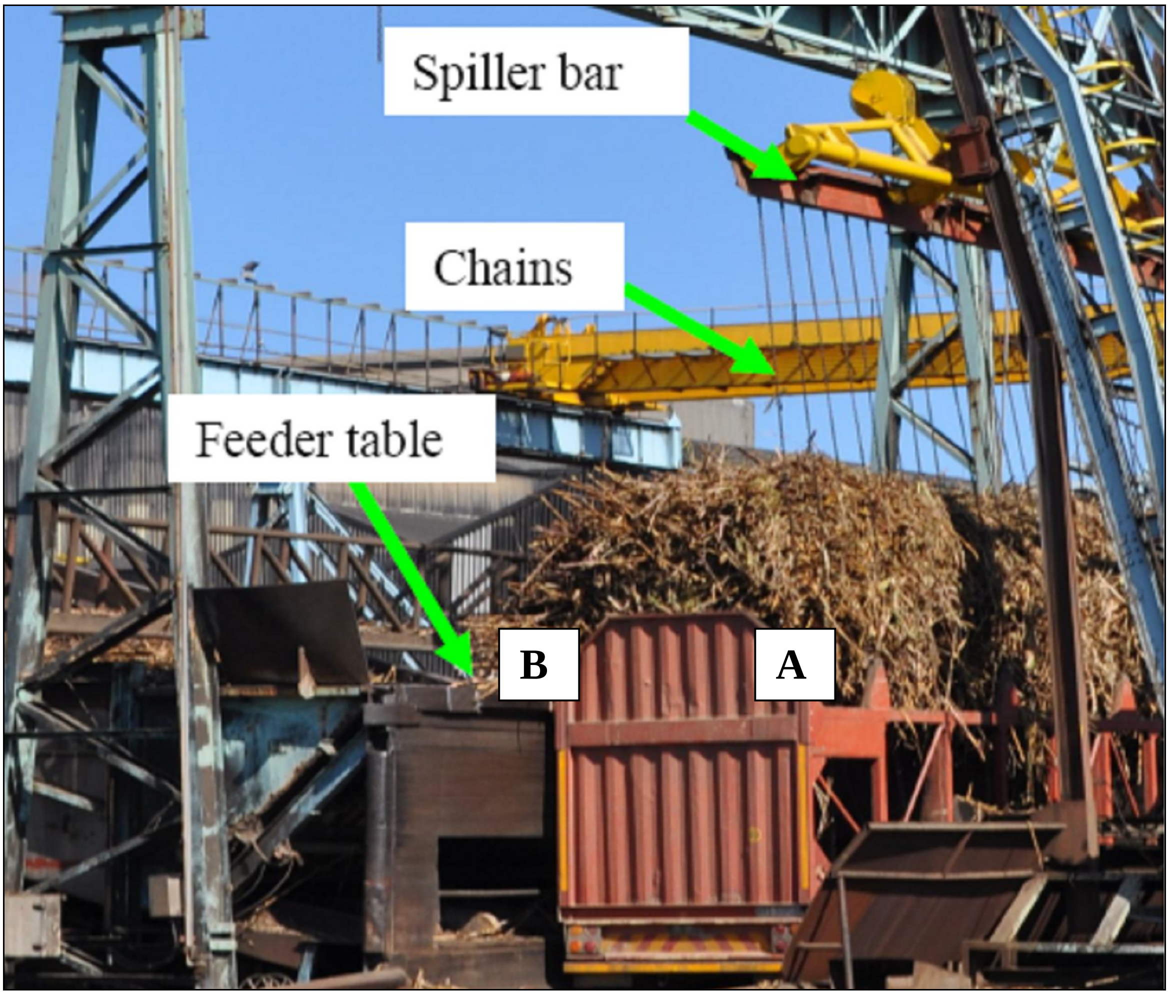


Figure 2.16 Spilling mechanism at the Sezela mill in South Africa

The average off-loading time for this system is 2 minutes and 30 seconds (Kedian, 1979). In comparison with the chain-spiller, the hydraulic tipper is relatively inexpensive and more time-efficient as it takes 90 seconds to off-load. If these two processes are carried out on a continuous basis, the chain-spiller will be capable of off-loading a vehicle every 4 minutes, while the hydraulic system can off-load every 2 minutes (Kedian, 1979; Meyer *et al.*, 2001). Railway type hydraulic tippers and tractor-trailer tippers are used in South Africa (Kedian, 1979; Carter-Brown, 1980). A hydraulic side-tipping system employed in Australia is shown in Figure 2.17 and a hydraulic tractor-trailer tipper combination used in South Africa is shown in Figure 2.18.

Figure 2.17 Sugarcane transloading by a hydraulic side-tipping trailer in Australia

Figure 2.18 A South African transloading hydraulic side-tipping trailer

Robinson (1983) describes the Rota-Tipper off-loading mechanism employed in Mhlume, in Swaziland, where the off-loading structure attaches to the bin and vertically raises it to empty the contents within 90 seconds. Containers are also off-loaded in this manner in Columbia and the Philippines, with designs being customised according to the specifications of the haulage system employed (McWhinney, 1983; Hughan, 1998; Koppen *et al.*, 1998, Gomez *et al.*, 2010). Kedian (1979) argues that hydraulic side-tipping requires less cleaning compared to the chain-spiller mechanisms.

Rear-tipping is employed in the Philippines, where the truck is positioned on a raised ramp to off-load the sugarcane (Hughan, 1998). Hughan (1998) states that any unit loaded with sugarcane can be easily off-loaded in this way, making the system a viable option (Hughan, 1998). Self-tipping box trailers are off-loaded by the tipping action of the trailer unit (Carter-Brown, 1980). Rear off-loading is adopted in South Africa, Guyana and the Philippines (Spalding, 1992; Hughan, 1998; Meyer *et al.*, 2001; Davis *et al.*, 2005). Figure 2.19 illustrates the rear-tipping of sugarcane at a transloading zone in South Africa, which can severely affect the bulk density of the sugarcane.

Figure 2.19 Rear-tipping trailer off-loading sugarcane at a transloading zone in South Africa

2.2 Factors that Influence the Efficiency of the Transfer System

This section reviews the various factors that have an impact on the overall efficiency of the transfer system. These factors can be categorised into, sugarcane properties, sugarcane handling and environmental factors. Although interrelated, these are presented and discussed in the following three sub-sections (*cf.* Sections 2.2.1 – 2.2.3).

2.2.1 Sugarcane properties

Properties such as the length, the diameter, the density and the fibre content of sugarcane, affect payload accuracies (Abreu *et al.*, 1980; Geddes *et al.*, 1998; Meyer, 2001a; Meyer *et al.*, 2001; Tshawuka and Ellis, 2001; Lagrange *et al.*, 2008; Giles *et* *al.*, 2009). Sugarcane density refers to the actual biological characteristic while the bulk density describes the consignment. Sugarcane possesses a relatively low bulk density which varies between 250 – 450 kg.m^{-3} (Koppen *et al.*, 1998; Lagrange *et al.*, 2008; Roberts *et al.*, 2009). Lodging is a term used to describe when mature sugarcane falls over due to structural weakness, rainfall or wind (Stutterheim, 2006). Lodged sugarcane reduces the payloads because the stalks grow in a curved manner, which results in relatively low bulk densities (Tshawuka and Ellis, 2001; Stutterheim, 2006; Cowling, 2008a; Lagrange *et al.*, 2008). In South Africa one sugarcane variety, N31, was found to have a significantly poorer performance in terms of payloads, because it is fibrous and prone to lodging (Meyer *et al.*, 2001; Lagrange *et al.*, 2008).

Sugarcane with the leafy material removed is referred to as clean (Hughan, 1998; Wynne and van Antwerpen, 2004). Green refers to illustrate sugarcane which has not been burnt. It is difficult to estimate the density of green, unclean sugarcane due to the large quantity of extraneous material (ash tops, leaves). Payload is reduced significantly when there is an increase in extraneous matter of sugarcane (de Beer *et al.*, 1989; Wynne and van Antwerpen, 2004; Purchase *et al.*, 2008). The variable nature of sugarcane influences the efficiency of the transfer system.

2.2.2 Factors influencing sugarcane handling

Factors influencing sugarcane handling include the type of harvesting method and the preparation for loading (Lee, 1978; Carter-Brown, 1980; Geddes *et al.*, 1998; Meyer, 2001a; Meyer *et al.* 2001; Stutterheim, 2006; Purchase *et al.* 2008). Preparation operations include stacking or the windrowing of the sugarcane stalks (Lee, 1978; Carter-Brown, 1980; Meyer and Fenwick, 2003; Stutterheim, 2006). The loading operation for green sugarcane is more difficult compared to that of burnt sugarcane, because its fibre content can be 50 % higher (Wynne and van Antwerpen, 2004; Purchase *et al.*, 2008). Figure 2.20 illustrates unaligned with well-aligned sugarcane. The loading of unaligned sugarcane is inconsistent, since the amount of sugarcane transferred varies with each grab-load compared to aligned sugarcane. Sugarcane placed in stacks or windrows make the transfer of sugarcane more efficient in terms of time, bulk density and hence payload accuracy. To allow for efficient loading operations, the sugarcane should be placed in neat windrows, as shown in Figure 2.20 (b). In terms of payload accuracy the cut and windrow system was found to be more effective than the cut and stack operation (Neethling, 1982; Steward and Fischer, 1983). The specifications of the equipment, including the size of the grab and the ability of the loader to compact sugarcane inside the trailer, also influence the loading operations (Hughan, 1998; Meyer *et al.,* 2001; Giles *et al.,* 2009).

(a)

(b)

Figure 2.20 (a) Unaligned sugarcane at a transloading zone. (b) Neat windrows prepared for loading in-field

2.2.3 Environmental factors

The environmental factors influencing the load efficiency include the biological yield, the sugarcane length, the sugarcane stalk diameter and the density (Abreu *et al.,* 1980). The topography and field conditions influence the manoeuvrability of the loader and vehicle, hence impacting on loading efficiency (Carter-Brown, 1980; de Beer, 1982; Cowling, 2008a). Wet conditions increase the amount of soil present and may also determine the transport system adopted, *i.e.* it can result in a direct transport system being converted into an indirect one (Steward and Fischer, 1983). The change of the seasons impacts on the amount of daylight hours available, which affects the loading process (Roberts *et al.,* 2009). The field conditions, such as crop yield and row length was found to have an influence on the efficiency of the transfer system (Lee, 1978).

2.3 Synthesis

This literature survey comprises a review of the various components of the sugarcane transfer system. Although this field of study is not well-published in peer-reviewed international journals; it is a prevalent topic in a number of conference proceedings around the world. The survey established a list of important factors that impact on the efficiency of the components of the transfer system.

There are a wide variety of processes and systems which have undergone continuous improvement in South Africa, to ensure that the sugarcane sector remains competitive. Systems are shifting towards loose sugarcane handling, as opposed to bundled sugarcane. This is due to increased labour productivity, an increase in the efficiency of operations, as well as safety aspects. Manual loading results in the cleanest sugarcane, despite this it is being phased out, due to the increasing labour costs and high health risks involved. The grab-loader is more widely used and was found to significantly increase productivity. The main method used for sugarcane transfer in South Africa is an indirect system, where loading is carried out by grab-loaders, in-field transport is done by tractor-trailer units, road transport is carried out by spiller-type interlinks and off-loading is done by a chain-spiller mechanism at the mill. The design of transport vehicles can be revised in terms of the materials used for construction, as well as the geometry and size of the units. Systems can be converted from indirect to direct systems, to avoid the costs of transporting sugarcane to an intermediate zone where transloading is carried out.

The properties of sugarcane, as well as external factors, affect the payload, loading and off-loading methods and their respective efficiencies. These factors are divided into sugarcane properties, handling attributes and environmental factors, which are summarised in Table 2.3. The factors which vary include the sugarcane bulk density, the equipment utilised and the transport system adopted.

Table 2.3 Factors which influence efficiency of the sugarcane transfer system

Sugarcane	**Sugarcane handling**	**Environmental**
Geometry of stalks (diameter and length)	Harvesting method (green *vs.* burnt)	Climate (wind, rain)
Sugarcane density	Equipment specifications and vehicle designs	Site conditions In-field – inclination On-zone – design and configuration of the sugarcane pile
Trash content (sugarcane type)	Transport system (direct *vs.* indirect)	Season
Degree of lodging	Sugarcane presentation (windrow *vs.* unaligned)	
	Sugarcane bulk density (ρ_b)	

Training is an essential component to enhance loading operations; however, there are no current standards or guidelines available in one coherent document. Guidelines for loading will assist in addressing high haulage costs and in increasing the efficiency of the loading of sugarcane within the transfer system (Meyer, *et al.*, 2001; Meyer, 2004; Stutterheim, 2006; Giles *et al.*, 2009). The transport of sugarcane can be made more efficient by accurate loading, an increase in supervision of operations, improved use of equipment at various points within the system and by offering incentives to loading operators (Barnes, 1964). A detailed description of the process followed for this study is presented in the next chapter.

3. METHODOLOGY

An integral part of determining an optimal transport system is to review the components of the system. In the previous chapter it was found that there are various systems available for the transfer of sugarcane within South Africa. The primary objective of this chapter is to set up methods to investigate the impact of physical sugarcane properties on loading accuracies, such as the sugarcane alignment and configuration, along with the profile of the sugarcane consignments which can be associated with the loading techniques adopted when using a grab-loader. The research was divided into (a) an evaluation of the actual loading operations carried out at a loading zone and (b) an investigation of vehicle consignment characteristics. This assisted in the establishment of guidelines for loading sugarcane with grab-loaders.

3.1 Overall Research Approach

An analysis of sugarcane loading operations and sugarcane consignments was carried out. The mass for the consignments were linked to photographs and video clip footage to relate the accuracy of the payloads per consignment. The details of the methodology are discussed in the sub-sections of this chapter. The following step-wise procedure was adopted:

- On-zone loading operations were monitored to determine some of the current practices (further described in Section 3.2).
- A viewing and discussion of the current loading practices with specialist consultants were carried out.
- A discussion and feedback session with loading operators was performed.
- 203 photographs of spiller sugarcane consignments were taken at the Sezela Sugar Mill.
- The mass of each consignment were obtained from the mill’s weighbridge database.

- A range of visual features were assessed and quantified (these are described in Section 3.3.2).
- A statistical and multi-variate analysis was carried out to establish relations between the visual features and loading accuracy (described in Chapter 4).
- Guidelines for loading were established.

3.2 Loading Operations

Video footage of loading operations at transloading zones was taken. Operations involved loading with a grab-loader into Hilo-spiller trailers. The operations were recorded and the footage was analysed to determine different techniques and to ascertain the possible causes for differences in loading accuracies. The camera was hidden ensure a true reflection of the loading operation.

An in-depth evaluation of all the loading operation video clips was carried out. This involved an assessment ranging from the characteristics of each grab to the loading zone set-up. This did not form a comprehensive analysis due to missing data (*i.e.* parts of loading operation were not captured by the camera). In addition, other variables, such as fuel consumption, were not recorded. The various loading patterns adopted were noted; however, more data is required to enhance the understanding of this operation. A basic time-motion analysis of a loading operation was undertaken where the time was sub-divided in terms of (a) zone movement and cleaning, (b) movement with full grab, (c) loading sugarcane into the trailer (d) compacting and neatening the sugarcane load and (e) movement with an empty grab.

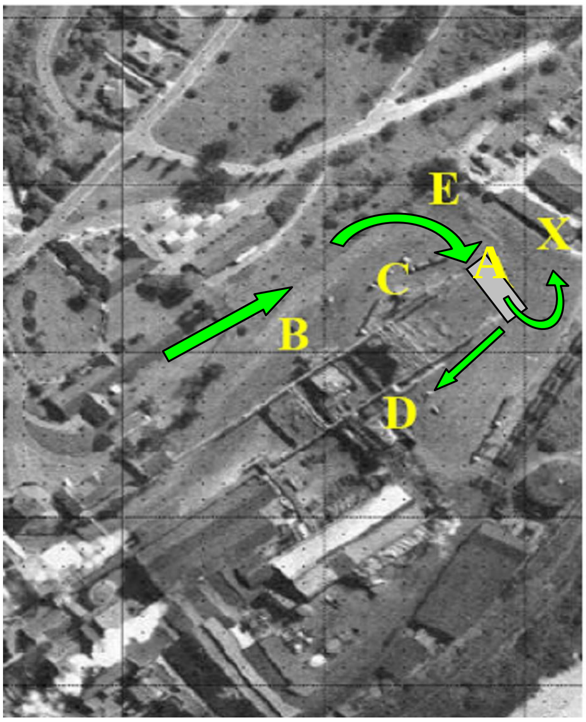
A subsequent meeting with loading specialists involved a demonstration of the loading footage followed by in-depth discussions. Emphasis was placed on the trade-offs between operating time, accuracy, sugarcane loading quantity and quality in terms of the practices adopted. In a second meeting, loader operators were presented with questions relating to the current loading techniques and their views regarding the optimal procedures were recorded. Table 3.1 summarises some of the issues that were discussed. This work was mainly performed in a qualitative manner, but complemented the quantitative results which are further discussed in Chapter 4.

Table 3.1 Critical practices to be assessed during the loading process

No.	Practice
1	Loading direction - load from front to back or back to front
2	Trailer sequence - which trailer to be loaded first
3	Loading technique - column *vs.* layer loading
4	Side of loading - which side of the truck to load from (opposite to spiller bar)
5	Degree of compaction - when and how much compaction should be done
6	Axle load distribution
7	Positioning - truck in relation to the sugarcane pile (related to wind direction)
8	Grab neatness - alignment of sugarcane within the grab
9	Presentation of sugarcane: • the distance between the truck and sugarcane pile, and • sugarcane orientation on the zone.
10	Sugarcane preparation – sorting time and techniques *e.g.* push-piling
11	Characteristics of sugarcane – straight *vs.* lodged, mixed, burnt or green

3.3 Consignment Analysis

The Sezela Mill, located on the KZN south coast, was selected for this study. On average this mill receives 2.2 million tons of sugarcane with an average haulage distance of 30 km per annum (Giles *et al.,* 2005). The off-loading and sugarcane feeding component at the Sezela Mill comprises three Hilo spiller off-loading stations and a gantry crane. Two of the spillers supply sugarcane directly to the mill, while a third spiller serves a stockpile facility to ensure that sugarcane is continuously available, even when vehicles are not arriving. An aerial photograph of the mill is presented in Figure 3.1 and illustrates the positions of the spillers as well as the point at which the sugarcane trucks were stopped to capture photographs for this study (Point A). The side view of the mill yard is presented in Figure 3.2.



A – Truck parking bay (Point of data collection)
B – West-side spiller
C – Stockpile spiller
D – East-side spiller
E – Cleaning area of trucks after off-loading
X – Position of camera

Figure 3.1 Aerial photograph of the Sezela Mill (after Giles, 2009)

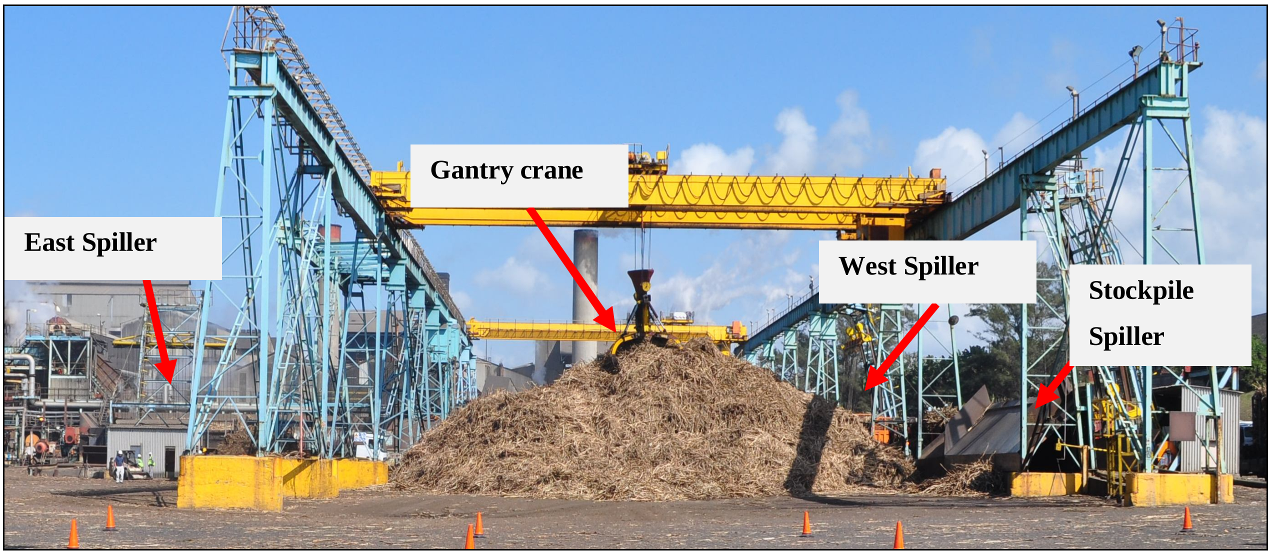


Figure 3.2 Sezela Mill yard and positions of off-loading equipment (this photograph was taken from Point X in Figure 3.2)

3.3.1 Data collection

The data collected consisted of photographs of consignments, along with the sugarcane payload (γ) and vehicle design payload (γ') from the weighbridge database. Road cones and a stop sign were used to demarcate a parking bay (*cf.* Figure 3.3). A high resolution digital camera was set up approximately 20 m from the parking bay in order to capture the entire length of the consignment. Information in terms of the sugarcane bulk density and the sugarcane distribution profile of each consignment was extracted from the photographs. These, along with other factors, are discussed in detail in Section 3.3.2. Rulers of 1 m length were placed within the photographs which were used to calibrate the measurements for later image analyses. These are visible in front of the vehicle in Figure 3.3. Each truck was guided into the parking bay and the time of entry into the mill was recorded from the consignment note along with the registration number to allow for easy cross-referencing with the weighbridge data (*cf.* Figure 3.4). A copy of a typical consignment note is shown in Figure 7.1 in the Appendix. The driver was questioned whether load cells were present and in use.

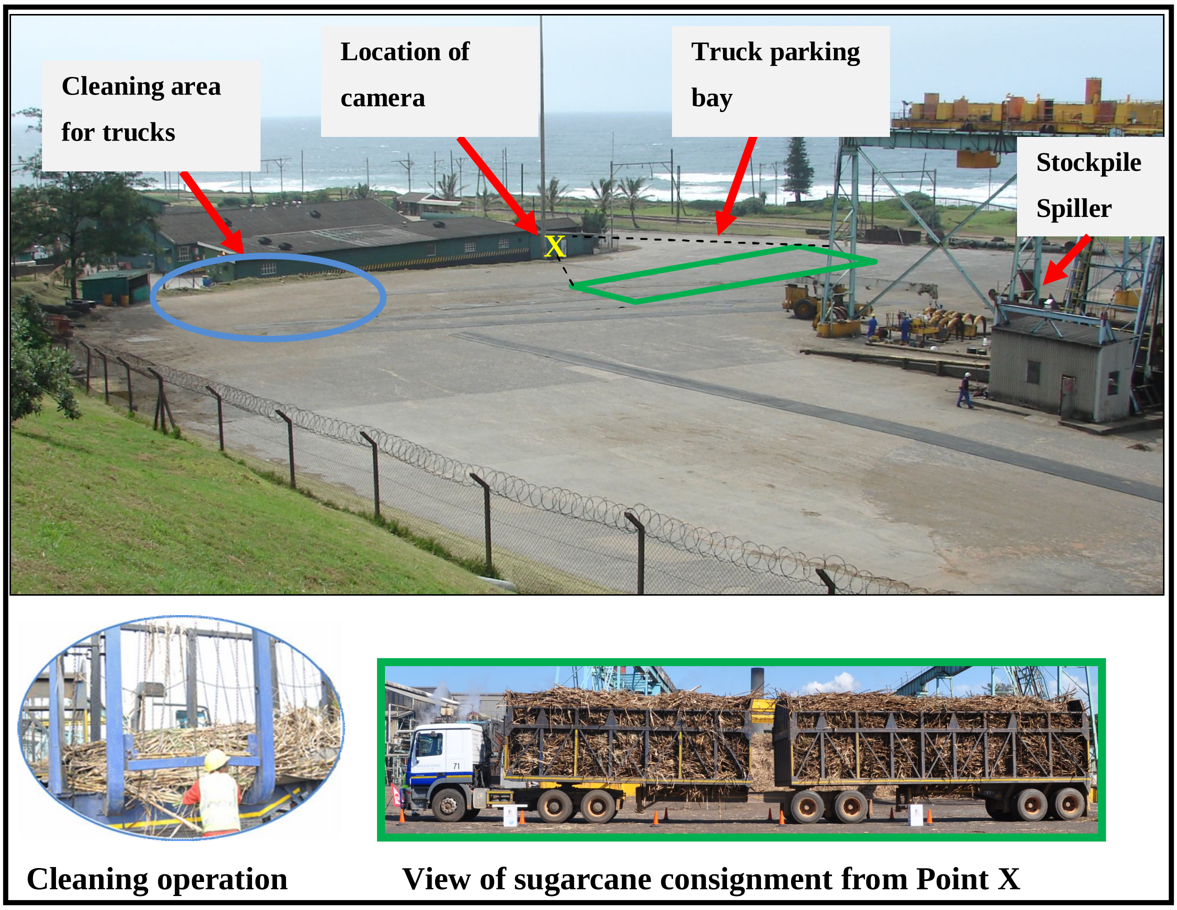


Figure 3.3 Positioning and set-up of the camera for collection of photographs of the consignments in the Sezela Mill yard

(a) 

(b) 

Guided truck into position

Collected weighbridge slip details

Figure 3.4 Process of collecting data of sugarcane consignments

The off-loading operation at the spiller was not monitored and future work relating to this is justified. Cleaning after off-loading, however, was monitored and is further explained in this section. An example of the data collection sheet is presented in Figure 7.2 in the Appendix.

3.3.2 Data analysis

The program "ImageJ" was used to analyse the photographs. This program is a public domain Java based package, which can calculate areas, distances and angles (http://rsbweb.nih.gov/ij/). A macro- and micro-analysis was carried out on each consignment.

Macro-analysis comprised of calculations relating to the entire consignment, such as sugarcane bulk density (ρ_b), vehicle design density (ρ_b'), an undulation ratio (φ), a discharge score and a cleaning requirement score. Polygons were drawn around the entire sugarcane load within each trailer to calculate the surface area, as shown in Figure 3.5. The approximate volume (v in m^3) of the sugarcane for each trailer was then estimated by multiplying the polygon surface areas with the standard trailer width of 2.6 m. This was combined with the weighbridge data (γ) to estimate the sugarcane bulk density (ρ_b). The vehicle's design density (ρ_b') was calculated following a similar approach, which is based on the height of the bolsters for bolster-type trailers and the size of the frame for the frame-type trailers. The design density for the bolster-type trailer is slightly lower than that of the frame-type, due to it possessing and larger volume. The method adopted for calculating ρ_b and ρ_b' for the sugarcane load, may include some errors and may need further verification. The ρ_b calculated based on the assumption that the sugarcane within the trailer along with its width was uniform. This is not the case since sugarcane is packed differently per consignment due to different vehicle designs and loading techniques adopted. The effect was an overestimate of the sugarcane volume resulting in a lower calculated sugarcane bulk density (ρ_b). The procedure adopted for calculating ρ_b was consistent and was used for comparative purposes; hence the impact of the inaccuracy is minimal.

A percentage under-load (% UL) value was calculated to assess the variation between the actual (γ) and the design payload (γ') for each consignment. Consignments were grouped per vehicle, before the sugarcane bulk density (ρ_b) and payload accuracies were assessed. The vehicles were sorted according to the median sugarcane bulk density ($\tilde{\rho_b}$) and were presented in box-and-whisker plots to assess the payload accuracy.

An undulation ratio (φ) was estimated to indicate the distribution profile (top surface) of the load. This included the drawing and measuring of a line along the sugarcane profile in the trailer (l in m) as shown in Figure 3.5. This was divided by the length of the trailer (L in m) according to Equation 3.1. The axle load distribution was not calculated or measured. This may need to form part of future research studies.

$$\varphi = \frac{l}{L} \qquad (3.1)$$

where: φ = undulation ratio,

l = profile distance [m], and

L = length of the trailer [m].

The height of sugarcane above the spiller bar was calculated by measuring the height of sugarcane at different points along the length of the trailers. Three measurements were taken per trailer at estimated equivalent distances between them. A positive measurement was assigned when the sugarcane was above the horizontal bar of the trailer and a negative value was assigned when the sugarcane was below the bar. An average of these measurements was then determined per trailer (*cf.* Figure 3.5).

The efficiency of the spilling was assessed by visual interpretation and resulted in a qualitative rating system. A cleaning score (C) between 1 and 5 was allocated to depict how effectively a trailer was off-loaded. A of score of 1 corresponded to approximately 5 sugarcane stalks remaining in the trailer after off-loading, while a score of 5 would imply that a trailer had a significant amount of sugarcane left after spilling. Figure 3.6 (Page 41) offers an indication of the categorisation for this assessment process. The photographs of loaded consignments were also assessed to determine if the efficiency of off-loading can be predicted. A subjective discharge rating (D) per trailer was allocated to serve as an indicator of the ease of off-loading. This rate was estimated by an assessment of the loaded consignment photographs in terms of sugarcane alignment and the amount overhanging sugarcane. This was also a rating between 1 and 5, which was allocated by subjective assessment taking into consideration the angle at which the majority of sugarcane within the trailer was orientated along with the degree of overhanging. Examples of this rating are provided in Figure 3.7 (Page 39).

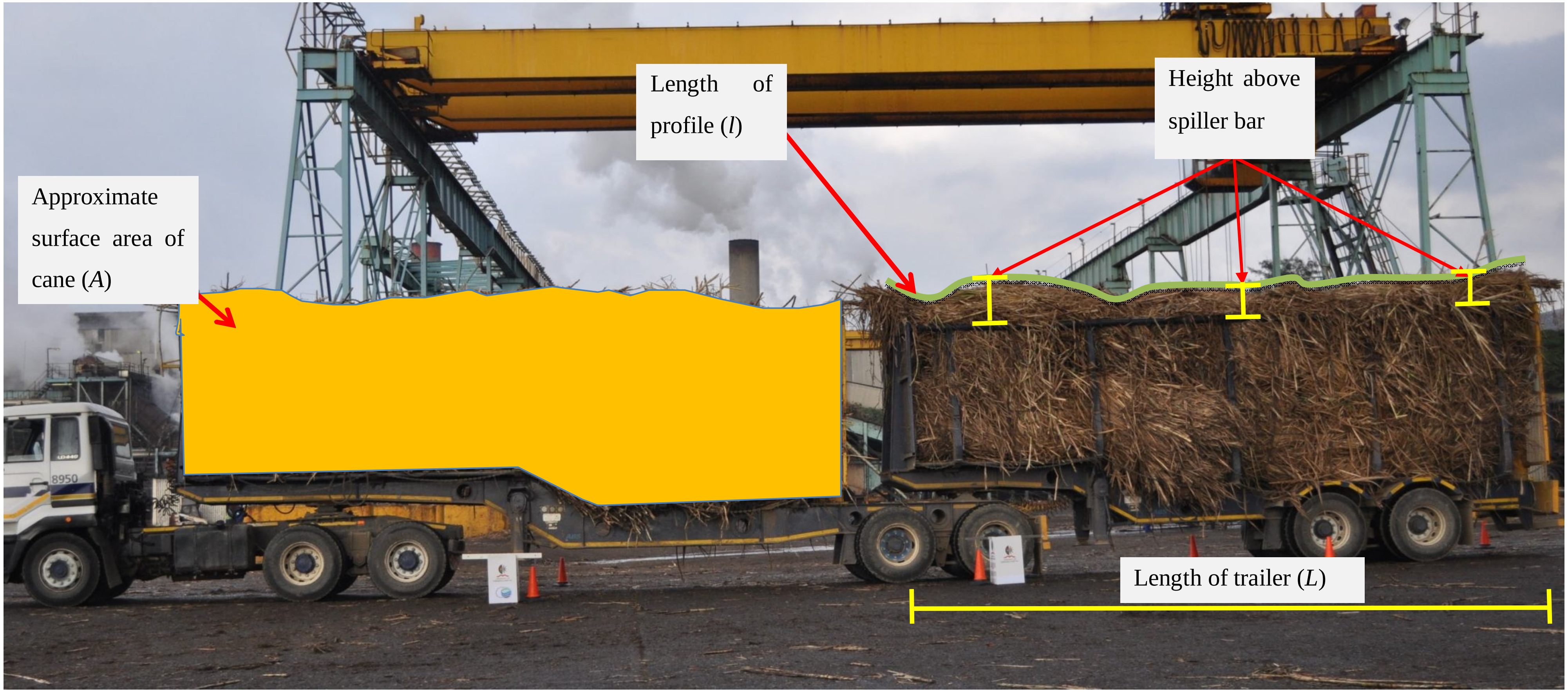


Figure 3.5 Illustration of information derived from photographs of sugarcane consignments (refer to symbols on page vii)

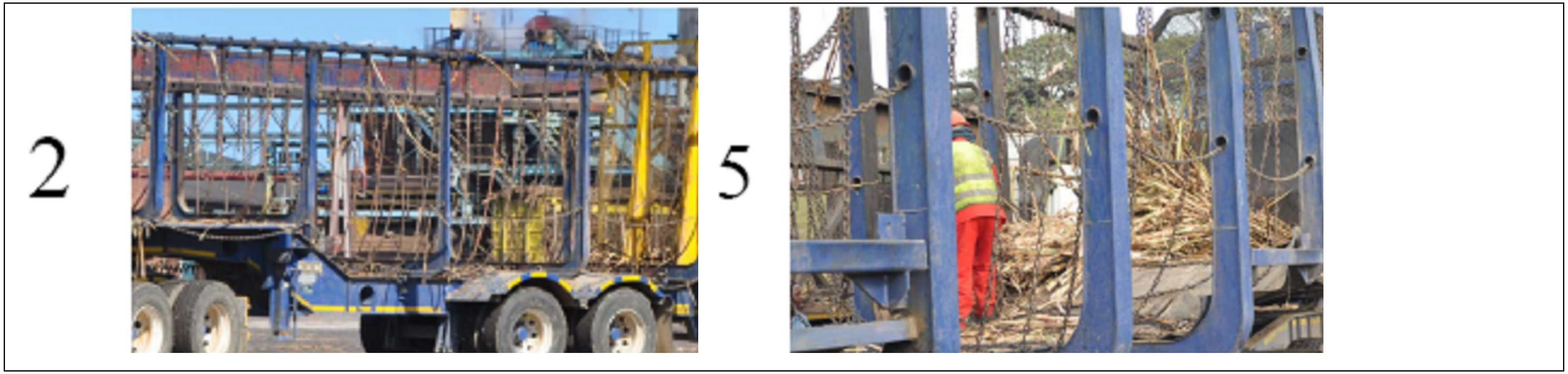


Figure 3.6 Examples for the categorisation for the assessment for the efficiency of the off-loading process, which was used to derive a cleaning score (C = 2, C = 5).

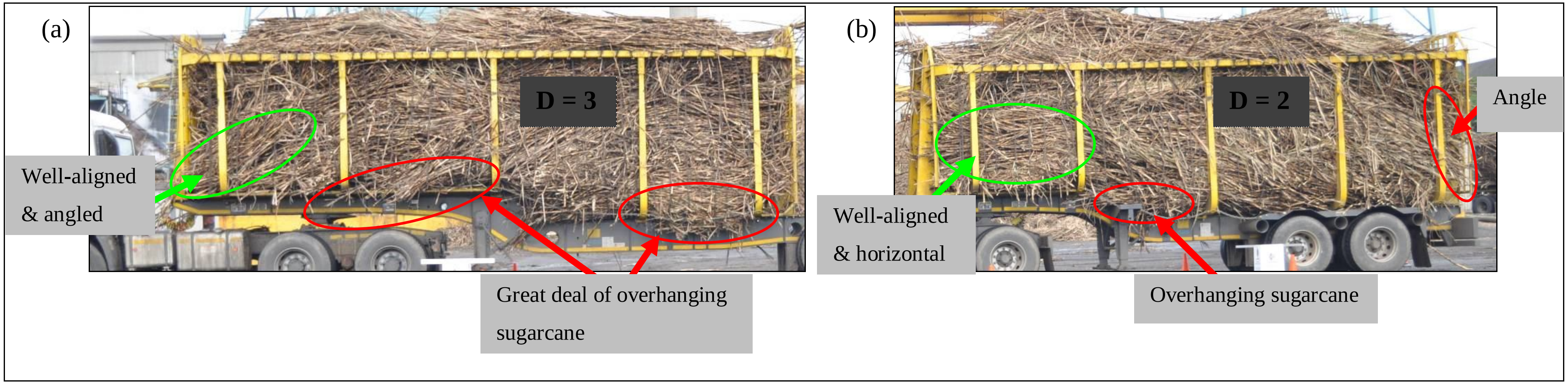


Figure 3.7 Demonstration of the assessment of the discharge rating (D) where (a) D = 3 (b) D = 2.

The micro-analysis involved an analysis of the texture of the load, by extracting and analysing four 1 m × 1 m frames from the photographs. The manner in which the samples were selected is shown in Figure 3.8 (a). ImageJ includes adjustment options to allow for easier identification of key features, such as aligned sugarcane and empty spaces. The options used include enhancement, threshold adjustment and colour balancing. These changes made the sugarcane within the shadows more visible and hence ensured a more accurate analysis. The typical improvement of the image using these functions is shown in Figures 3.8 (b) and (c). Well-aligned sugarcane refers to sugarcane that is parallel and closely-packed regardless of the angle of alignment. The regions containing well-aligned sugarcane were digitised and the areas were calculated as a percentage of the sample block. A single estimate was attained for each consignment by calculating the average from the four samples taken. This was also carried out to attain a value for the volume of empty spaces. It was assumed that the remainder consisted of trash and unaligned sugarcane.

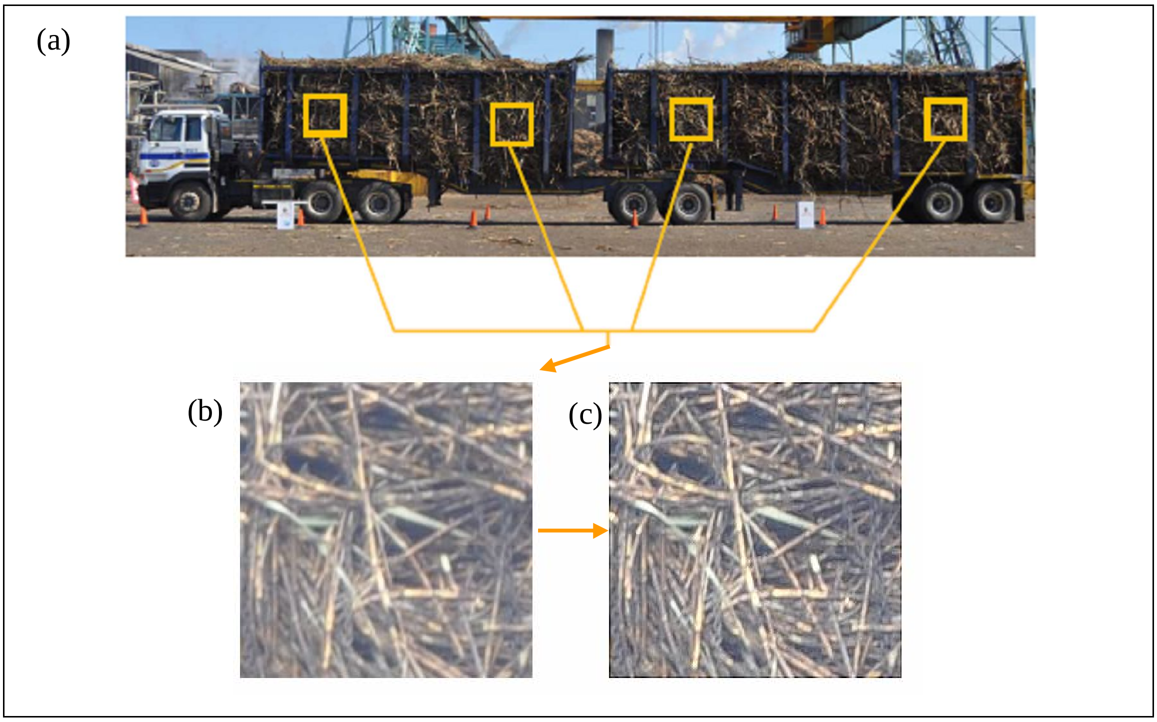


Figure 3.8 (a) Sample selection for micro-analysis of the consignments along with the demonstration of the image improvement of a sample (b) to (c)

The sugarcane brought into the mill during the time of data collection (28 – 30 April 2010) for this study was relatively old carry-over sugarcane, which resulted in a significant quantity of vehicles having low bulk sugarcane densities. Bread-loafing is a phenomenon which refers to severely volume-restricted vehicles, where the sugarcane load exceeds the height of the spiller bar and the overshoot displays a curved profile. This occurs widely within the sugar industry and is illustrated in Figure 3.9 and was found to be common within the sample set. Future research should consider taking samples at different times of the milling season.

Figure 3.9 A consignment demonstrating the bread-loafing phenomenon

Scatter plots, descriptive statistical tables and box-and-whisker plots were generated from the data set. The data were grouped according to individual vehicles, in order to identify critical driving factors. The raw data are presented in the Appendix in Table 7.1. The data were analysed from a statistical as well as from a visual perspective. Sixty-seven different vehicles formed the data set. The data collected included one Tri-axle vehicle, making it difficult to draw conclusions for this type of vehicle. Hence, most of the analysis is centred around interlink and rigid drawbar type vehicles. General statistics concerning the consignments in the study are summarised in Table 3.2.

Table 3.2 The sample distribution of consignments with respect to the different trailer and vehicle types in addition the presence and use of load cells. The values within brackets represent the number of vehicles delivering the respective number of consignments.

	Interlink (I)	**Rigid drawbar (R)**	**Tri-axle (T)**	**Total**
Bolster (B)	111 (36)	12 (5)	0	123 (41)
Frame (F)	59 (21)	16 (4)	5 (1)	80 (26)
Load cells				
No	33 (12)	16 (5)	5 (1)	54 (18)
Yes	118 (40)	12 (4)	0	130 (44)
Yes, not being utilised	19 (5)	0	0	19 (5)
Total	170 (57)	28 (9)	5 (1)	203 (67)

3.4 Synthesis

The characteristics of the loading practices and sugarcane consignments were extracted in an attempt to identify the critical factors that influence the efficiency of loading operations. This was carried out by assessing typical loading operations currently adopted in South Africa. Results obtained from these investigations are presented in the next chapter and the guidelines are summarised in Chapter 5.

4. RESULTS AND DISCUSSION

The analysis was carried out to gain an understanding of loading inaccuracies with the aim of improving the efficiency of the loading operation. The results attained are presented in this chapter, followed by a discussion. All the results are inter-connected and this chapter primarily presents all the results. A more comprehensive discussion (*cf.* Section 4.5) then draws the results into context. Loading operations currently carried out in the South African sugar industry were assessed. A sample of 203 consignments which arrived at the Sezela mill on 67 different vehicles was assessed.

4.1 Zone Loading Operations

The video footage that was collected helped to identify several qualitative guidelines with respect to best loading practices. Figure 4.1 displays statistics concerning the loading of two consignments. Each sugarcane grab was numbered and the placement of each grab within the trailer is depicted. Green arrows indicate consecutive drops of sugarcane at the same position within the trailer. Column building is well-established as evident by the great number of green arrows within the figure. This practice can result in empty spaces between the sugarcane. Unlevelled trailer bases, could tilt the sugarcane causing spilling and off-loading problems. Generally vehicles are loaded from the front to the back; however, this was not the case for the first operation. A percentage under-loaded value (% UL) was calculated by comparing the actual payload (γ) to the design payload (γ') for a vehicle. A negative % UL value represents an over-loaded consignment. The first operation was completed in almost half the time compared to the second, but had a % UL of 10 %. This demonstration depicts the trade-offs between time and accuracy. An in-depth evaluation of the video clips has illustrated that the efficiency of each operation is dependent on various characteristics, ranging from zone dynamics to equipment specifications. Recommendations for future research with regard to the loading operation are presented in Chapter 5.

Loading time	Sorting time	∑ grabs	Ave tons/grab	% UL	∑ compaction actions
28 min 47 sec	2 min 49 sec	38	0.75	10.7	40

Loading time	Sorting time	∑ grabs	Ave tons/grab	% UL	∑ compaction actions
53 min 30 sec	4 min	77	0.4	3.1	52

Figure 4.1 Images and sequence analyses for two loading operations assessed at transloading zones

Two methods of sugarcane presentation at the zone were identified and are illustrated in Figure 4.2. Pie charts depict a breakdown of the time used for the different components of the loading operation. The second configuration resulted in more time wastage to carry out cleaning and to move around the zone which may be due to the larger distance between the sugarcane pile and the truck. These pie charts were determined from one assessment per configuration only and some conclusions may be premature. No conclusive results can be drawn from this exercise and only preliminary suggestions can be made.

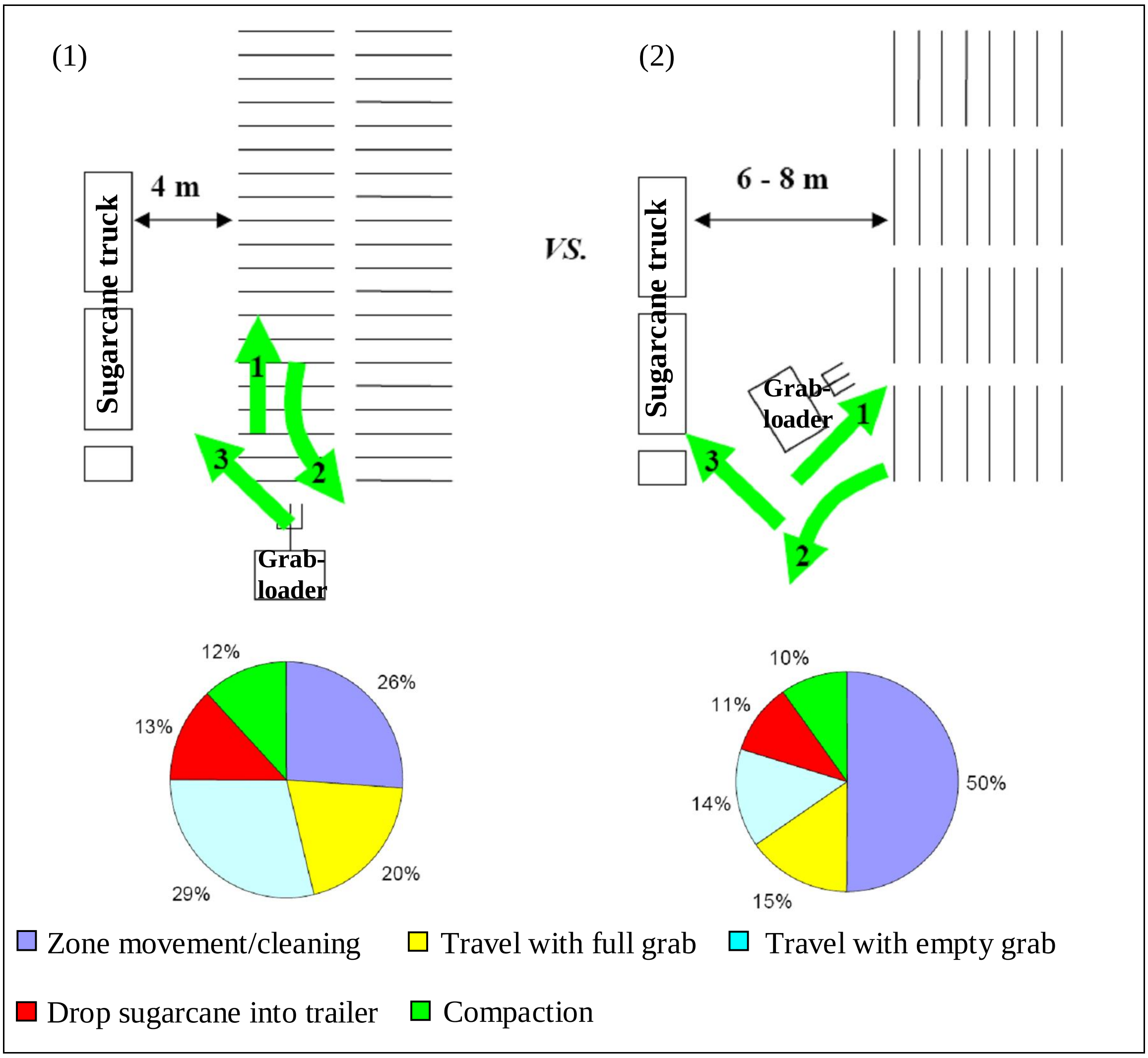


Figure 4.2 The division of time between the various components of a loading operation for two sugarcane pile configurations

4.2 Vehicle Design

The variation of the design bulk density (ρ_b') for the different vehicle types is depicted in Figure 4.3. The number of vehicles per type is specified above each box-and-whisker plot along with the median. It can be deduced that no consistent vehicle design for ρ_b' in the South African sugar industry exists. The interlink vehicles appear to be designed for lower sugarcane bulk densities compared to the rigid-drawbar vehicles. Table 4.1 depicts the mean sugarcane bulk density (ρ_b) and design bulk density (ρ_b') for the different vehicle types along with the percentage variation. Also, based on t-tests, both ρ_b and ρ_b' differed significantly (p = 0.007 and p = 0.001, respectively) between interlink and rigid drawbar type vehicles. ρ_b in vehicles with frames also differed significantly from with bolsters (p = 0.002), although ρ_b' did not differ between these vehicles. It is evident that sugarcane packs differently in frame type trailers compared to bolster type trailers, even though these trailer types were designed for similar densities (*cf.* Table 4.1). The sugarcane is more confined in frame type trailers.

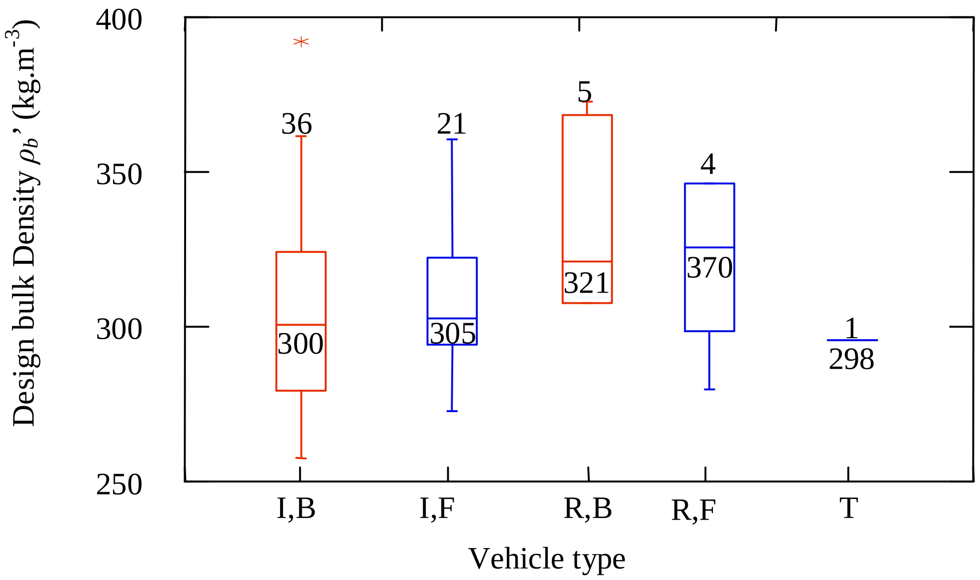


Figure 4.3 A box-and-whisker plot for the design bulk density (ρ_b') for different vehicle types (Symbols I, R, T represent Interlink, Rigid-drawbar and Tri-axle vehicles while B, F represent Bolster and Frame trailer types).

Table 4.1 was added to offer a comparison between the different types of vehicles and trailers being used currently. The actual sugarcane density and the design density are compared to determine if these were being matched. This was not the case as evident by the differences (*cf.* Table 4.1, last column). The actual sugarcane bulk densities seem to have not been considered during the design process for sugarcane haulage units. Designers were restricted in terms of legal regulations and mill receiving equipment (Meyer *et al.,* 2001; Cowling, 2008a). These form critical constraints which impact on the ρ_b'. The vehicles are designed for as large as possible volumes which results in these vehicles being suited for low bulk densities (Bezuidenhout, 2010). The rigid drawbar vehicles are more suited to higher ρ_b due to the limited volume.

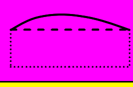
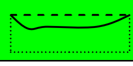
Table 4.1 Mean sugarcane bulk density and mean design bulk density (kg.m^{-3}) for different vehicle types

Vehicle / trailer type	$\bar{\rho}_b$ (kg/m^3)	$\bar{\rho}_b'$ (kg/m^3)	**Percentage difference (%)**
Interlink	313	350	10
Rigid drawbar	336	374	10
Bolster	323	352	8
Frame	303	354	14

Figure 4.4 depicts the median-sorted box-and-whisker plots for the actual sugarcane bulk density (ρ_b) per vehicle. The blue circles depict the vehicle's design bulk density (ρ_b') and the statistical distributions of ρ_b and ρ_b' are shown on the side of the graph. Colour coded bar graphs in the background of the box-and-whisker plots offer a comparison between the sugarcane bulk density (ρ_b) and the vehicle design bulk density (ρ_b'). The colour codes are described in Table 4.2. Since the number of consignments arriving per vehicle varied a proportional scale could not be added to the graph to differentiate the 3 categories. The vehicle type (I, R, T) and trailer type (B, F) are specified for each vehicle by their respective symbols, as specified in the list of symbols (Page vii). The scale of the y-axis also corresponds to the distribution shown on the right of the graph.

The range of sugarcane bulk density (ρ_b) of the sample set was found to be substantial, ranging from 225 - 435 kg.m^{-3} (*cf.* Figure 4.4). Also the variation in ρ_b for most vehicles is also large, implying that the vehicles may not be managed in terms of consistency. It is also noted that the range in ρ_b can differ significantly from one vehicle to the next. This can be also attributed to the different harvesting methods adopted along with the various loading techniques used. Figure 4.4 highlights that there have been very few consignments which had arrived with ρ_b matched with ρ_b'. The variation of the different vehicle designs are outlined by the wide spread of the blue circles. No pattern can be identified from this plot.

Table 4.2 Description of the colour coding index used within Figures 4.4, 4.5 and 4.9

Colour	**Definition**	**Description**
Pink	Sugarcane bulk density < Vehicle design bulk density ($\rho_b < \rho_b$')	Sugarcane bulk density was **over-estimated** during the design, potentially resulting in "bread-loafing" or under-loading 
Yellow	Sugarcane bulk densities are within a 2 % tolerance ($\rho_b \approx \rho_b$')	
Green	Sugarcane bulk density > Vehicle design bulk density ($\rho_b > \rho_b$')	Sugarcane density was **under-estimated**, potentially resulting in excess available volume or overloading 

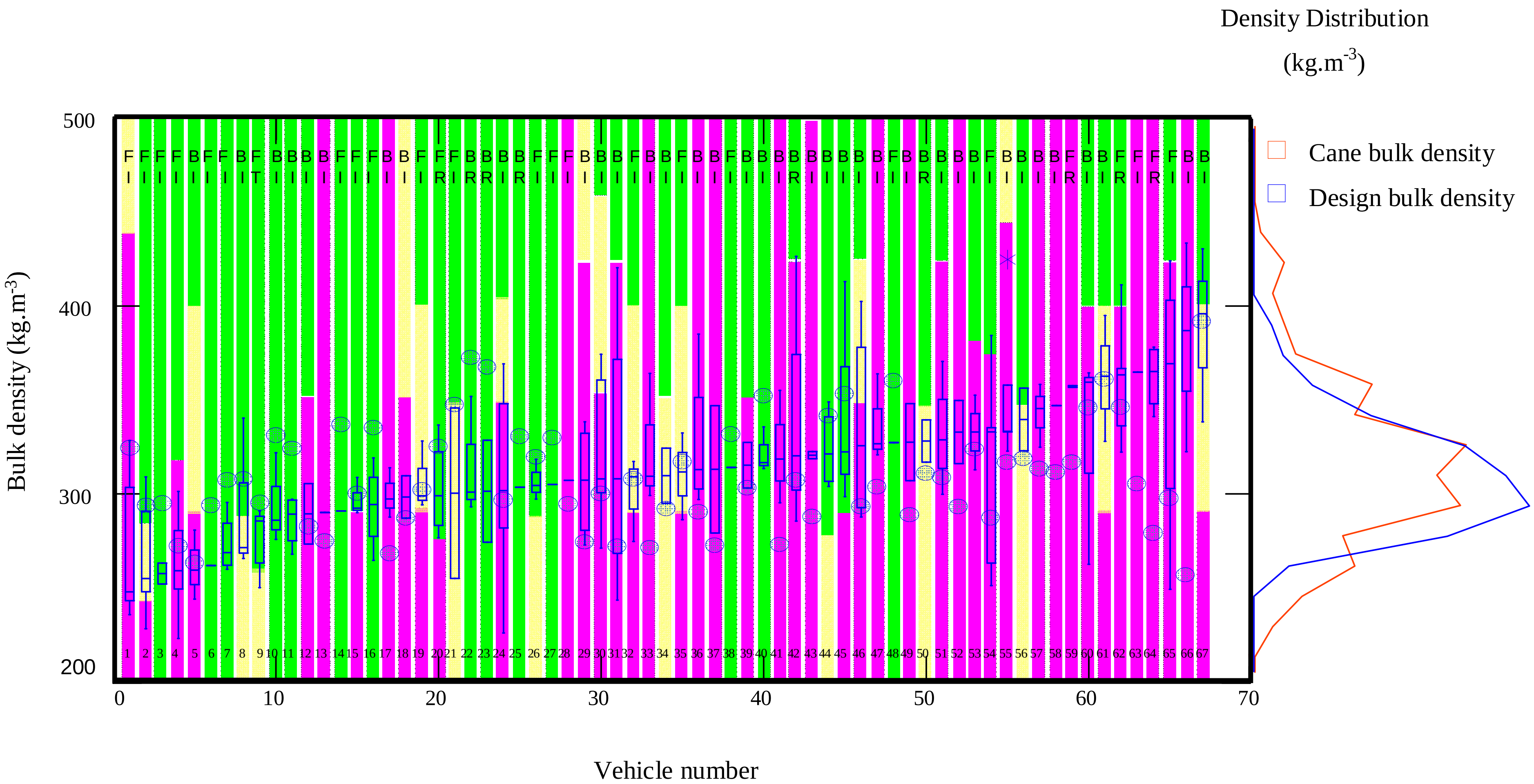


Figure 4.4 Distribution of sugarcane bulk density for each vehicle within the sample sorted according to the vehicle's median sugarcane bulk density ρ_b

4.3 Payload Accuracy

Figure 4.5 depicts the median-sorted box-and-whisker plots for the payload (γ) achieved with blue circles, which depict the vehicle's design payload (γ'). The colour coded background is similar to the previous plot. The majority of vehicles (82 %) arrived at the mill with median payloads below γ'. The collective payload received at the mill for the three-day period was 6091 tons. Actual payloads ranged from 22 to 38 tons. If the vehicles were loaded to their capacity an addition of 425 tons of sugarcane would have been delivered (additional 7 %). The variation between payloads on a single vehicle is less than the overall payload variation in the sample-set. This implies that vehicles operate relatively consistently, even if they are repeatedly under-loaded. If the bar graph is pink or green, it implies that ρ_b did not meet the $\rho_{b'}$ with a 2 % tolerance. It can be seen that seldom was $\rho_b = \rho_b'$ (*cf.* Figure 4.5), however some vehicles were well loaded ($\gamma \approx \gamma'$). Under-loaded vehicles with green bars imply that sufficient volume was available and vehicles could have been managed more carefully. Pink represents vehicles that are sub-optimally designed for lower sugarcane bulk densities. The frame type interlink vehicles arrived severely under-loaded which can be seen at the start of Figure 4.5. Also the design payloads are almost always greater then the actual payloads ($\gamma' > \gamma$).

One frame type and one bolster type vehicle with similar design payloads (γ') are shown in Figure 4.6. Although these vehicles are designed for similar payloads it is evident that the design volumes (v') and consequently the design bulk densities (ρ_b') vary significantly. The design volume for the frame type is lower and this is probably caused by the dense frame structure compared to the widely spaced bolsters. As a result, vehicle (a) was loaded higher above the spiller bar.

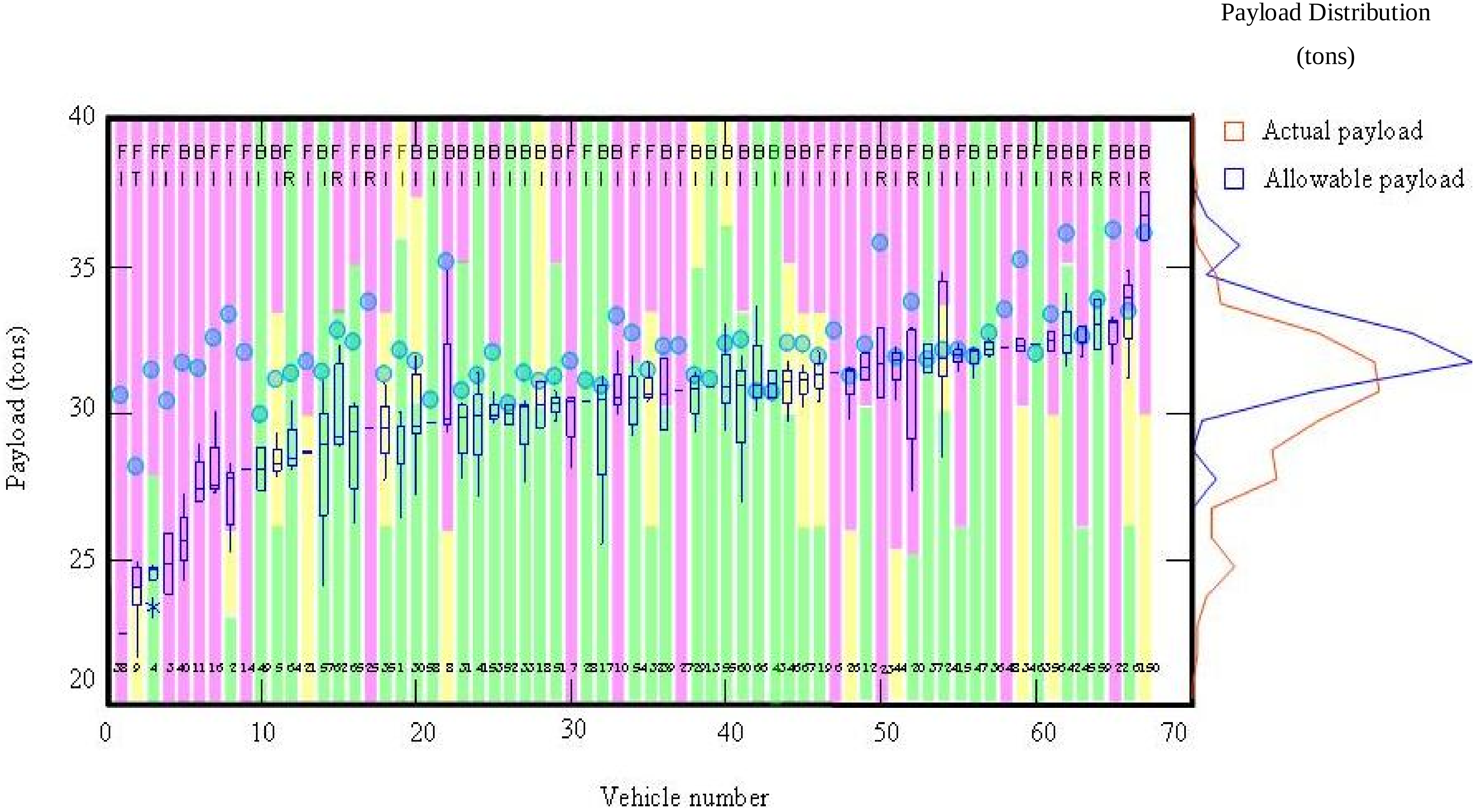


Figure 4.5 Distribution of payload for each vehicle within the sample sorted according to the vehicle's median payload.

(a)

ρ (kg.m^{-3})	ρ' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
305.0	330.2	30.8	32.1	4.0	97.2

(b)

ρ (kg.m^{-3})	ρ' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
327.4	303.4	31.8	32.1	0.7	105.7

Figure 4.6 Comparison of consignment statistics for (a) Frame type trailer and (b) Bolster type trailer with similar design payloads.

Figures 4.7 and 4.8 illustrate typical consignments where the sugarcane bulk density and the design bulk density appeared to be inconsistent. The first set of consignments (*cf.* Figure 4.7) was loaded over the spiller bar; however, these were still under-loaded. The ρ_b had a major impact on the accuracy of these loads. The consignments in Figure 4.8 have higher ρ_b values compared to Figure 4.7. Two of these consignments arrived slightly over-loaded and the volume was never restricted. These two figures illustrate the impact of different density sugarcane. If the sugarcane is of lower density the consignments can be loaded to above the spiller bar and still be under-loaded (*cf.* Figure 4.7). Whereas for higher density sugarcane the trailers may appear to be under-loaded due to the presence of empty spaces and may actually be overloaded (*cf.* Figure 4.8). This emphasises the importance of understanding and estimating the sugarcane density during the loading operation.

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
263.2	295.4	25.9	30.2	14.2	102.2

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
261.9	294.4	31.4	32.6	3.7	96.9

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
259.9	307.6	30.5	31.6	3.4	89.1

Figure 4.7 Typical consignments which arrived with the $\rho_b < \rho_b$'

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
364.8	305.7	32.4	31.8	-1.7	104.1

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
375.5	279.8	30.4	31.1	2.4	111.3

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
386.9	257.6	31.0	30.5	-1.4	118.6

Figure 4.8 Typical consignments which arrived with the $\rho_b > \rho_b$'

Figure 4.9 illustrates the percentage under-load (% UL) per vehicle and was sorted according to the median % UL. The box-and-whisker plots represent the range of percentage under-load for the different consignments for each vehicle. A small number of consignments were over-loaded, *viz.* 17 %, while 13 % were well-loaded within a 2 % tolerance and the remaining 70 % was under-loaded. The overall distribution is shown to the right of the graph. This implies that there is a significant opportunity to improve transport efficiency. The rigid drawbar units seem to be more under-loaded when compared to the other units due to the volume restriction. There appears to be a higher frequency of pink for the severely under-loaded vehicles (latter part of the graph in Figure 4.9). The bolster interlink type vehicles seem to be more accurately loaded as compared to the frame interlink type vehicles. No pattern can be identified in Figure 4.9, however it can be concluded that the vehicles which are well-loaded (close to the zero % UL line) display less variation in the payload. This implies that these vehicles arrive with consistent payloads.

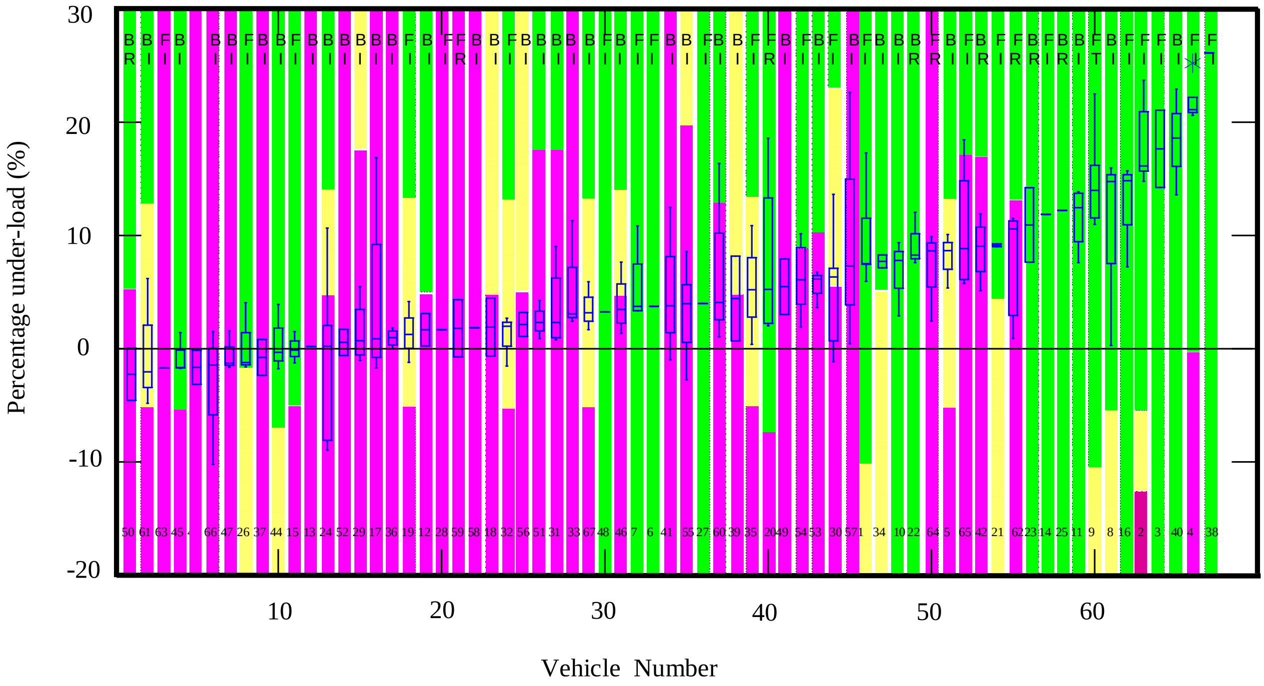


Figure 4.9 Distribution of percentage under-load for each vehicle within the sample sorted according to the vehicle's median percentage under-load (% UL).

Each of the consignments were evaluated by subtracting the design payloads (γ') from the actual payload ($\gamma - \gamma'$) and by subtracting the design bulk density from the sugarcane bulk density ($\rho_b - \rho_b'$). The differences ($\Delta\gamma$ and $\Delta\rho$) were plotted for each vehicle on the y- and x-axis of a graph in Figure 4.10. Each quadrant represents a different loading regime. A photograph from each regime is presented and the background colour adheres to the description in Table 4.2. The percentage of data points in each quadrant is also presented. Consignments that arrived on the same vehicle are depicted by different data points but conform to the same symbol and colour. All the consignments above the x-axis were, to some extent overloaded. A significant amount of under-loaded consignments were observed.

There is an effort being made to reduce overloading, however it appears that people are not concerned to limit the amount of under-loading that occurs in the South African sugar industry. The use of load cells is one method that could alleviate under-loading, but this technology must be correctly managed in order to ensure accurate loads (Pletts, 2009). Within the sample, at least 10 % of vehicles with load cells were not appropriately using load cell technologies, even though it was installed on the vehicles. Consignments found to the right of the y-axis represent vehicles that arrived with $\rho_b > \rho_b'$ (green), while those close to the y-axis represent consignments where $\rho_b \approx \rho_b'$ (yellow). It is noted that many consignments with suitable ρ_b' still arrived under-loaded. All consignments in the bottom right quadrant of the graph could be better managed since volume is available, while the payload is concurrently not met. This amounts to 44 % of all the consignments in the sample.

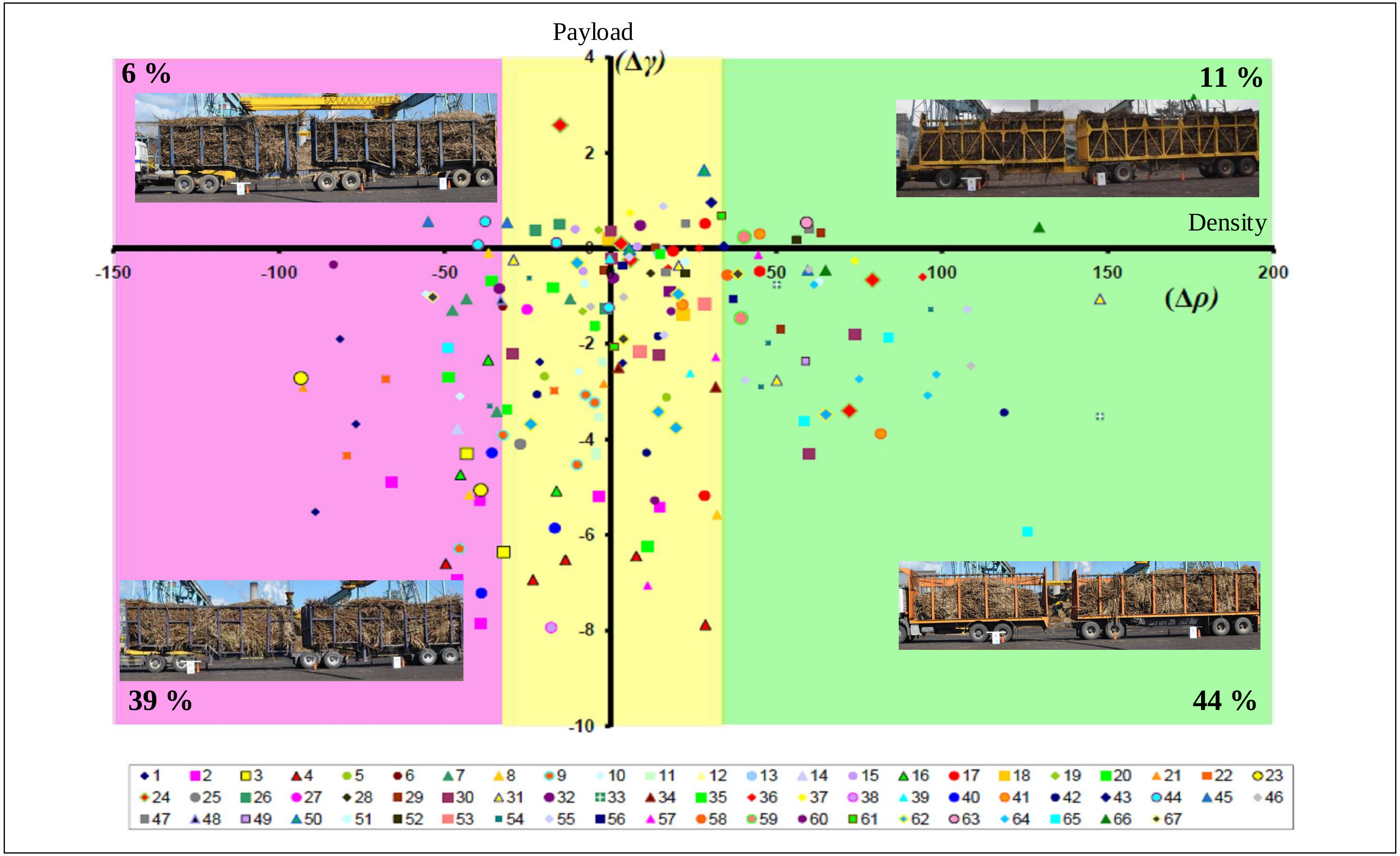


Figure 4.10 Payload accuracy ($\Delta\gamma$) and design density accuracy ($\Delta\rho$) of all the consignments in the data sample.

Figures 4.11 and 4.12 represent box-and-whisker plots of consignment payloads for vehicles without and with load cells, respectively. These graphs are subset of Figure 4.5. There is greater deviation in the design payload among vehicles without load cells, as shown by the circled portion in Figure 4.11. This suggests that load cells are beneficial, however, a significant amount of variation and under-loading still exist in vehicles with load cells (*cf.* Figure 4.12). Likewise, some vehicles in Figure 4.11 seem to maintain good payload accuracies, compared to a number of vehicles with load cells in Figure 4.12. This justifies further research.

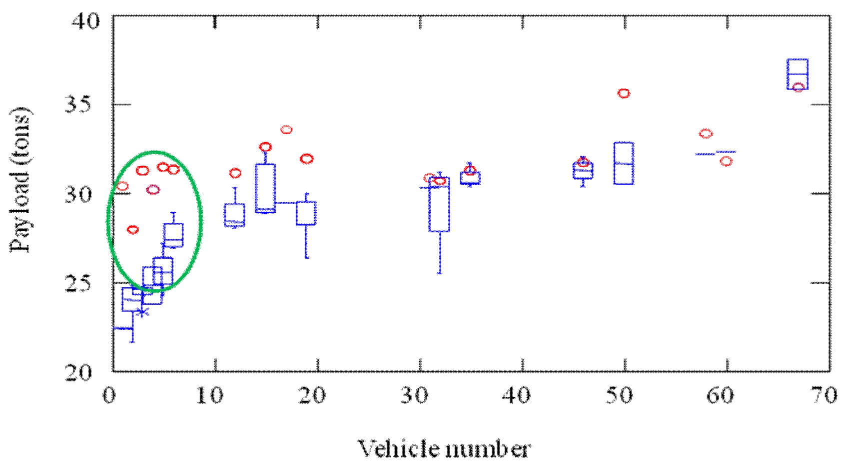


Figure 4.11 Box-and-whisker plot of the consignment payloads with the design payloads represented by red circles for vehicles without load cells.

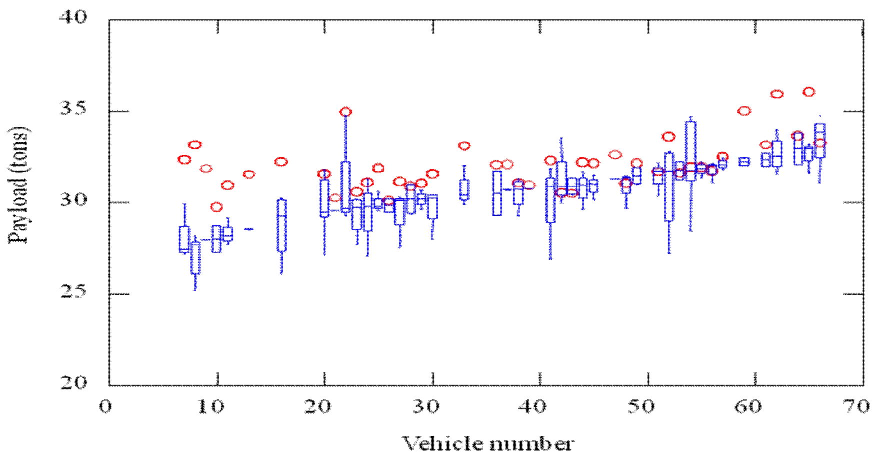


Figure 4.12 Box-and-whisker plot of the consignment payloads with the design payloads represented by red circles for vehicles with load cells.

4.4 Off-loading Efficiency

Table 4.3 summarises how often the actual Cleaning Score (C) coincided with the predicted Discharge Score (D). A perfect prediction would imply that C = D and only cells along the diagonal would have non-zero values. The colour intensity coincides with higher values. For example in the table relating to trailer 1, the Discharge Score and Cleaning Score was allocated a value of 1 seven times. While a Discharge Score and Cleaning Score was allocated a value of 2, nineteen times, hence it is highlighted in a darker shade of green. It was noted that most vehicles require a small degree of cleaning (C = 2) and that in many cases the severity of cleaning could be predicted. A relatively good prediction was achieved even though the author was inexperienced in this field. Interlink vehicles have an unlevelled base within each trailer. This inclined surface incurred a notable (37.1 % of the interlink type vehicles) amount of spillage at the point. Photographic evidence of this is provided in Figure 4.13.

Table 4.3 A comparison between the discharge (D) and cleaning (C) rates for each trailer, where the numbers represent frequency.

Trailer 1	**Discharge (D)**				
Cleaning (C)	1	2	3	4	5
1	7	5	2	1	2
2	12	19	16	8	7
3	8	9	9	3	10
4	1	1	1	3	3
5	0	0	2	1	3

Trailer 1	**Discharge (D)**				
Cleaning (C)	1	2	3	4	5
1	3	4	2	1	1
2	7	16	19	6	14
3	1	9	9	5	5
4	5	5	4	1	7
5	0	0	2	0	2

Figure 4.13 Demonstration of significant spillage at the unlevelled point of the trailer for interlink type vehicles.

The micro-analysis did not yield significant results. The undulation ratio (φ) did not correspond with any performance measures. Some consignments were very undulated and others were flat, but no correlations with payload accuracy were found. The estimation of the percentage of well-aligned sugarcane and void spaces per consignment also did not yield a significant correlation with any performance criteria.

4.5 Discussion

Various dynamics have an influence on the accuracy of loading, which include; (a) equipment specifications, (b) loading operator skills, (c) vehicle design, (d) sugarcane characteristics and (e) the orientation and placement of sugarcane on the zone, as well as the actual layout and design of the zone. The critical practices which require attention include; loading direction, degree of compaction, axle mass distribution, configuration of the transloading zone, sorting time, neatness of grabs and the method of loading *i.e.* column *vs.* layer loading. All these practices are related and trade-offs are sometimes required in terms of time, cost, accuracy and safety. The presentation of sugarcane at the transloading zone in terms of position of the sugarcane pile and truck, as well as the presentation of the sugarcane pile is critical to the efficiency of the loading operation. The correct usage of the grab loader is critical as it is a key component of the supply chain, hence further research into the loading component would be beneficial.

Vehicles seem to be designed for higher bulk densities than the average bulk density of sugarcane, resulting in limited volumes and a high degree of under-loading. The interlink type vehicles are designed for lower bulk densities compared to the rigid drawbar type. Sugarcane packs differently on frame type trailers compared to bolster type trailers, which may be attributed to the more rigid design. Bolsters trailers also require a lower force to off-load compared to the frame type which is due to the increased friction surface between the sugarcane and the horizontal and diagonal bars (Cowling 2008a).

The sugarcane bulk density and vehicle design density was found to vary significantly and four different consignment regimes were identified in relation to payload accuracy. A large portion were being underloaded due to management techniques. The well-loaded consignments displayed consistency between loads, indicating that payload accuracy can be improved. However numerous vehicles bulk densities were matched but were still under-loaded. This can be attributed to the actual sugarcane density; hence loading operations should be adjusted for different sugarcane types (green *vs.* burnt). The five most overloaded and under-loaded consignments were extracted from the sample along with their statistics and are presented in the Appendix (*cf.* Figure 7.3 and Figure 7.4). This is offered to illustrate the variability of the consignments. It also demonstrates the difficulty of establishing whether a consignment is over/ under-loaded by viewing the consignments with respect to the extent of bread-loafing.

In this study a significant improvement in loading accuracy was associated with load cells. However, it was found that some vehicles with load cells did not use these units, which can be translated to a lack of appropriate management. A significant number of interlink type consignments arrived at the mill with a considerable quantity of sugarcane spillage at the unlevelled surface of the trailers. The loading operator should load this area of the trailer carefully to reduce sugarcane spillage. A relatively good correlation between the Cleaning (C) and Discharge (D) score was achieved indicating that the efficiency of the off-loading consignments can by assessed by visual techniques. The sugarcane in South Africa varies per region. The Sezela Mill receives sugarcane from the surrounding south coastal areas; hence the analyses of this study may be mill specific.

5. CONCLUSIONS, GUIDELINES AND REOMMENDATIONS FOR FUTURE RESEARCH

The characteristics of sugarcane which have an influence on the loading operation were investigated and a review of the current sugarcane loading practices adopted in South Africa was carried out. The conclusions drawn from this study are stated in this chapter, followed by guidelines for loading and recommendations for future research are also presented.

5.1 Conclusions

Under-loading is a major issue and results in increased numbers of haulage vehicles on the roads and an inefficient system. This study was carried out in an attempt to make the transfer system more *efficient* and *effective*. Sugarcane loading over recent years, has not been researched extensively. Many studies are, however, related to advancements to vehicle designs and reduction of overloaded consignments. Studies have shown that sugarcane loading is a viable component for improvement and the literature review (*cf*. Chapter 2) outlined the large number of sugarcane loading operations. The factors which have an impact on payload accuracy were identified from the literature study. Giles (2009) identified loading time as a significant cost saving component and found that a reduction of 3.9 minutes in average loading time would result in one less vehicle in the transport fleet at Sezela.

Loading operations involve the use of equipment and their efficiency is dependent on correct usage by the loading operator hence a visual and participatory approach was adopted. Important factors were deduced from assessments of loading operations along with meetings held with loading operators and sugarcane specialists. The drivers impacting on payload accuracy were identified through an analysis of sugarcane consignments arriving at the Sezela mill. The technique of visual interpretation of the consignments was found to be a viable research approach. It was relatively easy to predict whether a vehicle will off-load efficiently by assessing the photographs. A large amount of spillage was noted at the unlevelled point within the interlink trailers and guidelines have been created to alleviate this along with other problems.

The loading operation can be improved by technology or through improved management. Load cells and measuring devices attached to loading equipment can enhance payload accuracy; however these options are sometimes too costly for many. Adjustment to management through the implementation of simple guidelines will sensitise loading operators to the key aspects. Grab-loaders often form a critical point of the sugarcane transfer function within South Africa as it used by the majority for loading operations. It is envisaged that the benefits such as loading accuracy and reduced cost can be realised through the use of simple practical guidelines for loading. The guidelines detailed in Chapter 5 are relatively simple and implementable. More research is required with respect to sugarcane varieties and other on-zone dynamics.

The vehicles are not optimally designed to haul sugarcane due to legal restrictions; hence other means of improving the system need to be investigated. The bolster type trailers were found to be better suited to transport sugarcane, in terms of capacity and off-loading efficiency, compared to the older frame type trailers.

The consignments tested in this study, were under-loaded on average by 6 %. The sugarcane bulk density (ρ_b) varied significantly between the different vehicle types. This can be attributed to management techniques, sugarcane characteristics and loading equipment specifications. It was found that the actual sugarcane density has an impact on loading accuracy, hence it is critical to be able to estimate the density of the sugarcane. Results of this study indicated that haulage vehicles are not being managed well. Some vehicles had load cell technologies but these were not being used to load more accurately. In addition numerous vehicles arrived at the mill under-loaded but with available space within the trailers.

The sugarcane presentation on-zone plays a major role in the productivity of the system along with various other issues, which are specified in the guidelines (*cf.* Section 5.2). The guidelines form a critical outcome of this study. These guidelines are presented in an attempt to offer practical and simple rules of improvement to the loading component in terms of fleet reduction, enhanced off-loading, reduced cleaning times and reduced costs. The outcome of this study was a set of guidelines, which is currently being documented into a training DVD.

5.2 Guidelines

This section outlines the practical guidelines recommended for the sugarcane loading process, which include loading techniques, system management and equipment usage. They are presented under three sections *viz.* (a) general, (b) sugarcane preparation techniques and (c) loading techniques. The aim is to sensitise the loading operator to the dynamics involved when loading sugarcane and to provide practical guidelines on how to run an efficient loading operation. The objectives of the loading operator are to (a) operate in a safe environment, (b) minimise strain on equipment, (c) meet payload requirements within a reasonable time and (d) ease the off-loading operation, in terms of time, strain on the vehicle structure and spillage. These guidelines were mainly derived from the results of this study, although additional guidelines have been included for completeness and are referenced where necessary.

5.2.1 General

1. To ensure correct and safe usage of loading equipment, only persons with the appropriate training should operate a loader.
2. For safety purposes, the working area must be checked to ensure that no people are in the way and that no other objects are in the vicinity that may cause accidents.
3. The operator must consider the wind direction when directing the positioning of the truck. Ideally trucks should be loaded up-wind and operators must always wear protective eye gear.
4. If any unsafe action is carried out which could damage the equipment, the operations must be immediately stopped. Care must be taken when lifting heavy loads, which may cause the loader to become unstable and cause it to

tilt forward. The operator should raise the load slightly to check for stability before proceeding. If a tipping condition occurs, the boom must be lowered immediately and the sugarcane quantity within the grab must be reduced.

5. Operators must not travel more than 10 m with the boom raised for safety reasons (Source: Shukela Training Centre, 2009).
6. Sugarcane sticks hanging out of the trailer must be cut off prior to departure for the safety of pedestrians and to reduce roadside losses.
7. The trailer chains must be pulled into place prior to loading, to reduce later spillages.
8. The cleaning of the zone should be carried out after the truck has left, in order to reduce the time of the loading operation. However, if there are large quantities of sugarcane on the zone, then the operator should push it to one side, ideally during a backhaul when the loader is empty and making its way back to the sugarcane pile.
9. The sugarcane within the grab should not be placed on the ground *i.e.* push-piling should be avoided. This is to avoid the inclusion of rocks, mud and other foreign objects in the sugarcane.
10. The operator should minimise the number of 180° and 360° turns to avoid damage on sugarcane that was spilled and damage to the zone's surface.
11. Unnecessary jerking motions of the loading equipment must be avoided in order to minimize the number of breakdowns and required maintenance.
12. The truck driver must play an active role in the operation, since he is aware of the truck's configuration and the mass of the previous consignments. He should speak to the loader operator about the sugarcane, the vehicle and the loads in order to find the best match in the operation.

5.2.2 Sugarcane preparation techniques

The two methods of presentation for sugarcane piles on the zone and the preliminary recommended distance between the truck and the trailer are illustrated in Figure 5.1. The following recommendations (13 – 16) apply to this figure.

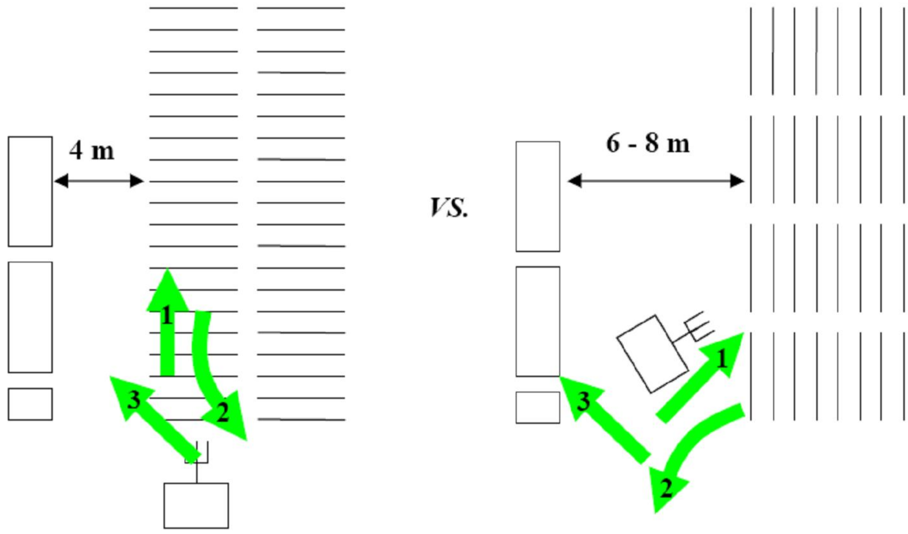


Figure 5.1 Two methods of sugarcane presentation at transloading zones

13. The operator should prepare the zone before the truck arrives. This can be done by controlling and/or managing the off-loading of sugarcane from the in-field vehicles. The operator should specify where the new sugarcane should be off-loaded and the manner in which this is to be carried out. This will assist the operator to have high bulk density (good) grabs available to load the base of the trailer.
14. The operator should try to be ready with the first grab of sugarcane as soon as the truck becomes stationary.
15. When loading with the first orientation (left diagram in Figure 5.1), the recommended distance between the truck and the sugarcane pile is 4 m or the width of the grab-loader. For the second orientation, the recommended distance is between 6 and 8 m or two times the grab-loader width. These distances are proposed to allow for sufficient room to manoeuvre, while minimising the distance between the sugarcane pile and the truck.
16. The sugarcane which has been placed on the zone first should be loaded first *i.e.* first in, first out. This is to ensure that sugarcane spends minimal time on the zone.

5.2.3 Loading techniques

17. The front trailer must be loaded first, which will increase the weight on the driver axles and increase traction. This will minimize the risk of the truck becoming immovable.
18. Loading must be carried out from the side of the vehicle without the spiller bar, since this side is lower and there is less risk for the grab-loader to displace the spiller bar.
19. Compaction is a process of compressing the sugarcane, with a grab full of sugarcane, to reduce empty spaces within the trailer. Compaction should be done as soon and as much as possible and must be carried out from both sides of the trailer. If compaction is not done from the start, the accuracy of the load may be negatively influenced. The top of the trailer must be well-compacted to avoid road-side spillages.
20. Each grab must be assessed prior to placement into the trailers. The well-aligned, dense grabs should be dropped to the bottom of the trailer and by opening the grab rapidly to form high density initial layers. This should be done, as sugarcane deep within the trailer cannot be compacted later. For interlinks, low density sugarcane should generally be loaded above the middle double axle and towards the top of the trailer. For rigid drawbar vehicles, low density sugarcane should be loaded in the front trailer and high density sugarcane in the back trailer. This is in order to create a more uniform axle loading distribution (Bezuidenhout, 2010). Bezuidenhout (2010) established the profile for an interlink and a rigid drawbar vehicle (*cf.* Figure 5.2), however these profiles are vehicle specific.

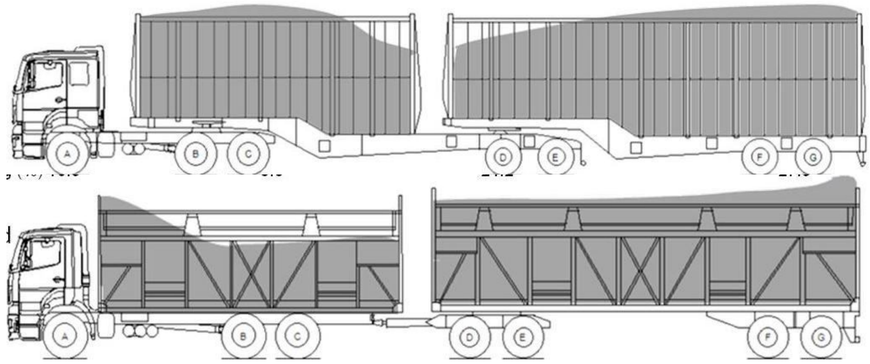


Figure 5.2 Sugarcane should be loaded to form these profiles for these specific vehicles to ensure consistent axle loading distribution, if the sugarcane of a uniform density (Bezuidenhout, 2010)

21. All the work available should be completed before the operator moves to a new task. This will reduce fuel usage and the wear of equipment components. For example, if sugarcane falls out of the grab, the operator should shake the load above the sugarcane pile and then proceed towards the trailer to load, instead of trying to pick up more sugarcane.
22. The sugarcane must be placed as far down into the trailer as possible and be released as quickly as possible with the grab perpendicular to the trailer (*cf.* Figure 5.3). This is to avoid scattering *i.e.* the spaghetti effect (*cf.* Figure 2.20 (a) page 28) and hence excessive spaces in the sugarcane trailer.

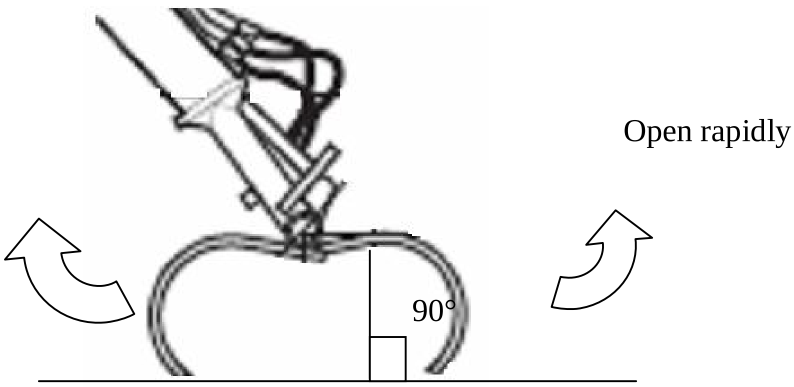


Figure 5.3 Illustration of the manner in which the grab should be orientated when placing sugarcane into the trailer

23. Techniques which would cause sugarcane tilting, such as flicking the sugarcane and dropping sugarcane too close to the side walls and the tailboard or placing sugarcane on uneven surfaces, must be minimized in

order to avoid excessive spaces between sugarcane sticks and to ease the off-loading procedure and to reduce losses.

5.3 Recommendations for Future Research

Several recommendations for future research have been identified, since a substantial amount of work is needed to improve loading accuracies in the South African sugar industry. This system has a number of different practices and the interaction between the equipment, sugarcane and the labour are crucial to the efficiency of the operation. A participatory research approach would offer a means to address the current problems of inaccurate and low quality loading and justifies further research. Since there have been no single comprehensive set of standards and rules available prior to this study for the loading of whole-stick loose sugarcane with grab-loaders, it is proposed that this study can be further developed.

A more accurate assessment of the loading operations should be undertaken where the mass of each grab, the configuration of the sugarcane pile, fuel usage, payload and off-loading efficiency are recorded and evaluated. The presentation of sugarcane and the configuration of the transloading zone are critical to the efficiency of the operation and future time-motion studies will allow for the comparison of different arrangements. Also the assessment of the sugarcane loading accuracies should be evaluated at different times of the milling season.

Additional further studies for the improvement of loading include:

- The allocation of specific vehicles to sites with sugarcane of particular characteristics (*e.g.* interlink frame type vehicles are suitable for lodged sugarcane, so these vehicles should be sent to the sites with this type of sugarcane). However, this requires an additional measurement for the volume of each consignment at the mill gate.
- Research relating to new vehicle designs to offer greater capacity. This may be attained by increasing the heights of the bolsters and reducing the size of

the tyres to ensure that the legal height limit is not exceeded. Research should also be carried out to assess these newer designs which may complicate off-loading at the mills therefore, an in-depth feasibility study is also required.

- It was found that grab-loaders did not compact the sugarcane to a high degree. This occurred due to a lack of skills and/or the specifications of the equipment. The option of constructing ramps at loading sites should be evaluated, since this will allow for the sugarcane to be placed deeper into the trailer and for early compaction of the load. In recent years, many loading operations have been carried out with the use of new excavator-type grab-loaders. Further studies into these advances are justified.

- Off-loading efficiency at the mill could be monitored by measuring the work of the spiller's crane motor. This may reveal additional valuable trends.

- Further research should be done on the suspension displacement for different loads, to determine the impact on axle loading sensitivity.

- The sugarcane type and variety influences were not included in this study. There is a shift towards the use of trash sugarcane due to environmental concerns related to the burning of sugarcane crops. This change will have an impact on the efficiency of the loading process and further studies are therefore justified. The sugarcane varieties affect the physical parameters of sugarcane stalks; hence it impacts on the accuracy of loading. These impacts should be determined through further studies.

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7. APPENDIX: DATA COLLECTION INFORMATION

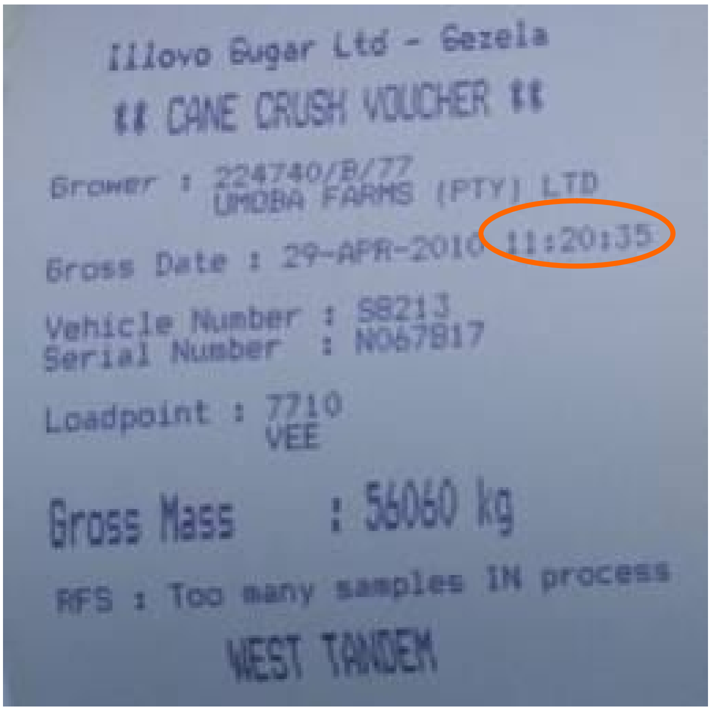
Illovo Sugar Ltd - Gezela
** CANE CRUSH VOUCHER **
Grower : 224740/B/77
UMOBA FARMS (PTY) LTD
Gross Date : 29-APR-2010 11:20:35
Vehicle Number : S8213
Serial Number : N067817
Loadpoint : 7710
VEE
Gross Mass : 56060 kg
RFS : Too many samples IN process
WEST TANDEM

Figure 7.1 Weigh-bridge slip from which the time of entry into the mill area was recorded to allow for linkage of the photographs with weigh-bridge data

Date: ______________

Sheet no.___________

No.	Consignment details		Load cells (Y/N)	Visual Identification	Cleaning Ranking
	Consignment slip time	Registration no. Horse			
1					
2					
3					
4					
5					

Figure 7.2 Data collection sheet used to collect information to aid with linking the photographs with the mill data

Table 7.1 Raw data extracted from the weigh-bridge database

Label	Trailer type	Vehicle type	Load cell	Payload (kg)	Cane type	Variety	Vehicle mass (kg)	Allowable sugarcane mass (kg)
Sht_1_Trck_10	F	R	N	29200	B	UNKNOWN	23380	32620
Sht_1_Trck_11	F	I	N	32240	B	N27	22680	33320
Sht_1_Trck_12	B	I	Y	32520	M	N12	23480	32520
Sht_1_Trck_13	B	I	Y	30080	B	UNKNOWN	25460	30540
Sht_1_Trck_14	F	I	N	24660	B	UNKNOWN	24740	31260
Sht_1_Trck_15	B	I	Y	30340	B	N12	24960	31040
Sht_1_Trck_16	B	I	Y	30980	M	MIXED	23700	32300
Sht_1_Trck_17	F	R	Y	27340	B	UNKNOWN	22420	33580
Sht_1_Trck_18	F	R	Y	32200	B	N16	22340	33660
Sht_1_Trck_19	B	I	N	25540	M	UNKNOWN	25280	30720
Sht_1_Trck_2	F	I	N	30640	B	N16	24740	31260
Sht_1_Trck_20	F	I	N	22460	B	N12	25600	30400
Sht_1_Trck_21	F	I	Y	28080	B	UNKNOWN	24140	31860
Sht_1_Trck_22	F	I	Y	30800	B	UNKNOWN	23920	32080
Sht_1_Trck_23	F	I	Y	28260	B	UNKNOWN	22840	33160
Sht_1_Trck_24	B	I	Y	32360	B	N12	24380	31620
Sht_1_Trck_25	B	I	N	26980	B	UNKNOWN	24680	31320
Sht_1_Trck_26	B	I	Y	31220	B	UNKNOWN	24280	31720
Sht_1_Trck_27	F	I	Y	27500	M	UNKNOWN	23640	32360
Sht_1_Trck_28	F	I	Y	28140	B	N16	24440	31560
Sht_1_Trck_3	B	I	Y	31120	B	N12	23860	32140
Sht_1_Trck_4	B	R	Y	31640	B	N12	20080	35920
Sht_1_Trck_5	B	I	N	27220	B	UNKNOWN	24500	31500
Sht_1_Trck_7	B	I	Y	29360	T	NCO376	24440	31560
Sht_1_Trck_8	B	I	Y	30960	B	N16	23820	32180
Sht_1_Trck_9	F	I	Y	28600	M	UNKNOWN	23780	32220
Sht_2_Trck_1	B	I	Y	34800	B	N12	24060	31940
Sht_2_Trck_10	B	I	Y	31380	B	N12	24920	31080
Sht_2_Trck_11	B	I	Y	33940	B	N12	22740	33260
Sht_2_Trck_12	B	I	Y	31920	B	MIXED	24440	31560
Sht_2_Trck_13	B	I	Y	31780	B	N29	24300	31700
Sht_2_Trck_14	F	R	N	28860	B	MIXED	23380	32620
Sht_2_Trck_15	F	I	Y	28620	B	N27	24460	31540
Sht_2_Trck_16	B	I	Y	30620	B	N12	24920	31080
Sht_2_Trck_17	B	R	Y	31700	B	N12	19960	36040

Label	Trailer type	Vehicle type	Load cell	Payload (kg)	Cane type	Variety	Vehicle mass (kg)	Allowable sugarcane mass (kg)
Sht_2_Trck_18	B	I	Y	32140	B	N12	22900	33100
Sht_2_Trck_19	B	I	N	25640	T	UNKNOWN	24500	31500
Sht_2_Trck_2	B	I	Y	34860	B	UNKNOWN	21040	34960
Sht_2_Trck_20	F	I	YN	27740	B	N12	24880	31120
Sht_2_Trck_21	B	I	Y	30240	B	N12	23860	32140
Sht_2_Trck_22	B	I	Y	30320	B	N12	25440	30560
Sht_2_Trck_23	B	I	Y	32520	B	UNKNOWN	20980	35020
Sht_2_Trck_25	B	R	N	29480	B	N12	22420	33580
Sht_2_Trck_26	F	I	N	31740	B	N12	24740	31260
Sht_2_Trck_27	F	I	Y	30140	B	N16	23780	32220
Sht_2_Trck_28	B	I	Y	28840	B	N12	26260	29740
Sht_2_Trck_3	F	R	N	28060	B	UNKNOWN	24860	31140
Sht_2_Trck_4	F	T	N	24740	B	N27	21320	27970
Sht_2_Trck_5	B	I	Y	29680	B	MIXED	25760	30240
Sht_2_Trck_6	B	I	Y	30700	B	UNKNOWN	24140	31860
Sht_2_Trck_7	B	I	Y	30200	B	UNKNOWN	24840	31160
Sht_2_Trck_8	B	I	YN	30340	B	UNKNOWN	23840	32160
Sht_2_Trck_9	B	I	YN	32960	B	UNKNOWN	23600	32400
Sht_3_Trck_1	F	I	Y	26220	M	UNKNOWN	22840	33160
Sht_3_Trck_10	B	I	Y	30460	B	N16	24300	31700
Sht_3_Trck_11	F	R	N	31660	B	UNKNOWN	23380	32620
Sht_3_Trck_12	B	I	YN	30880	B	N27	23840	32160
Sht_3_Trck_13	F	I	N	24740	B	UNKNOWN	24740	31260
Sht_3_Trck_14	F	I	Y	29800	B	N12	24940	31060
Sht_3_Trck_15	B	I	Y	32040	B	N12	24060	31940
Sht_3_Trck_16	F	I	N	30400	B	N12	24280	31720
Sht_3_Trck_17	B	I	Y	30000	B	N12	22900	33100
Sht_3_Trck_18	F	I	Y	26280	T	UNKNOWN	23780	32220
Sht_3_Trck_19	B	I	Y	29600	B	N12	25880	30120
Sht_3_Trck_2	F	R	Y	32760	B	N27	22420	33580
Sht_3_Trck_20	F	T	N	24060	B	UNKNOWN	21320	27970
Sht_3_Trck_21	F	I	N	30420	B	N27	24740	31260
Sht_3_Trck_22	B	I	Y	31340	B	N12	24440	31560
Sht_3_Trck_23	F	I	N	32360	B	N16	24180	31820
Sht_3_Trck_24	F	I	Y	28700	B	N12	24460	31540
Sht_3_Trck_25	B	I	Y	29380	B	N12	21040	34960
Sht_3_Trck_26	B	I	N	28940	B	N16	24680	31320

Label	Trailer type	Vehicle type	Load cell	Payload (kg)	Cane type	Variety	Vehicle mass (kg)	Allowable sugarcane mass (kg)
Sht_3_Trck_27	B	I	YN	24140	B	N12	24800	31200
Sht_3_Trck_28	B	I	Y	30300	M	UNKNOWN	24960	31040
Sht_3_Trck_3	F	I	Y	30500	B	N12	24440	31560
Sht_3_Trck_4	B	I	Y	32100	B	N27	23480	32520
Sht_3_Trck_5	F	I	N	29560	B	N12	24060	31940
Sht_3_Trck_6	F	I	YN	31900	B	MIXED	23480	32520
Sht_3_Trck_7	F	R	N	28400	B	MIXED	24860	31140
Sht_3_Trck_8	B	I	Y	27640	B	N27	24840	31160
Sht_3_Trck_9	F	I	Y	27620	B	UNKNOWN	23640	32360
Sht_4_Trck_1	F	I	Y	31980	M	UNKNOWN	24060	31940
Sht_4_Trck_10	B	R	Y	32860	B	UNKNOWN	20080	35920
Sht_4_Trck_11	F	R	Y	33900	B	N12	22340	33660
Sht_4_Trck_12	F	I	Y	30020	B	UNKNOWN	23640	32360
Sht_4_Trck_13	B	I	N	27060	B	MIXED	24680	31320
Sht_4_Trck_2	F	I	Y	27880	B	N12	22840	33160
Sht_4_Trck_3	B	I	Y	27820	B	N12	25060	30940
Sht_4_Trck_4	B	I	Y	30980	B	N29	25460	30540
Sht_4_Trck_5	B	I	Y	29900	B	N12	24140	31860
Sht_4_Trck_6	B	I	Y	34860	B	UNKNOWN	22740	33260
Sht_5_Trck_1	B	I	N	24280	B	N27	24500	31500
Sht_5_Trck_10	B	I	Y	31120	B	N27	23880	32120
Sht_5_Trck_11	B	I	Y	31160	B	UNKNOWN	23820	32180
Sht_5_Trck_12	B	I	Y	31080	M	N12	25120	30880
Sht_5_Trck_13	F	R	N	29140	B	UNKNOWN	23380	32620
Sht_5_Trck_14	B	I	Y	30200	B	N12	25440	30560
Sht_5_Trck_15	B	I	N	30660	B	N12	25280	30720
Sht_5_Trck_16	B	I	Y	31820	M	UNKNOWN	24300	31700
Sht_5_Trck_17	F	I	YN	29500	B	UNKNOWN	24880	31120
Sht_5_Trck_18	B	I	Y	31280	B	N12	24060	31940
Sht_5_Trck_19	B	I	Y	32240	B	N27	24280	31720
Sht_5_Trck_2	B	R	N	32880	B	N12	20400	35600
Sht_5_Trck_20	B	I	YN	31980	M	N12	23840	32160
Sht_5_Trck_21	B	R	Y	33300	B	UNKNOWN	19960	36040
Sht_5_Trck_22	F	T	N	23440	T	UNKNOWN	21320	27970
Sht_5_Trck_23	B	R	N	35900	B	N12	20080	35920
Sht_5_Trck_24	B	I	Y	27380	B	N12	26260	29740
Sht_5_Trck_25	B	I	Y	30520	B	UNKNOWN	22900	33100

Label	Trailer type	Vehicle type	Load cell	Payload (kg)	Cane type	Variety	Vehicle mass (kg)	Allowable sugarcane mass (kg)
Sht_5_Trck_26	F	I	N	24820	B	UNKNOWN	24740	31260
Sht_5_Trck_27	F	I	Y	31440	B	N29	24940	31060
Sht_5_Trck_28	F	I	Y	25300	M	UNKNOWN	22840	33160
Sht_5_Trck_3	F	I	YN	31240	T	NCO376	23480	32520
Sht_5_Trck_4	F	I	Y	30260	M	UNKNOWN	24440	31560
Sht_5_Trck_5	B	R	Y	32480	B	UNKNOWN	20080	35920
Sht_5_Trck_6	F	I	N	29540	T	UNKNOWN	24060	31940
Sht_5_Trck_8	B	I	Y	30880	T	UNKNOWN	25060	30940
Sht_5_Trck_9	B	I	Y	31100	M	N12	24920	31080
Sht_6_Trck_1	B	I	Y	32800	B	N16	22840	33160
Sht_6_Trck_10	B	I	Y	31960	B	MIXED	23700	32300
Sht_6_Trck_12	F	I	N	28260	B	N29	24060	31940
Sht_6_Trck_13	B	I	N	30240	B	N12	25280	30720
Sht_6_Trck_14	B	I	YN	28920	B	N12	24800	31200
Sht_6_Trck_15	B	I	Y	29380	B	N27	24920	31080
Sht_6_Trck_16	F	I	N	25900	B	N27	25800	30200
Sht_6_Trck_17	B	I	Y	31700	B	UNKNOWN	24060	31940
Sht_6_Trck_18	F	R	N	28500	B	UNKNOWN	24860	31140
Sht_6_Trck_19	F	T	N	24900	B	UNKNOWN	21320	27970
Sht_6_Trck_2	B	I	Y	29320	B	UNKNOWN	24440	31560
Sht_6_Trck_20	F	R	Y	32900	B	N16	22420	33580
Sht_6_Trck_21	B	I	YN	29400	B	N12	23840	32160
Sht_6_Trck_22	B	I	Y	27260	B	N12	24440	31560
Sht_6_Trck_23	B	I	YN	32940	B	UNKNOWN	23600	32400
Sht_6_Trck_24	B	I	Y	31840	B	N12	23940	32060
Sht_6_Trck_25	F	I	Y	32340	B	UNKNOWN	24060	31940
Sht_6_Trck_26	B	I	Y	27800	M	N12	25440	30560
Sht_6_Trck_27	F	I	N	32100	B	UNKNOWN	24280	31720
Sht_6_Trck_28	F	I	YN	30540	M	UNKNOWN	23480	32520
Sht_6_Trck_29	B	I	Y	31740	M	N12	23820	32180
Sht_6_Trck_3	B	I	Y	31460	B	UNKNOWN	25500	30500
Sht_6_Trck_4	B	I	Y	27200	B	UNKNOWN	24920	31080
Sht_6_Trck_5	B	I	Y	30760	B	N29	24960	31040
Sht_6_Trck_6	B	I	Y	31600	M	UNKNOWN	23860	32140
Sht_6_Trck_7	F	I	N	30380	M	UNKNOWN	25100	30900
Sht_6_Trck_8	B	I	Y	28260	T	UNKNOWN	25060	30940
Sht_6_Trck_9	B	I	Y	30300	B	N12	25880	30120

Label	Trailer type	Vehicle type	Load cell	Payload (kg)	Cane type	Variety	Vehicle mass (kg)	Allowable sugarcane mass (kg)
Sht_7_Trck_1	F	I	YN	29220	B	MIXED	23480	32520
Sht_7_Trck_10	B	R	N	30540	B	MIXED	20400	35600
Sht_7_Trck_11	B	I	Y	34520	B	N27	24060	31940
Sht_7_Trck_12	F	I	Y	27960	B	N27	22840	33160
Sht_7_Trck_13	F	R	N	28940	B	N12	23380	32620
Sht_7_Trck_14	F	I	Y	27280	B	N16	23640	32360
Sht_7_Trck_15	B	I	N	27780	B	UNKNOWN	24680	31320
Sht_7_Trck_16	B	I	Y	31360	B	N12	24380	31620
Sht_7_Trck_17	F	I	Y	31460	B	N12	24060	31940
Sht_7_Trck_18	B	I	Y	27020	B	N29	23700	32300
Sht_7_Trck_19	B	I	Y	29440	B	UNKNOWN	23940	32060
Sht_7_Trck_2	F	I	N	26420	T	N39	24060	31940
Sht_7_Trck_20	B	I	YN	31940	B	UNKNOWN	23600	32400
Sht_7_Trck_21	F	T	N	21680	B	UNKNOWN	21320	27970
Sht_7_Trck_22	B	I	Y	29280	B	N29	25060	30940
Sht_7_Trck_23	B	I	Y	32040	T	UNKNOWN	23880	32120
Sht_7_Trck_24	B	I	YN	31060	B	UNKNOWN	24800	31200
Sht_7_Trck_25	F	I	YN	31000	B	UNKNOWN	24880	31120
Sht_7_Trck_26	F	I	Y	30500	B	N27	24440	31560
Sht_7_Trck_27	F	I	N	31320	B	N12	24280	31720
Sht_7_Trck_28	B	R	Y	33060	B	N12	19960	36040
Sht_7_Trck_3	B	I	Y	29500	M	N39	25440	30560
Sht_7_Trck_4	B	I	Y	31400	M	UNKNOWN	24920	31080
Sht_7_Trck_5	B	I	Y	32260	M	UNKNOWN	24300	31700
Sht_7_Trck_6	F	I	Y	31560	B	N12	24940	31060
Sht_7_Trck_7	F	I	N	24320	B	N12	24740	31260
Sht_7_Trck_8	B	I	Y	29500	B	MIXED	25120	30880
Sht_7_Trck_9	B	I	Y	31920	B	N12	23480	32520
Sht_8_Trck_1	F	I	N	23840	B	N12	25800	30200
Sht_8_Trck_10	B	I	Y	30400	M	UNKNOWN	24840	31160
Sht_8_Trck_11	B	I	Y	29720	B	UNKNOWN	24960	31040
Sht_8_Trck_12	F	I	Y	31380	T	UNKNOWN	23400	32600
Sht_8_Trck_13	B	I	Y	29900	B	MIXED	24920	31080
Sht_8_Trck_14	B	I	Y	33660	B	UNKNOWN	25460	30540
Sht_8_Trck_15	B	I	Y	29720	B	N12	23820	32180
Sht_8_Trck_16	B	I	Y	28540	M	UNKNOWN	24060	31940
Sht_8_Trck_17	B	I	Y	32120	M	UNKNOWN	20980	35020

Label	Trailer type	Vehicle type	Load cell	Payload (kg)	Cane type	Variety	Vehicle mass (kg)	Allowable sugarcane mass (kg)
Sht_8_Trck_18	B	I	Y	31200	B	N12	22740	33260
Sht_8_Trck_19	B	I	N	31240	B	N12	25280	30720
Sht_8_Trck_2	B	I	Y	29700	B	UNKNOWN	24140	31860
Sht_8_Trck_20	B	R	N	37560	B	UNKNOWN	20080	35920
Sht_8_Trck_21	B	I	Y	29760	B	N29	24440	31560
Sht_8_Trck_22	F	I	Y	30360	M	UNKNOWN	23780	32220
Sht_8_Trck_23	B	R	Y	34080	B	N12	20080	35920
Sht_8_Trck_24	F	R	Y	30880	B	UNKNOWN	22420	33580
Sht_8_Trck_25	F	I	Y	27740	M	UNKNOWN	22840	33160
Sht_8_Trck_26	F	R	N	32320	M	N39	23380	32620
Sht_8_Trck_27	B	I	Y	32300	M	UNKNOWN	23480	32520
Sht_8_Trck_28	F	I	N	23380	B	N12	24740	31260
Sht_8_Trck_29	F	I	YN	29620	B	N12	23480	32520
Sht_8_Trck_3	B	I	Y	32120	M	UNKNOWN	24280	31720
Sht_8_Trck_4	F	R	N	30380	B	N39	24860	31140
Sht_8_Trck_5	F	I	N	30040	B	UNKNOWN	24060	31940
Sht_8_Trck_6	B	I	YN	33040	M	UNKNOWN	23840	32160
Sht_8_Trck_7	B	I	Y	32100	B	N12	22840	33160
Sht_8_Trck_8	B	I	Y	30540	B	UNKNOWN	25500	30500
Sht_8_Trck_9	B	I	Y	29800	M	N16	21040	34960

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
322.5	257.6	33.7	30.5	-10.2	118.6

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
369.2	297.1	34.8	31.9	-9.0	107.5

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
300.3	297.1	34.5	31.9	-8.1	107.5

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
394.9	361.4	34.9	33.3	-4.8	92.0

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
339.4	311.2	37.6	35.9	-4.6	115.4

Figure 7.3 The five most overloaded consignments in the sample

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
314.1	332.0	22.5	30.4	26.1	91.6

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
223.1	272.7	23.4	31.3	25.2	114.6

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
255.1	294.2	25.3	33.2	23.7	112.7

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
316.6	352.5	24.3	31.5	22.9	89.4

ρ_b (kg.m^{-3})	ρ_b' (kg.m^{-3})	γ (kg)	γ' (kg)	% UL	v' (m^3)
345.4	313.7	24.1	31.2	22.6	99.5

Figure 7.4 The five most under-loaded consignments in the sample