THE FEASIBILITY OF AUTOMATIC ON-BOARD WEIGHING SYSTEMS IN THE SOUTH AFRICAN SUGARCANE TRANSPORT INDUSTRY

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ABSTRACT

Sugarcane hauliers in South Africa have high variations in vehicle payloads, which influence both transport economics and the legitimacy of their operations.

Increasing economic pressure due to declining sugar prices and ever increasing fuel prices has invoked interest to improve vehicle utilisation and reduce costs, while complying with the local traffic legislation. On-board weighing technologies, such as on-board load cells, could assist operators to control their payloads more accurately and hence reduce the frequency of both over and under loaded consignments. In this study, an investigation is conducted to evaluate the feasibility of on-board weighing systems in the South African sugarcane transport industry.

An overview of on-board weighing systems is presented. The overview gives insight into the technical composition of an on-board weighing system as well as presenting various benefits and drawbacks that are associated with an on-board weighing system. Earlier studies conducted on the use of on-board weighing systems are scrutinised and evaluated and it is concluded from these that vehicle utilisation could be improved, while concurrently reducing the overloading of vehicles.

Field research was conducted to evaluate the accuracy and consistency of on-board weighing systems currently being utilised in the sugarcane transport industry as well as to determine the critical factors that influence the effectiveness of the system while assessing if overloading of vehicles was reduced when on-board weighing systems were employed. It was concluded that the systems evaluated were reasonably accurate with mean error being 0.4 tons. The consistency of the systems was good with 75% of all measurement being within 0.5 tons of each other. The critical factors determining the effectiveness of the on-board weighing systems were established as being management of the system as well as cane variety and quality. Overloading was reduced by 9% in one field evaluation and 5% in another. Further reduction can be realised through tighter management of the on-board weighing systems.

An economic evaluation of an on-board weighing system was performed using the capital budget method. This method was used to determine the pay off period required to realise the investment into an on-board weighing system for scenarios where the

payload is increased by 2, 3 and 4 tons and transport lead distance is 20, 40, 60, 80, and 100 km. The shortest pay off period occurred when the lead distance was 60 km and the time was 1, 2 and 3 years for payload increases of 2, 3 and 4 tons respectively. For lead distances of 40, 60 and 80 km the investment is worthwhile and considerable returns in investment can be realised, however, for the other lead distances the pay off period could be deemed to be too long.

From the observation made during the field evaluation together with the literature studied, guidelines for the use of on-board weighing systems under various transport scenarios were formulated and are presented in chapter six.

DISCLAIMER

I wish to certify that the work reported in this dissertation is my own original and unaided work except where specific acknowledgement is made.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The background to this thesis as well as the objectives of this study and the research approach followed are presented in this chapter. A layout of the document structure is also shown.

1.1 Project Background

In the South African Sugarcane Industry, machinery costs (including transport) represent between 30% and 40% of growers' total production costs. While transport costs are estimated as being 11% of total production costs, reality portrays that it is much higher at approximately 25%, as it incorporates elements of costs from other categories (e.g. machinery maintenance, fuel and lubricants, licensing and insurance, sundries, contractors and farm staff). Figure 1.1 shows the breakdown of sugarcane production costs of a typical South African sugarcane enterprise. At an estimated 25%, transport cost consequently constitutes the second largest expense for a sugar cane producer with the greatest cost attributed to farm staff (Meyer, 2005). Increasing economic pressures resulting from declining sugar prices and increasing fuel prices have resulted in the necessity to reduce transport costs in order for sugarcane producers to remain profitable. In order to reduce transport costs, machine performance and utilisation needs to be improved (Broadway, 2006).

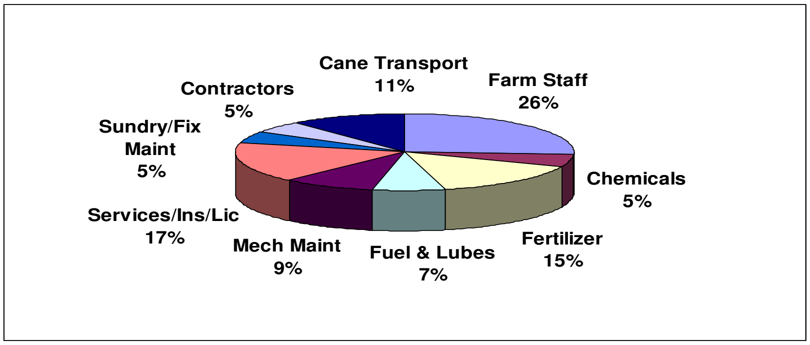

Figure 1.1 South African sugarcane production costs (Meyer, 2005)

In conjunction with the need to improve machine performance and utilization, the South African Department of Transport (DoT) has identified that the transporting of raw materials on South African roads by truck, contributes to increased road maintenance costs mainly due to such trucks being overloaded (Bezuidenhout, 2006).

The nature of raw products, such as sugarcane that has a varying bulk density, is the cause of trucks often being overloaded. The South African sugarcane industry produces approximately 21 million tons of sugarcane annually which is transported to 14 mills throughout the country. Of the 21 million tons, 75% is transported by articulated trucks, with the remaining cane being transported by rail and tractor trailer rigs (Meyer, 2005). The average lead distance that these trucks travel to reach a mill is 25 kilometres which translates into 31 million kilometres travelled per annum.

The South African Sugarcane Industry has identified on-board weighing as one technology that could improve vehicle performance and utilization while ultimately reducing costs (Lyne, 2006). The South African Department of Transport also considers on-board weighing to be a technology that could be utilised in reducing overloading of trucks and thus reducing the damage caused by overloaded (sugarcane) trucks.

Preliminary results reported by Cole *et al.* (2005) demonstrated that the use of on-board weighing systems on sugarcane transport trucks effectively increases the utilisation of trucks while minimising overloading of trucks.

1.2 Objectives of Study

The main objective of this thesis is to evaluate on-board weighing systems to determine the effectiveness of this technology in reducing transport costs and decreasing overloading in the South African Sugar cane transport industry. A secondary objective is to formulate guidelines for the implementation of an on-board weighing system based on the observations made while evaluating the technology. Specific functions identified to perform the main objectives were as follows:

- Provide an overview of on-board weighing systems demonstrating the benefits and drawbacks of the technology,
- Evaluate the accuracy and consistency of on-board weighing systems under different loading scenarios,
- Identify factors that influence the operation and effectiveness of on-board weighing systems,
- Evaluate economic factors pertaining to the technology,

- Formulate guidelines for the operating, managing and maintaining of an on-board weighing system.

1.3 Research Approach

An overview of on-board weighing systems is presented, which serves the purpose of understanding the operational characteristics of the system while demonstrating its strengths and shortcomings. The overview is based on technical papers relating to on-board weighing systems as well as reports from previous work on the assessment of on-board weighing technology. A brief overview of the South African sugarcane transport industry is also presented in order to highlight where on-board weighing technology is applicable in the transport of sugarcane.

Field evaluations examine the use of on-board weighing systems in three transport operations within the South African sugarcane industry. The field evaluations determine the accuracy and consistency of the system, the system's effectiveness in increasing vehicle utilisation and reducing overloading while identifying what factors within the transport system have an effect on the operation of an on-board weighing system.

Following the field evaluation, an economic analysis of an on-board weighing system is presented. A capital budgeting procedure is used to determine the payback period for investing in an on-board weighing system. The analysis includes different scenarios based on the amount of increase in vehicle utilisation as well as different travelling distances which affect the cost of transport. The economic evaluation enables the feasibility of investing in an on-board weighing system to be determined for different transport scenarios.

From the procedures observed in the field evaluations, guidelines for implementing, managing and maintaining an on-board weighing system are presented.

1.4 Document Layout

Following the introduction (Chapter One), Chapter Two contains an overview of on-board weighing systems and Chapter Three contains a brief overview of the South African sugarcane transport system. Next, Chapter Four contains the field evaluations of on-board weighing systems currently operating. Chapter Five presents an in-depth economic analysis of the technology and Chapter Six provides guidelines for the implementation, management and maintenance of an on-board weighing system. Chapter Seven contains a synthesis of the thesis with conclusions and recommendations for further research. The layout of the document is summarised by Figure 1.2.

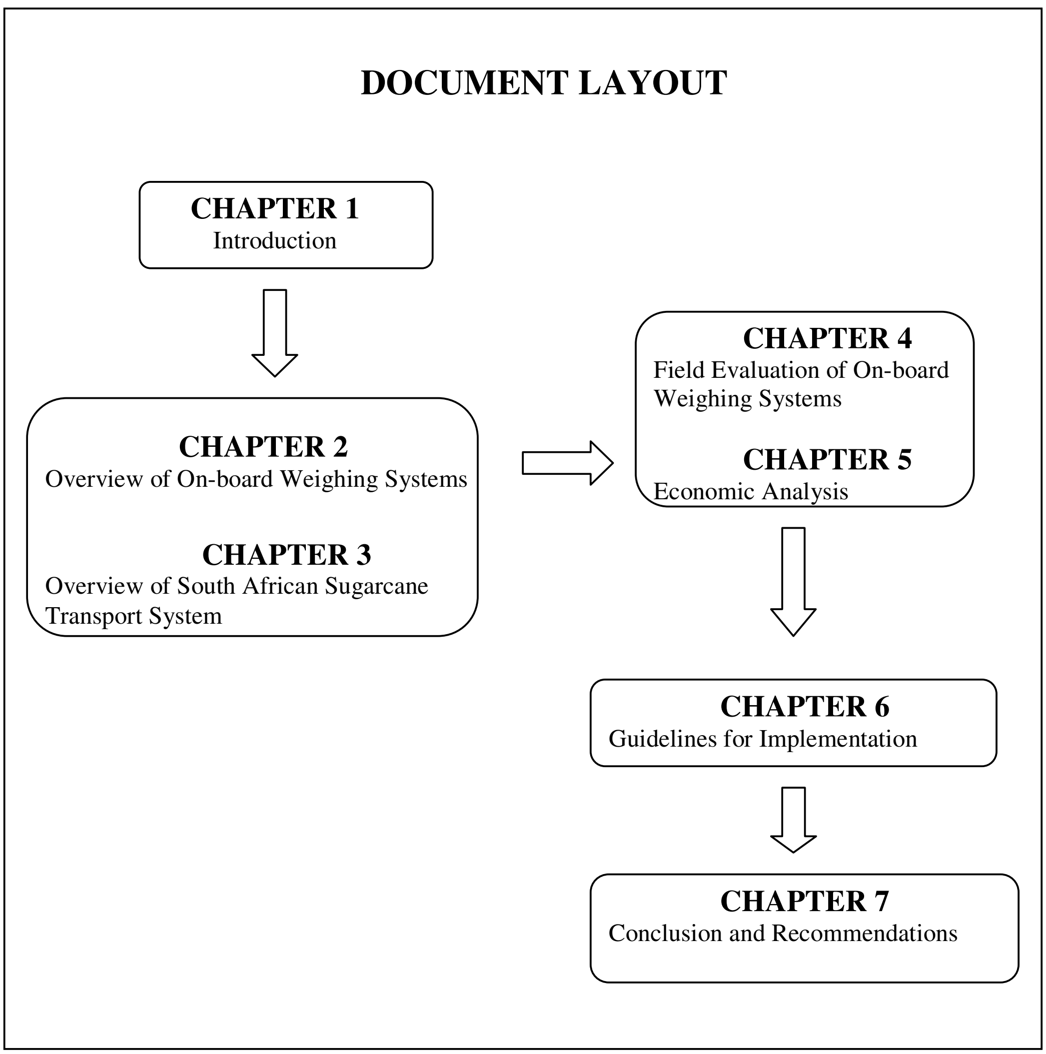

Figure 1.2 Layout of Document

2. OVERVIEW OF ON-BOARD WEIGHING SYSTEMS

This chapter presents an overview of on-board weighing systems that are used in timber and sugarcane transport operations.

2.1 Introduction

Trucking of raw products such as timber and sugarcane can be the most expensive phase of a typical harvesting operation (Hansen *et al.,* 2002). In the timber industry, the trucking cost typically represents as much as 50% of the total logging cost (Smith, 1981) and in sugarcane up to 25% of the total transportation cost (Meyer, 2005). A transporter engaged in the transporting of raw materials is commonly faced with high capital investment, low profit margins, increasing fuel costs and strict government regulations. A transporter's economic survival has therefore become dependent on the efficiency of the trucking operation (Shaffer *et al*., 1987). In the South African transport industry the new Road Traffic Management System (RTMS) imposes tighter regulations on the transport industry therefore operating within the limits of the law will be essential for the survival of transporters.

On-board weighing systems offer a potential solution to increase the efficiency of a transport operation as well as assisting transporters to remain within the government regulations (Gelinas, 2003). Over the years there has been a constant stream of new products within the transport industry, new technologies that have been claimed to be the biggest, the best, the most economical and the most efficient. Some have become commonplace while others have failed to make an impact or have struggled to maintain themselves. One technology that has become commonplace within the American transport industry, especially the logging industry, is on-board weighing scales (Gelinas, 2003).

An on-board weighing system allows for the weight of a truck to be known as the loading of the truck is taking place. The truck is therefore able to be loaded to within the maximum allowable limit stipulated by government road regulations. The system is permanently installed in a fixed location on a vehicle; it has a load receiving element specially adapted to specifically determine the combined load of all wheels on a single axle or on a tandem axle of a multi-axle vehicle (Michaelsen, 1998).

This overview of on-board weighing systems is comprised of two parts. Part A contains a technical overview of how on-board weighing systems work and Part B reviews literature relating to the potential benefits that can be realised from the use of an on-board weighing system. Further, the overview highlights the negative drawbacks of such systems and the factors that have been perceived to affect the effectiveness of on-board weighing systems. The overview is for on-board weighing systems that can be installed on articulated trucks that transport raw products such as sugarcane and timber and which are required to travel on roads governed by government regulations.

2.2 Types of systems

There are numerous types of on-board weighing systems available on the market designed for use on trucks with traditional mechanical suspension, as well as trucks with pneumatic (air) suspensions (Bendel, 2001).All of the different types of on-board weighing systems, however, are based on a single technology or a combination of two technologies namely load cells and pneumatic devices with load cells and pneumatic devices being the primary two technologies. Load cells are applicable to trucks with mechanical suspensions, while pneumatic devices are used on trucks that have air suspensions. An on-board weighing system that makes use of a combination of these technologies is therefore uncommon as there is seldom a case where a truck has a combination of both mechanical and air suspensions (Shaffer *et al.,* 1987). While every on-board weighing system will differ according to the manufacturer, a generalised overview of load cell and pneumatic systems is presented below.

2.3 Components

Both load cell and pneumatic systems are comprised of four main components, these being; (i) load sensors, (ii) cables and connectors, (iii) computer processing unit

(CPU) and (iv) display and printer unit, with the important difference between a load cell and a pneumatic system being the load sensing component (Phillips, 1989).

Load sensors are located at each load bearing point on a truck and trailer. As a truck is loaded the load sensors sends a signal, via cables and connectors to the CPU. The CPU then interprets the signal which is then displayed by the display unit as a weight reading, the reading is then able to be printed as a tripsheet by the printer (Shaffer *et al.,* 1987). Figure 2.1 illustrates the location of each component on the truck and trailer while the flow diagram shows how the system works. Each component of the on-board weighing system will be examined further.

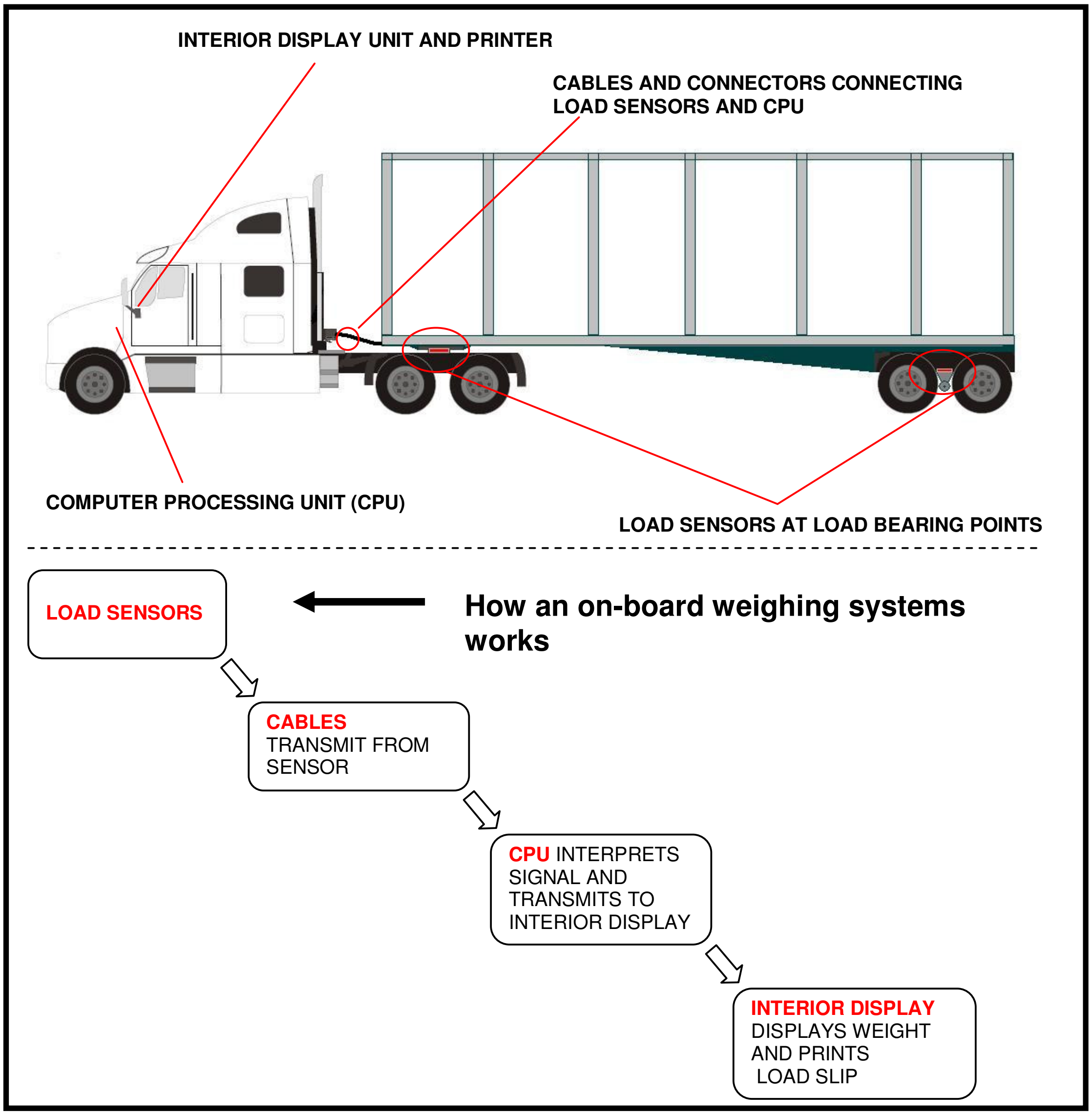

Figure 2.1 Components of an on-board weighing system and flow diagram of how the system works

2.3.1 Load sensors

As mentioned, the load senor component of an on-board weighing system is either load cells, when a vehicle has mechanical suspension or pressure transducers when a vehicle has air suspension.

2.3.1.1 Load cell sensors

Loads cells are sensor devices that support the weight of a truck's load continuously. The load cells are installed as an integral part of the load bearing structure of the truck at all load bearing points on the truck and trailer (Thomphson, 2006). Figure 2.2 and 2.3 show the location of load cells on common interlink and rigid drawbar truck configurations. Such trucks are commonly used to transport raw bulk material such as sugarcane and timber.

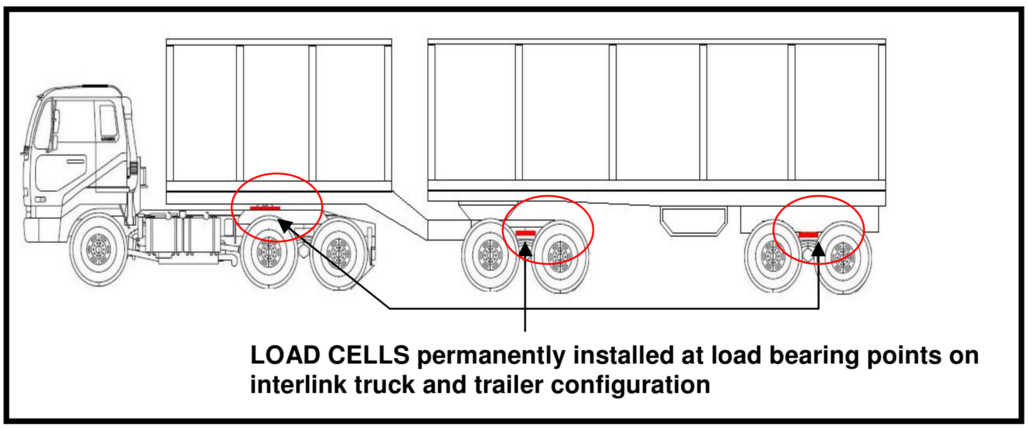

Figure 2.2 Location of load cells on an interlink truck configuration

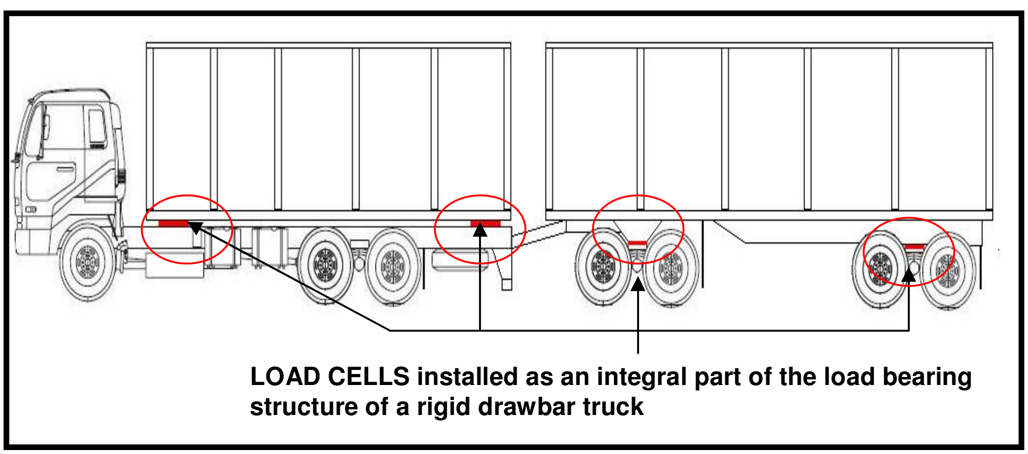

Figure 2.3 Location of load cells on a rigid drawbar truck configuration

From Figure 2.2 and Figure 2.3 it can be seen that for the trailer sections of both interlink and rigid drawbar trucks, loads cells are located at the axles of the trailer. These load cells are mounted in between the frame of the trailer and the equaliser hanger bracket of the suspension on each side of the single or tandem axle. Figure 2.4 below is an illustration of a load cell mounted at the axle point of a trailer.

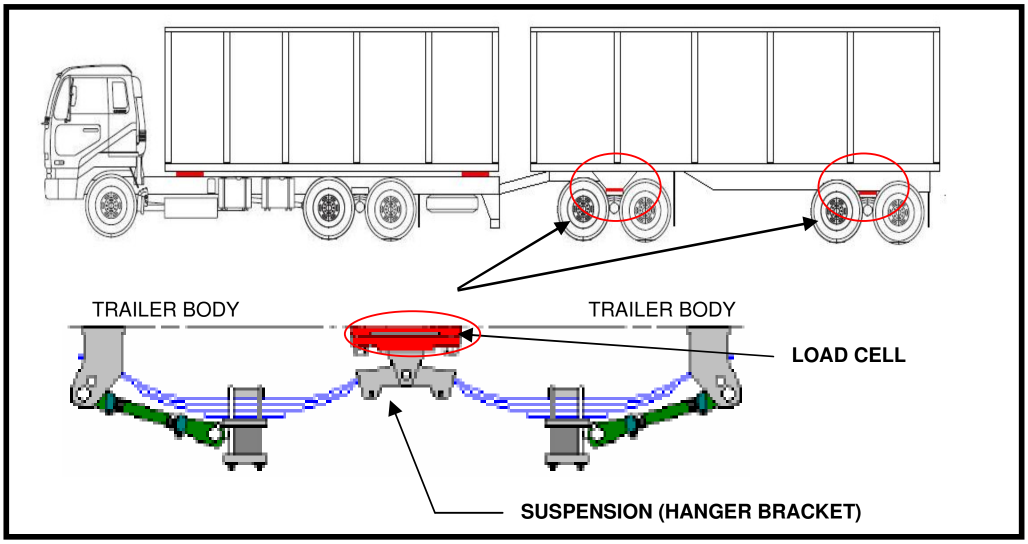

Figure 2.4 Load cell mounted in between trailer body and hanger bracket at trailer axle points

In the case of rigid drawbar trucks, load cells are mounted in between the body of the truck and the truck's chassis (*c.f.* Figure 2.3), and with interlink trucks load cells typically replace the standard supports for the fifth wheel of the trucks (Thomphson, 2006). Loads cells mounted at the fifth wheel of an interlink truck are illustrated by Figure 2.5.

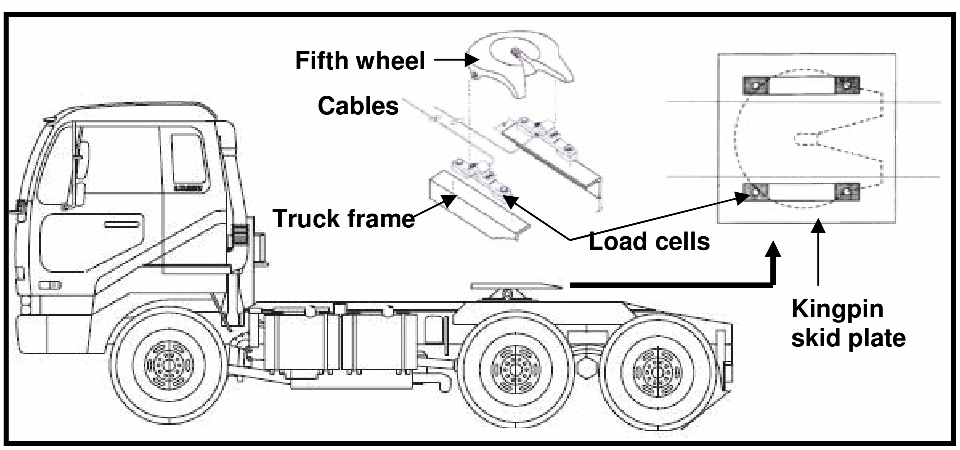

Figure 2.5 Load cells mounted at the fifth wheel of an interlink truck

Load cells are electronic devices typically used to convert a force into an electrical signal. A load cell is made up of a precisely machined steel bar onto which a strain gauge is affixed. Each load cell has a clear centre span which flexes during loading. The strain gauge attached to the steel bar consists of an insulated backing, which supports a metallic foil pattern. When the load cell deforms under the applied force the strain gauge deforms and the electrical resistance of the metallic foil pattern changes. The strain gauge is wired to the CPU which then registers the change in electrical resistance and relates it to the weight of the load (Phillips 1989).

Strain gauges either measure the bending (*c.f.* Figure 2.6) or the shear (*c.f.* Figure 2.7) of the bar caused by the load weight. The type used is dependent on the manufacturer of the load cell.

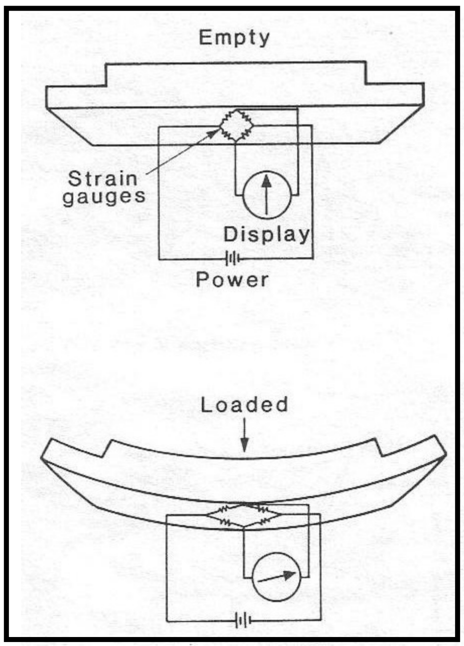

Figure 2.6 Bending-beam type load cell

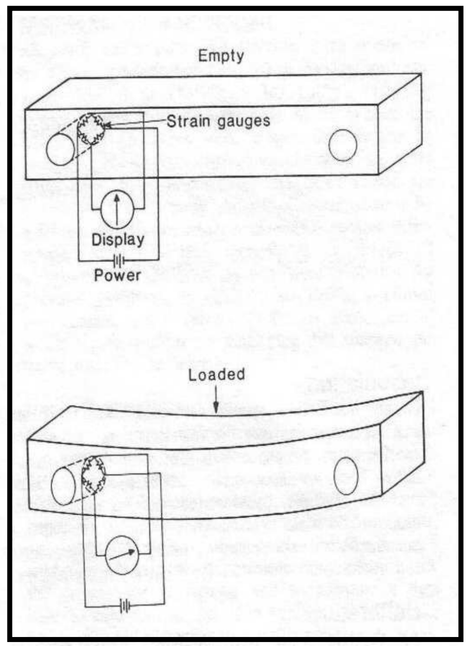

Figure 2.7 Shear-beam type load cell

2.3.1.2 Pneumatic load sensors

Pneumatic load sensors consist of pressure transducers. In the case where a truck has air suspension, the suspension of the truck is made up of rubber air bags that support the load weight of the truck. The air bags are connected to hoses that monitor the pressure in the bag and inflate or deflate the air bag as required. For an on-board weighing system, pressure transducers are connected into the air hose that monitor the air pressure in the air bags. As the truck is loaded the pressure within the air bags increases, the transducers convert the pressure registered in the air bag to an electric signal which is related back to the CPU and duly converted into a load weight reading (Skydel, 2003). An illustration of a pressure transducer connected into the trucks air suspension line is shown in Figure 2.8.

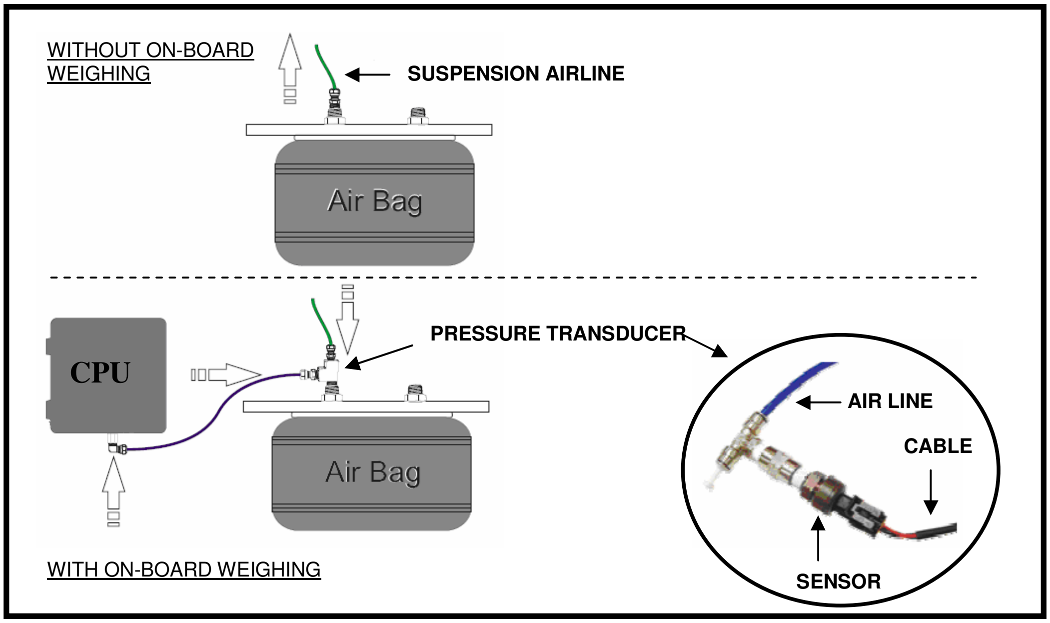

Figure 2.8 Pressure transducer connected into the air line of an air suspension (Skydell, 2003)

Other older methods exist to monitor the weight of trucks using air suspensions such as analog air gauges that can be connected into the suspensions air lines and the pressure reading on the gauge can be used to determine the load weight. Modern on-board weighing systems, however, make use of pressure transducers to determine load weights.

2.3.2 Computer processing unit (CPU)

The CPU is the main computing component of an on-board weighing system. The CPU is typically connected to the load cells or pressure transducers via cables and connectors, and receives the electrical signals generated by the load sensing devices. No wireless systems were investigated in this study.

The CPU processes the sensor data, stores calibration values, performs transceiver duties for the tractor/trailer multiplexing communications, and transmits weight data to the vehicle's display and printer units. Additionally, the CPU can retain important settings such as security PIN numbers (if the on-board weighing system has such features) and can have direct output connections to an overweight alarm circuit. The CPU can either be a separate unit that is mounted in a suitable location on the truck (typically under the dashboard) or it can be integrated into the trucks interior display unit.

2.3.3 Interior display unit

The interior display unit of the on-board weighing system is the primary interface between the truck operator and the weighing system. The truck operator uses the display unit to observe the load weight as the truck is being loaded, loading can then be halted when the display units indicates that the truck is loaded to it maximum legal limit. The display unit is also used to enter weight data for calibration purposes. The scale display is typically mounted on the truck's dashboard on a mounting bracket or can be mounted directly into the dash and is connected to the CPU (if the two units are separate components).

An illustration of a typical interior display unit is shown in Figure 2.9. In this particular unit the axle weights of each axle group is displayed with the total weight being shown at the end. There are four alarm lights that indicate when an axle has been overloaded beyond its set point weight and if the total payload is beyond the set limit.

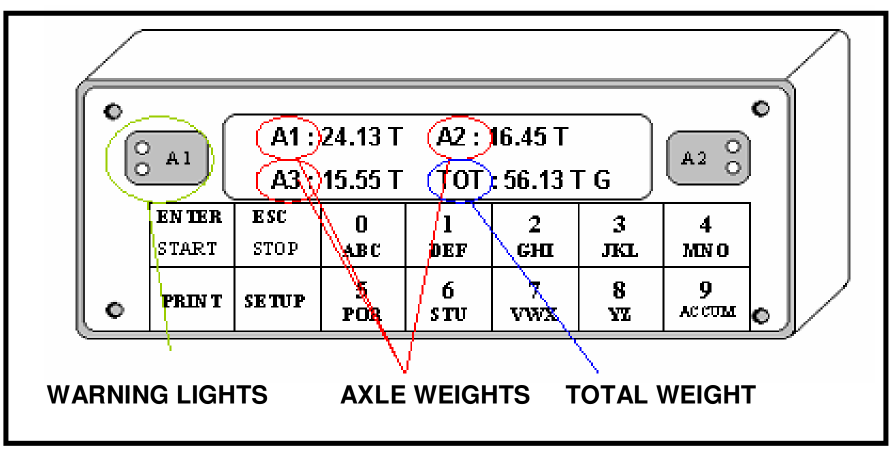

Figure 2.9 Interior display unit of an on-board weighing system

2.3.4 Printer Unit

A durable printer can also be connected to the computer processor or the interior display unit; the printer prints a scale ticket report that includes axle weights, gross vehicle weight, net payload, with signature lines for the driver and receiver. A printed tripsheet enables the load weights to be monitored and managed. A typical ticket report would look like the one illustrated in Figure 2.10. The printer is commonly mounted within the cab of the truck in a suitable location.

```
............Tripsheet............

UNITRANS
Fleet No:       8929
Date: 25/04/07    Time: 07:56

Axle 1:      11.53 Ton    NETT
Axle 2:      11.92 Ton    NETT
Axle 3:      10.62 Ton    NETT
              - - - - - - - - - - - - - -
TOTAL:       34.06 Ton    NETT


Axle 1:      24.20 Ton   GROSS
Axle 2:      17.23 Ton   GROSS
Axle 3:      15.71 Ton   GROSS
              - - - - - - - - - - - - - - - -
TOTAL:       57.13 Ton   GROSS

Batch No  :............................
Signed    :...........................
Location signed :.....................
```

Figure 2.10 Tripsheet reported printed by the on-board printer

2.3.5 Adaptations and optional extras

The components of an on-board weighing system as discribed above are for a generalised system. Adaptations occur for different manufactures and additions to the system can be made according to the customer's requirements. Such adaptations include externally mounted display units rather than a unit that is mounted within the truck's cab. An external display enables the load weight to be viewed from outside the truck if that is required. Extra care needs to be taken in mounting an eternal display in order that it should be easily accessible to the operator, but will be simultaneously protected from being harmed during loading operations. An ideal location typically depends on the make, model and configuration of the specific vehicle. Another adaptation or addition to the system is a hand held display unit. Hand held display units can either be plugged into a connection port on the tractor/trailer or can be connected to the system by a wireless receiver. An addition to the system is a display unit that is mounted in the loader vehicle and is wirelessly connected to the truck on-board system. This enables the loader operator, as well as the truck driver, to know the load weight of the truck as loading is taking place. Other modifications are determined by the specific requirements of the user and the environment in which the system operates (Harrison, 2006).

2.4 Benefits

In general, benefits derived from new technologies depend on the extent to which these technologies are adopted and utilized (Mitropoulos and Tatum, 1999). On-board weighing technology is in its infancy in the South African sugarcane transport industry and is not widely adopted or utilised. However, numerous benefits are realised by other transport sectors that are utilizing this technology to its potential such as in the timber industry (Kopp, 2007).

On-board weighing technology does not only offer numerous benefits to the transport industry but the roads on which these trucks travel can also realise benefits from the implementation of this technology. Benefits of the system can be compartmentalised into vehicle, fleet management, and road benefits (Lyne, 2006). The benefits associated with the three compartments are shown in the flow diagram contained in Figure 2.11. Each benefit listed for each compartment is discussed in detail in the following sections.

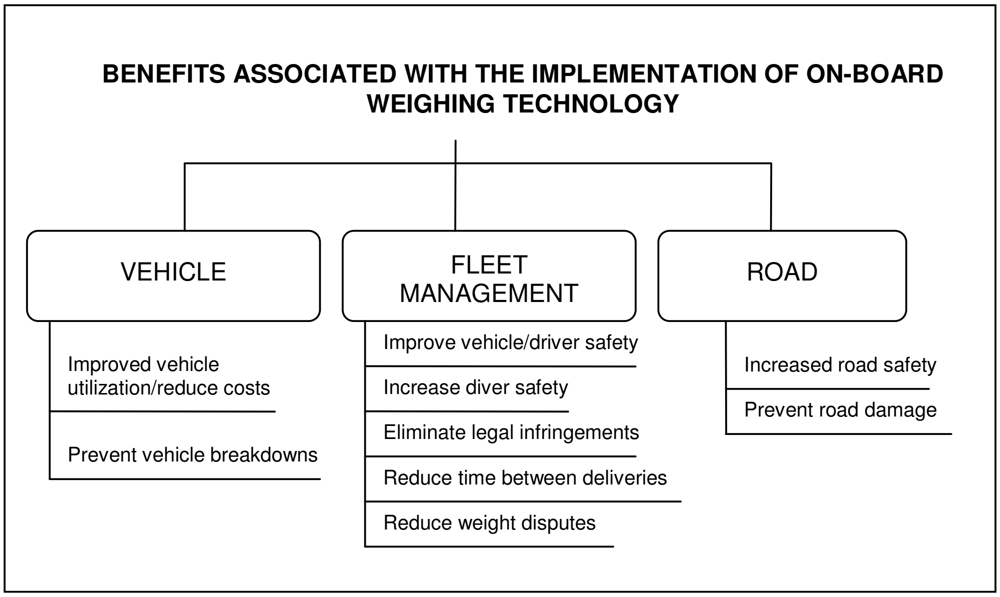

Figure 2.11 Vehicle, fleet managerial and road benefits associated with the implementation of on-board weighing technology

2.4.1 Vehicle Benefits

Vehicle benefits are related to improving the utilization of the vehicle, which can result in reduced transport cost, and the prevention of vehicle breakdowns. While an on-board weighing system enables a vehicle to be loaded to its maximum legal capacity, and thereby maximising utilisation, the vehicle is always loaded within the vehicle's design limits which prevents damage to the structure of the vehicle which occurs when a vehicle is consistently overloaded (Richards, 2003).

2.4.1.1 Improved vehicle utilization/reduced transport costs

An on-board weighing system enables a vehicle to be loaded to its maximum legal limit every time it is loaded. In South Africa the maximum GVM of a vehicle is 56 tons. With an on-board weighing system the vehicle is able to be operated at maximum utilization which results in decreased transport costs and a resulting increase in revenue generated (Gelinias, 2003). In the transportation of raw bulk materials, revenue generated is typically a function of the payload that is delivered and, by increasing the payload of vehicles through the use of on-board weighing results in a direct increase in revenue.

McNeel (1990) evaluated the effectiveness of on-board weighing scales on logging trucks. On average the mean net load was increased by 2.07 tons when the on-board scales were used. Gallagher *et al.* (2004) analysed the difference in gross vehicle mass (GVM) in study between trucks that used on-board scales and trucks that did not. In general, they found that trucks with on-board weighing had higher average GVM, with related higher net payloads, and they had reduced variation of GVW. Shaffer *et al.* (1987) examined the use of on-board scales using case studies of a Georgia logger and a Virginia logger in America. The use of on-board scales decreased the standard deviation of net payload by 0.52 tons. The projected cost savings yielded a rate of return of 24.3% on the scale investment for the Georgia logger.

Cole (2005), a sugarcane haulier in the South Coast region of KwaZulu-Natal, investigated the use of on-board weighing systems as a cost-effective tool to optimise sugarcane loading. Two vehicles were fitted with load cell on-board weighing systems and the consistency of mass of all loads delivered, the increase in average net payload, the accuracy of the system and the estimation of money saved during 2005 season was investigated. The study showed that 97.15% of all the loads delivered during the study period were loaded to the desired limit with the remaining 2.85% being underloaded. From these results it was concluded that the use of the system achieved fairly consistent payloads.

A comparison was made in the study between the average net payload of the two vehicles with on-board weighing systems and the average net payload of all other vehicles of the same configuration that delivered sugarcane to the same mill, namely Sezela. It was found that the average net payload of the vehicles with on-board weighing systems was two tons higher than any other vehicle. Table 2.1 contains a summary the statistics regarding the vehicle masses of all the loads delivered by the vehicles with on-board weighing systems in the study.

Table 2.1 Summary of statistics of vehicle masses for all loads delivered by vehicles with on-board weighing systems (Cole *et al.,* 2005)

No. of Loads	1070
Average GVM (Ton)	57.12
Max Load	60.52
Min Load	50.38
Standard deviation (Ton)	1.17
Tons Carried	61122
Extra Loads due to Under Loading	30.5
Proportion of Total Loads Carried (%)	2.85

The error in the estimations of gross vehicle mass by the weighbridge system for each load when loading (at the zone) and when unloading (at the mill weighbridge) was compared to evaluate the accuracy of the systems. Figure 2.12 shows that the accuracy of the estimates made when loading and when at the weighbridge are very similar. It was concluded that the on-board weighing systems were consistently similar when compared to the mill weighbridge.

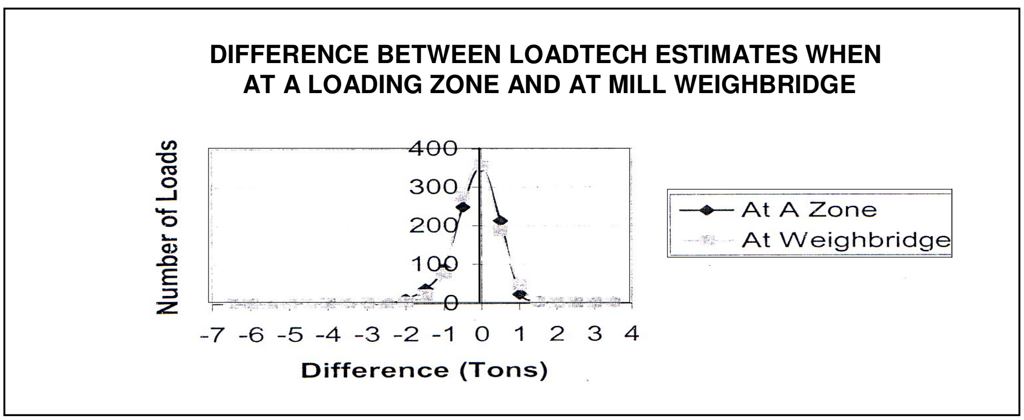

Figure 2.12 Difference between on-board weighing estimates at zone and the mill weighbridge (Cole *et al.*, 2005)

Predictions of money saved during 2005 from the use of on-board weighing systems were made by Cole *et al.* (2005). These predictions were based on the assumption that the average payload should increase by three tons when compared to loads carried before any weighing system was used. Table 2.2 below shows that the estimated funds that was saved during the 2005 season by increasing the payload by three tons was R118 606 for the two trucks. Considering that the cost of one on-board weighing system, used in the study, was R 120 000.00, then one system would be paid off in the first year of use with the second system being paid off in the second year of use. Thereafter a considerable increase in the revenue would be accrued.

Table 2.2 Estimation of money saved during 2005 due to use of on-board weighing (Cole *et al.*, 2005)

	Vehicle 1	Vehicle 2
Average Tare Weight	24.04	23.91
Max Permissible Payload	34.76	34.89
Average Payload	33.15	32.98
Mass Below Optimum (tons)	1.61	1.91
Average Gross Vehicle Mass	57.253	56.892
If payload had been 3 tons lower		
Average Payload	30.15	30.98
Extra Loads	16.9	13.7
Money Lost Due to Extra Loads	R 71 937.83	R 46 669.70
Total	R 118 606.83	

2.4.1.2 Prevention of vehicle breakdowns

The second benefit that can be realised in the vehicle benefit compartment is the prevention of vehicle breakdowns (Skydel, 2003). Overloading is practiced to gain financial benefits; however, although not directly seen, overloading has severe effects on the operational performance of a truck. The stress and strain that is placed on a vehicle when overloaded beyond its design capacity effects life of the vehicle suspension systems, adversely reduces the engine efficiency which also results in substantial increase in the amount of environmental emissions (Enercon, 2001). The actual cost of increased maintenance due to overloading has not been quantified but it is widely recognised that overloading is a major contributor to truck breakdowns. On-board weighing systems enables the overloading of vehicles to be prevented which will have a positive effect on fuel efficiency, economy of the truck operation due to reduced maintenance and the environment in which we all live in.

2.4.2 Fleet Managerial Benefits

There are many factors that have to be taken into consideration when managing a transport fleet. Some of the many factors associated with fleet management that can relate to on-board weighing systems are, vehicle and driver safety, driver productivity, legal implications, time usage and possible weight disputes between the transporter and the receiver (Richards, 2003). Various ways in which on-board weighing scales can benefit these factors are discussed below.

2.4.2.1 Improved vehicle/driver safety

A vehicle is designed to carry a certain payload. Overloading a vehicle causes a vehicle to be unsafe and is potentially harmful to other road users and the driver of the vehicle (Winter, 1998). Overloaded trucks are potentially dangerous due to:

- The vehicle will be less stable, difficult to steer and take longer to stop. Vehicles react differently when the maximum weights which they are designed to carry are exceeded,
- Overloaded vehicles can cause the tyres to overheat and wear rapidly which increases the chance of premature, dangerous and expensive failure or blow-outs,
- The overloaded vehicle cannot accelerate as normal – making it difficult to overtake,
- At night, the headlights of an overloaded vehicle will tilt up, blinding oncoming drivers to possible debris or obstructions on the roadway,
- Brakes have to work harder because the vehicle is heavier due to overloading. Brakes overheat which reduces their effectiveness to stop the truck,
- The whole suspension system comes under stress and, over time, the weakest point can fail (Keppler, 2005).

Onboard weighing systems enable trucks to be loaded within the trucks design limits therefore eliminating any of the above dangerous factors occurring. A fleet manager can operate with peace of mind knowing that his trucks are being safely operated and the drivers are operating under significantly safer conditions (Ladyman, 2005).

2.4.2.2 Increased driver productivity

Skydell (2003) stated that if a driver is operating with a peace of mind it tends to positively influence the productivity of drivers. With the implementation of an on-board weighing system a truck driver can operate knowing that the truck is loaded within the legal limits and is also operating within the design limit of the truck. Consequently operators tend to have a greater peace of mind which can result in improved productivity from the drivers.

2.4.2.3 Eliminate legal infringements

Due to adverse effects of overloading, increasing attention is being paid by governments all over the world to the prevention of overloading. In South Africa overloading has been recognized to be both a safety concern as well as a cost concern due to damage caused to infrastructure (Keppler, 2005), and the National Department of Transport has incorporated a campaign against overloading in its Road to Safety strategy. The implementation of the new Road Traffic Management System (RTMS) in South Africa will enable government to access vehicle weight data from mill records, this means that areas where previous overloading offenders went unnoticed, due to the lack of weighbridges in those areas, can now be prosecuted if seen to be overloading according to mill weighbridge records. In South Africa the government views overloading to be a serious offence (Koster, 2004), this is illustrated by the implementation of the National Overload Control Strategy shown in Figure 2.13.

As a result of increasing government control of overloading, it has become imperative for fleet managers to manage the payloads of their vehicles in order to prevent being prosecuted and incurring fines for overloading. With the use of on-board weighing, payloads can be accurately managed to be within the legal requirements. All legal infringements can be eliminated and any additional transport costs that are accrued through overloading fines can be prevented.

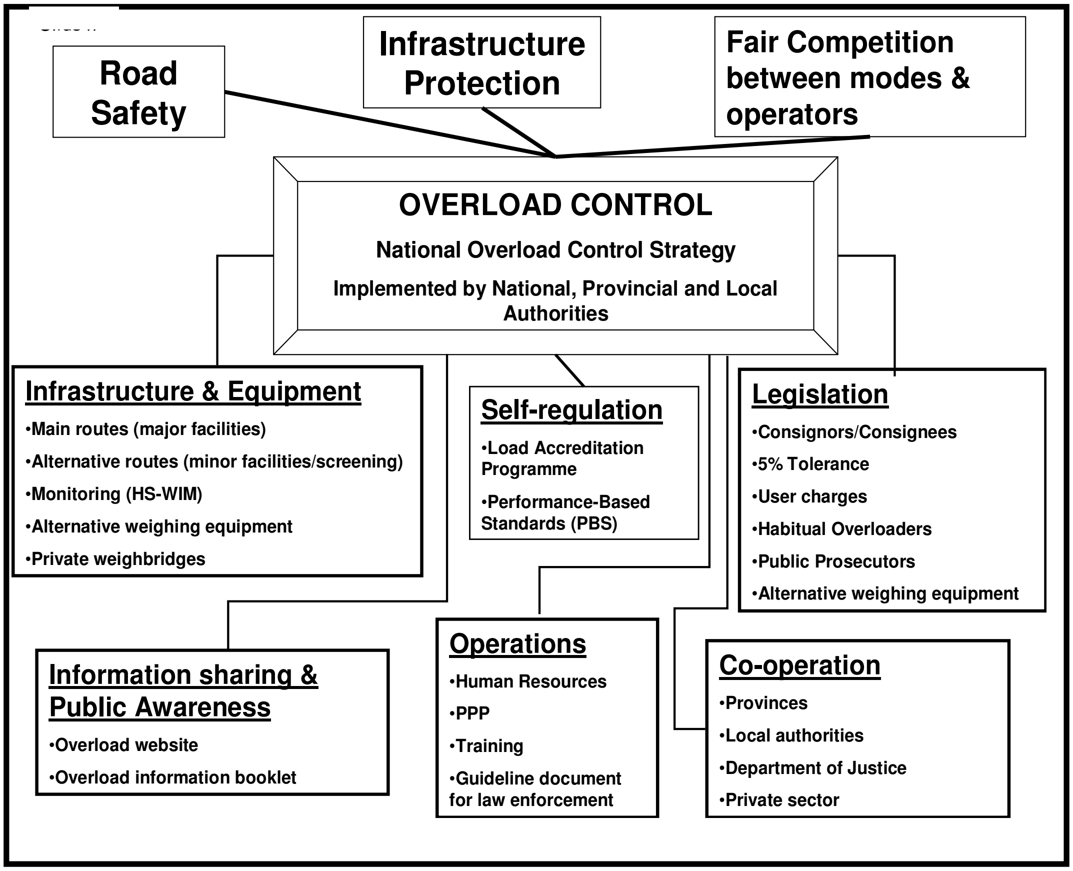

Figure 2.13 National Overload Control Strategy (Koster, 2004)

2.4.2.4 Reduced time between deliveries

Freight carrying trucks are often required to be weighed at weighing stations along their route and sometimes at weighing stations that require a detour from their route. Queues at these weighing stations as well as the time that it takes to detour from the delivery route can cause major delays in a delivery schedule. Deckard *et al.* (2001) measured roundwood delivery times in the south-eastern United States and estimated potential efficiency gains. They gathered data for 9 476 loads delivered to eight mills in the Southeast USA and separated the top 25% loads with the shortest median turn times and named this sample subset the benchmark group. They determined that if the remaining 75% of the loads (rest of sample) reduced their median turn times to those of the benchmark group, it would save $12.39 per load in direct marginal system costs. They placed the potential impact in the Southern USA wood supply chain at between $44.1 million and $87.1 million in 2001. In South Africa, the implementation of government strategies such as Performance Based Standards (PBS) enables trucks with on-board weighing systems to be recognised and prevents them from being required to be weighed at government weigh stations. Consequently, considerable time that is wasted due to weigh stations can be saved and deliveries can be done faster with the possibility of more deliveries being delivered in a day than normally possible (Giles, 2006).

2.4.2.4 Reduced weight disputes

Payload disputes can occur between the freight transporter and the receiver of the freight. Richards (2003) stated that on-board weighing allows transporters to know exactly what their payloads are and therefore have grounds on which to dispute the weight stated by the receiver if a discrepancy occurs. The on-board weighing system enables the printout of a tripsheet, with the load weight delivered, for every load that is delivered. A transporter can then keep a record of load weights and dispute weights stated by the receiver of the load, such as the mill, if the need occurs.

The above mentioned benefits all confirm that the implementation of on-board weighing systems will enable fleet managers to mange their operations with increased efficiency.

2.4.3 Road Benefits

On-board weighing systems can benefit the road in two ways. Firstly, the safety of roads can be increased and, secondly, by the prevention of road infrastructure damage caused by overloaded trucks (Kishore *et al.*, 2000).

2.4.3.1 Increased road safety

Overloaded trucks are widely recognised to be a safety concern; the safety of trucks is compromised for various reasons as stated in Section 2.3.2.1. Overloaded trucks contribute too many fatal accidents and not only put the truck driver at risk, but also other road users (Keppler, 2005). Many trucks are overloaded unknowingly, especially trucks carrying raw products that have a varying bulk density such as sugarcane and timber. On-board weighing enables the weight of the truck to be known whatever the product is and can contribute significantly to making sure that the roads are kept as safe as possible.

2.4.3.2 Prevention of road infrastructure damage

Excessive damage to roads is caused by overloaded trucks. Kishore and Klashinsky (2000) estimated that the damage caused by overloaded trucks is exponential, a 10% increase in weight results in a 40% increase in road damage. It is estimated that 60% of the damage to the road network in South Africa is caused by illegally overloaded heavy vehicles, costing the taxpayer some R550 million per annum (Winter, 1998). Research in the USA and South Africa has shown that an axle carrying double the legal load, may cause from 4 to 60 times as much damage as one legal axle load, depending on the condition of the structure and type of road. It was also estimated that between 15% and 20% of all heavy freight vehicles travelling on South African roads are overloaded (Winter, 1998).

In KwaZulu-Natal, South Africa, a study was conducted by Roux *et al.* (2004) to estimate road damage due to overloaded vehicles. Data was collected from weighbridges in KwaZulu-Natal over a period of seven years from 1996 to 2003, and a model was developed based upon this data. The model was first used to calculate the value of the road per year for each year from 1996 to 2003 and then the value of the road damage for various degrees and extent of overloading was calculated. The extent of overloading refers to the number of vehicles that are overloaded and is expressed in overloaded vehicles as a percentage of all heavy vehicles on the road. The information from the various weighbridge sites in KwaZulu-Natal was used to determine the extent of overloading.

The degree of overloading refers to the average overload of heavy vehicles and is expressed in E80s. E80s or Equivalent Standard Axle Load (ESALs) were calculated using Equation 2.4 below

$$\text{ESALs (E80s)} = (P/P_s)^4 \tag{2.4}$$

where P= axle load and P_s = standard axle taken as 8 200kg

The amount of road damage that was caused by overloaded vehicles per year, for the period 1996 to 2003 is contained in Table 2.3.

Table 2.3 Estimated annual road damage caused by overloaded vehicles (Roux *et al.,* 2004)

Year	Vehicles weighed	Vehicles overloaded	Extent of overloading	Degree of overloading	Annual cost due to overloading R million		
				Ave. O/L E80s/vehicle	Low	High	Average
1996	50,595	14,220	16%	1.28	19.7	40.4	30.1
1997	45,657	13,691	15%	1.31	18.8	38.9	28.9
1998	33,235	14,291	15%	1.22	17.6	36.2	26.9
1999	72,546	25,788	15%	1.13	16.3	33.4	24.9
2000	135,152	46,837	12%	0.79	9.2	18.8	14.0
2001	115,193	42,268	12%	0.78	9.1	18.4	13.8
2002	142,295	47,938	14%	0.72	9.6	19.9	14.8
2003	113,377	28,149	15%	0.69	10.0	20.5	15.3

The estimated damage caused by overloaded vehicles reduced significantly from R30.1 million per year in 1996 to R13.8 million per year in 2001. This decrease was mainly attributed to the increased overload control that was introduced in KwaZulu-Natal during this time.

The reduction in estimated road damage was primarily due to a reduction in the degree of overloading, rather than in the extent of overloading, which remained fairly constant. The degree of overloading was however decreased significantly. In 1996 the average E80s per overloaded vehicle was 1.28 and this reduced to 0.69 in 2003, representing an improvement of 46% (Roux *et al.,* 2004).

Considerable saving in road damage cost were achieved in KwaZulu Natal, however overloaded vehicle continue to be the cause of major road damage and costs were estimated to be R 15 million in 2003 in KwaZulu-Natal alone. On-board weighing is recognised by all sectors to be a solution to further reduce overloading of vehicles and thus prevent our roads being excessively damaged.

2.5 Disadvantages

Two factors are perceived to be negative drawbacks of implementing an on-board weighing system. These factors are the initial capital investment in the system and the possible increase in fleet managerial duties due to the system.

2.5.1 Capital Investment

The first perceived drawback of implementing an on-board weighing system is the considerable (initial) capital investment required to purchase and install an on-board weighing system. However, as shown by Cole *et al.* (2005), the on-board weighing system provides an opportunity to increase the revenue generated by the vehicle on which it is installed and hence the system will pay for itself over time. Cole *et al.* (2005) showed that in that particular study the system was able to be paid off in the first year of its use.

In South Africa, LOADTECH on-board weighing systems are widely used throughout the timber industry and with a few used in the sugarcane industry currently. As this study's primary focus is on the sugarcane industry, approximate costs of LOADTECH on-board weighing systems for various different interlink and rigid drawbar sugarcane truck and trailer configurations are shown below. A comprehensive cost evaluation of the payoff period for the investment in an on-board weighing system is contained in Chapter Five of this document.

Interlink Configurations

There are four common configurations of air and/or spring suspension, the prices are as follows (Harrison, 2006):

A) Truck tractor with air suspension and both trailers with air suspension
Total cost = R 50 500.00

B) Truck tractor with air suspension and both trailers with dual axle spring suspension.
Total cost = R 67 500.00

C) Truck tractor with spring suspension and both trailers with air suspension
Total cost = R 67 500.00

D) Truck tractor with spring suspension and both trailers with dual axle spring suspension.
Total cost = R 80 500.00

Rigid Drawbar Configurations

There are two common configurations of air/or spring suspension:

A) Rigid truck fitted with eight load sensor between the chassis and sub-frame and trailer using dual axle spring suspension front and rear
Total cost = R 89 500.00

B) Rigid truck fitted with eight load sensors between the chassis and sub-frame and trailer using air suspension front and rear
Total cost = R 82 900.00

2.5.2 Increase in fleet managerial duties

The second perceived drawback of implementing an on-board weighing system is the perceived increase in managerial duties required by the system. Truck operators have to be trained by the fleet manager as to how the system works and how it needs to be operated; the system also needs to be monitored to ensure that the operators are using the system correctly. These extra managerial duties can be seen to be a negative drawback on the implementation of on-board weighing systems (Kopp, 2007).

2.6 Factors Affecting Scale Effectiveness

Philips (1989) conducted a study evaluating the effectiveness of on-board weighing systems for logging trucks in British Columbia. He concluded that the precision and reliability of on-board weighing systems are affected by the selection of system type and model, installation techniques, routine maintenance, and the operator’s experience and acceptance of the systems (Philips, 1989).The importance of selecting the type and model for on-board weighing systems most suitable to the application was shown in Philips's (1989) case studies. Although the systems used were sized to the potential loads they would weigh, they were not adequate for the hauling conditions that were experienced in the study. The environment in which trucks haul timber and sugarcane is often very harsh causing large shock loads that place unforeseen stress and strain on the vehicle. An on-board weighing system must be sized to the potential abnormal loads they will weigh and the shock loads that the scales will experience during their normal duty cycle (Shaffer *et al.*, 1987).

In order to achieve maximum accuracy and reliability, on-board weighing systems must be installed carefully. Philips (1989) reported that excessive flexibility of the mounting surface on the truck or trailer affected the accuracy to some extent and resulted in fatigue cracking of the load cell. The systems electrical cords that connect the load cells to the CPU and digital display need to be routed carefully in protected locations with all wear points adequately shielded. Cables are connected with sockets that need to be protected from accumulated mud or from getting damage by logs or sugarcane sticks. Trucks are often required to travel off-road and excessive bouncing of vehicles, especially when travelling empty, can cause damage to the connectors and cables. Once again, it is important to asses the environment in which the truck is required to operate when installing an on-board weighing system.

Routine maintenance of the on-board weighing systems was found to be absolutely necessary to achieve acceptable reliability and accuracy in the study conducted by Philips (1989). Routine maintenance involved checking and cleaning the connectors connecting the various components, providing protection to shield any wear points on cables, and lubricating the load-cell connectors periodically. The centre span of a load cell has a clear section which allows the load cell to bend when under load and the centre span should to be kept free from mud that could affect the bending of the load cell. Lastly, recalibration of the on-board weighing systems was required periodically. Recalibration is done when there is found to be a discrepancy between the load weights recorded by the on-board weighing system and the load weights recorded by the mill weighbridge (to which the system is initially calibrated). A fleet manager needs to compare the two load weight recording to asses when a system requires recalibration. Recalibration is typically carried out by technicians that install the systems (Thompson, 2006). A system is calibrated to the mill weighbridge to where the particular truck delivers its loads to.

Operator's skill and experience in using the system, and the operator's acceptance of the system, was seen to play important roles in the effectiveness of the on-board scales in the study conducted by Philipps (1989).The standard error in payloads for experienced drivers ranged between one and two percent whereas for inexperienced drivers the standard error ranged between two and four and a half percent, as illustrated in Figure 2.14. Kopp (2007) using on-board weighing systems in the South African timber industry stated that the difference in payload accuracy achieved by drivers that had been using on-board weighing systems for sometime was substantially greater than that of drivers with little or no experience with the systems. Philips (1989) also found that there was reluctance to accept some of the on-board weighing systems tested in the study as the drivers felt that they were not accurate enough.

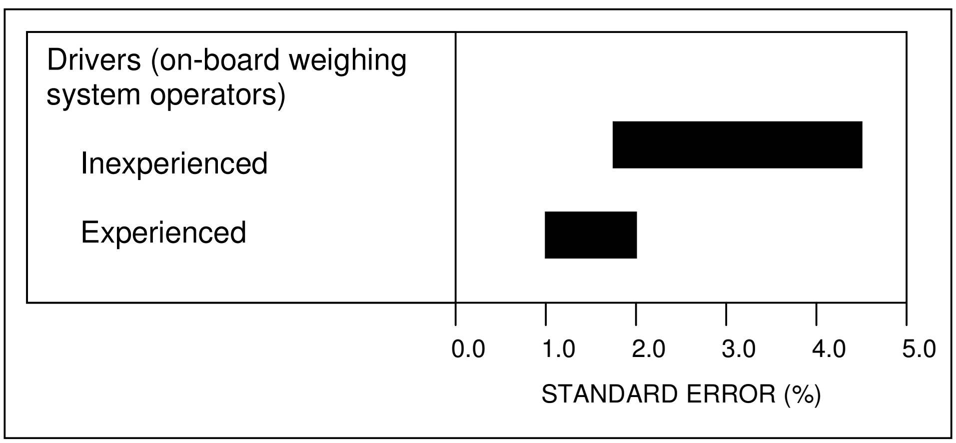

Figure 2.14 Accurate of inexperienced and experienced drivers (Philips, 1989)

The environment in which a truck is loaded is also seen to have an effect on the accuracy of an on-board weighing system. Cole *et al.* (2005) evaluated the difference in consistency of mass of loads delivered from two different loading farms by the same vehicles operating with on-board weighing systems. He established that, as a percentage of the total loads delivered, one zone achieved ten percent more loads at the target gross vehicle mass. The results are illustrated in Figure 2.15. The loading zones at the farm with the higher percentage had flatter and less uneven zones than the zones at the other farm. It was concluded that the conditions at each loading zone had an effect on both the consistency of gross vehicle mass and the accuracy of the weighing system.

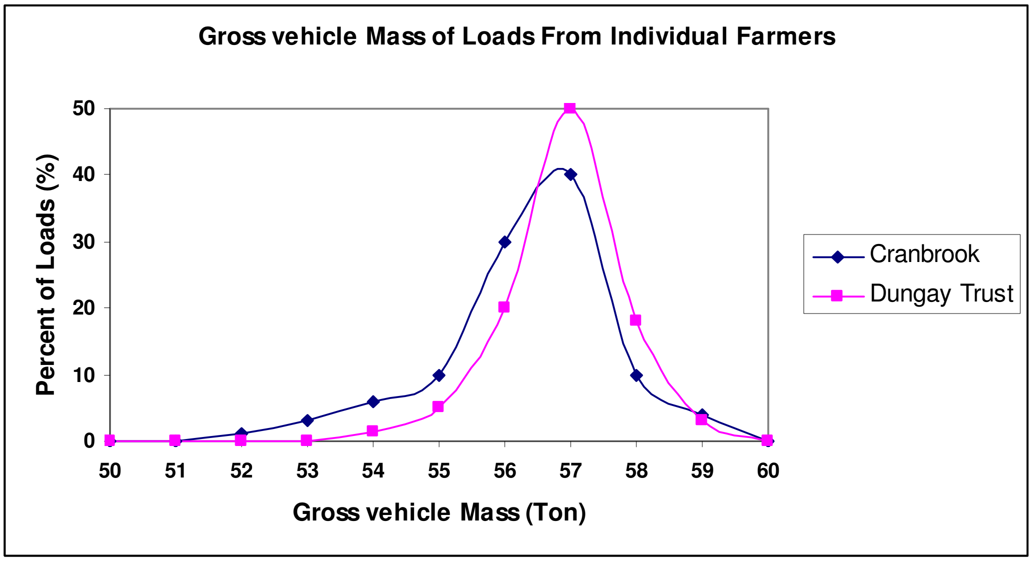

Figure 2.15 Gross vehicle mass of loads from two individual growers (Cole *et al*, 2005)

2.8 Discussion and Conclusion

An on-board weighing system is technology that is permanently installed into the structure of an articulated truck that enables the weight of the truck to be known by the truck operator as loading is taking place. On-board weighing systems consist of four primary components namely the load sensors, cables and connectors, CPU and the display unit. However, adaptations to the system can be made and additional components can be added on to meet the requirements of the user. On-board weighing systems for trucks with mechanic suspension make use of load cell technology while trucks with air suspension use pressure transducers connected into the suspension systems to determine the weight of the load.

The benefits that can be realised from the implementation of an on-board weighing system can be compartmentalised into vehicle, fleet managerial and road benefits. Vehicles benefit due to the optimisation of their utilization which results in an increase in the revenue generated by the vehicle. Less stress and strain is also placed on the vehicle, due to the prevention of overloading, which results in less breakdowns of the vehicle.

Fleet managers benefit due to the improvement of vehicle safety when an on-board weighing system is installed. The increase in vehicle safety tends to have a positive impact on drivers which can result in an increase in their productivity. Legal infringements which are incurred due to overloading of vehicles can also be prevented which is considered to be a major benefit to fleet managers and delivery times and weight disputes can be reduced due to the implementation of on board weighing systems.

The damage caused to road infrastructure due to overloaded trucks is considered to be a major problem worldwide with considerable attention being paid to the problem in South Africa. On-board weighing systems minimises the overloading of vehicles carrying raw bulk material which provides great benefits to the road industry.

Two perceived drawbacks to implementing an on-board weighing system are the initial capital investment required to purchase and install the system and the increase in managerial duties required to implement and manage the system. The revenue generated by the system, however, is able to pay off the system in a relatively short period of time depending on the particular transport scenario and configuration. The increase in managerial duties is far out-weighed by the benefits that fleet managers can realise from an on-board weighing system.

Factors that influence the effectiveness of on-board weighing systems are seen to be the selection of the system type and model, installation techniques, maintenance procedures and an operator’s acceptance of and experience in using the system. Lastly, the environment in which the truck is loaded has an impact on the consistency and accuracy of an on-board weighing system.

3. OVERVIEW OF SOUTH AFRICAN SUGARCANE ROAD TRANSPORT SYSTEMS

An overview of sugarcane road transportation systems will be presented in this chapter. Various different transport methods are described and different vehicle types are illustrated.

3.1 Introduction

Various different harvesting methods and equipment are used on farms, resulting in the harvesting of sugarcane and its delivery to the mill being a relatively complex process (Hansen *et al.*, 2002). Road transport is an integral component of this complex process. Figure 3.1 is a flow diagram depicting the different processes involved in the sugarcane harvesting and its delivery to the mill. It is important to note from the flow diagram that road transport is a major component of each system irrespective of the particular farm process.

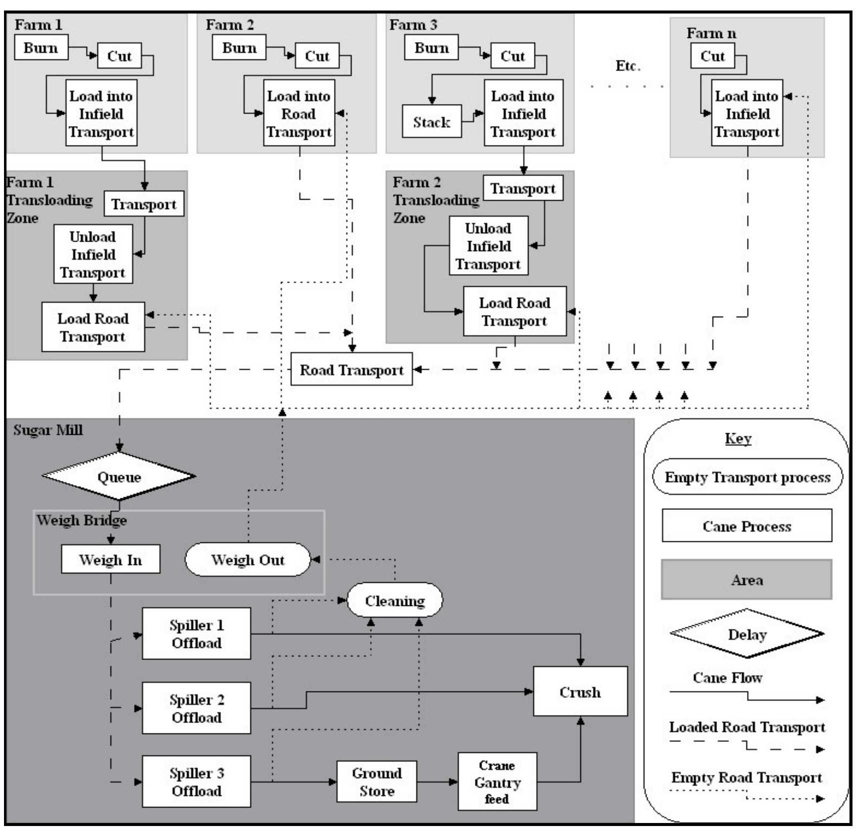

Figure 3.1 Flowchart of integrated system with different cane harvesting and delivery methods (Hansen *et al.*, 2002)

3.2 Road Transport

Road transport is defined as beginning at the grower's farm where the vehicle is loaded and terminates at the point where the vehicle is offloaded at the mill. A wide variety of road transport vehicles are used in the South African sugarcane industry with vehicles ranging from multipurpose agricultural tractors with trailers to specially designed, high technology cane haulage vehicles. The choice of vehicle is mainly a function of the lead distance to the mill, the number of tons of sugarcane required to be transported per season, the cost of the transport unit and the terrain and environment in which the vehicle is required to operate. Meyer (2005) categorised road transport systems used in the South African sugarcane industry into four broad categories, namely: rail, articulated trucks, rigid trucks and tractor rigs. Within each category a number of different vehicle types exist. Table 3.1 lists the various different vehicle types and shows the respective tonnages transported by each vehicle type for the 2005 season (numbers listed under for vehicle type relate to vehicle codes shown in Figure 3.2). The percentage of tons transported by each category in relation to the total tons transported throughout the season is shown in Table 3.2. Descriptions and illustrations of vehicle types are shown Table 3.3 and Figure 3.2.

Table 3.1 Road transport vehicle categories (Meyer, 2005)

Vehicle type	**Tonnage**
Rail	
10	433265
32	450550
36	284034
38	61308
Total	**1229157**
Rigid trucks	
50	137864
51	4073055
Total	4210919
Articulated trucks	
40	743203
41	1321413
42	8122329
Total	**10186945**
Tractor rigs	
60	984467
61	665765
62	1975378
Total	**3625610**

Table 3.2 Percentage of total tonnage Transported by each vehicle Category (Meyer, 2005)

Vehicle type	**Tonnage**	**%**
Wide gauge rail	433265	2.25
Narrow gauge rail	795892	4.13
Articulated trucks	10186945	52.91
Rigid trucks	4210919	21.87
Tractor rigs	3625610	18.83
Total	**19252631**	**100**

Table 3.3 Description of vehicle types (Meyer, 2005)

Vehicle Code	Vehicle Type	Vehicle Description
10	Spoornet	SAR rail truck
32	Blue golovan	Narrow gauge truck
36	Green golovan	Narrow gauge truck
40	Hilo	Truck tractor + tandem axle semi-trailer
41	Tri-axle	Truck tractor + tri-axle semi-trailer
42	Interlink	Truck tractor + Interlink trailers
43	Truck Land-Train	Truck tractor + Interlink + drawbar trailer
50	Lorry	Rigid truck - single or double axle
51	Rigid Drawbar	Rigid truck + drawbar trailer
60	Tractor rig	Tractor + one single axle trailer
61	Tractor hilo	Tractor + one double or tri-axle axle trailer
62	Tractor Interlink	Tractor + two tandem axle trailers
63	Tractor Land Train	Tractor + more than two trailers

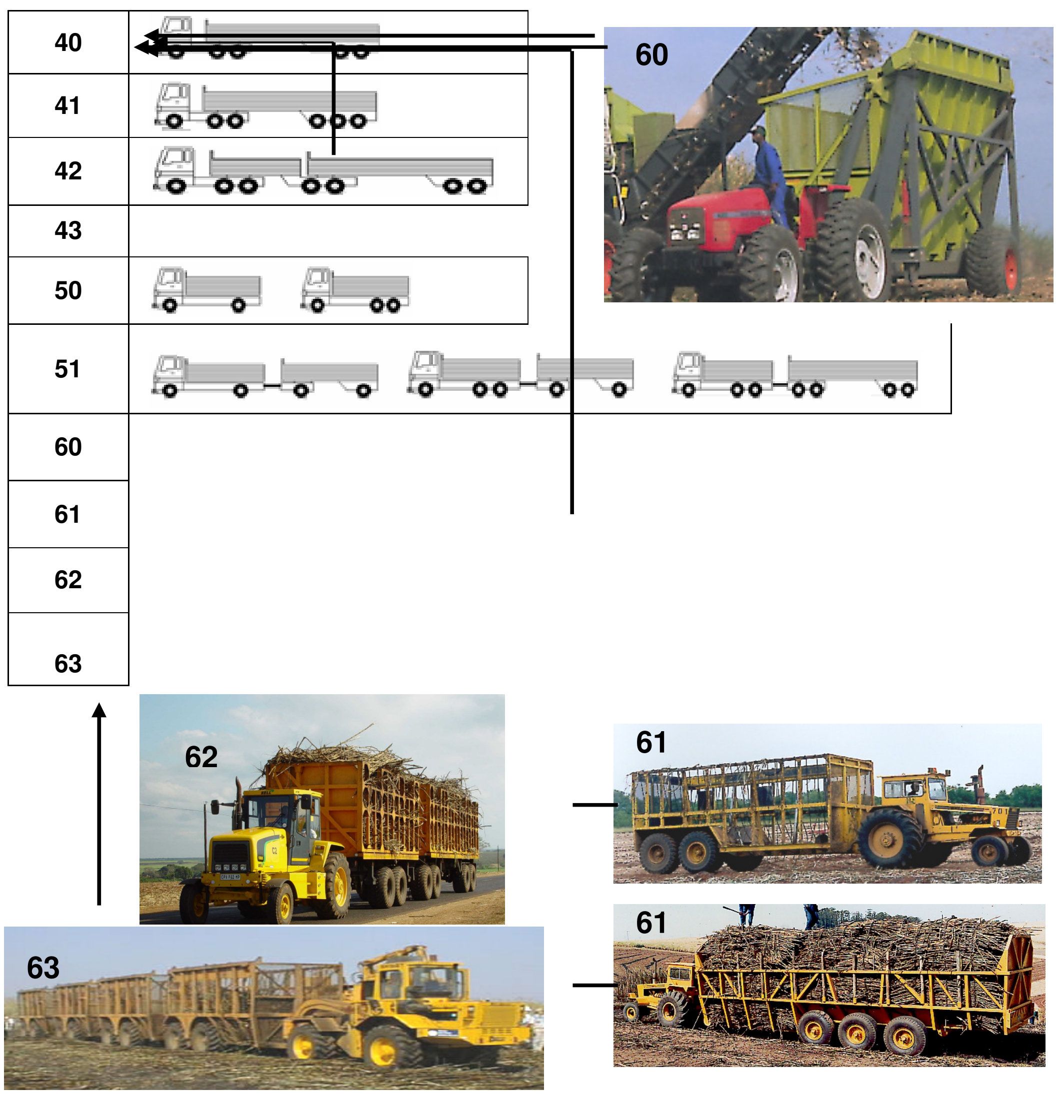

Figure 3.2 Illustration of vehicle types (Meyer, 2005)

3.3 On-board Weighing and Road Transport

It is notable from Table 3.2 that articulated trucks and rigid trucks constitute 75% of the total tonnage that is hauled per season. It is on these trucks that it is envisaged that on-board weighing is implemented in order to improve the utilisation of these vehicles and at the same time prevent overloading which is causing considerable damage to roads (Lyne, 2006).

3.3.1 Optimising payloads of articulated and rigid trucks

In the 2005 season 19 252 631 tons of sugarcane was produced in South Africa, of which 14 397 864 tons (75%) were transported by articulated and rigid trucks. The industry average payload of these trucks is 30 tons which relates into 479 929 loads per season. Cole *et al.* (2005) showed that with the use of onboard weighing an increase of average payload to 33 tons could be achieved. If all trucks within the industry were able to increase their payloads similarly, 436 299 loads would have been delivered which constitutes 43 629 less loads.

This could be considered to be an oversimplification due to the nature of sugarcane and the varying different harvesting and delivery methods as shown in Figure 3.1, however, a considerable saving could realistically be achieved. Sugarcane has a varying bulk density (depending on the varieties etc.) which can relate into volume problems as a truck can be fully loaded and yet have a low payload if the bulk density of the sugarcane is low. Another factor that influences the payload of the truck significantly is the method of loading. Articulated trucks are commonly loaded by using one of the following three methods:

- Loose cane loaded infield using a grab or push pile loader,
- Loose cane stockpiled on a transloading zone is loaded using a grab loader,
- Chain bundled cane stockpiled on transloading zones is loaded using a mobile crane.

3.3.2 Loading methods

It is estimated that at present 60 % of the total annual sugarcane crop in South Africa is mechanically loaded infield (Meyer and Fenwick, 2003). The sugarcane is cut and windrowed whereupon it is loaded directly into a road transport truck. Loading is effected by a variety of different equipment with the two most popular methods being self propelled three wheeled, non-slewing grab loaders and push pile grab loaders (*c.f.* Figure 3.3 and 3.4).

Figure 3.3 Loose cane in windrows being loaded infield by a grab loader

Figure 3.4 Push pile grab loader loading infield

Trucks loaded infield are underloaded if the infield topography is exceptionally steep and difficult to load on and, on the other hand, overloading occurs due to the sugarcane 'settling' as the vehicle moves through a bumpy field, enabling the truck to be loaded above what it would have been if it was parked in a stationary position. Consistent load masses are difficult to achieve with infield loading

The second method of loading involves loose cane that is stockpiled onto a transloading zone. A large portion of the South African industry crop is transported from the field to strategically located transloading zones on sugarcane farms. Loose cane is stockpiled on these zones whereupon trucks are loaded by a wide range of equipment. At present the most popular equipment used to load loose cane onto trucks is a grab loader (Meyer, 2005). The truck is parked in a stationary position next to the stockpile of cane, where the grab loader will load the truck from the stockpile (*c.f.* Figure 3.5). The topography of transloading zones can vary considerably; however, the majority of zones are reasonably flat and well maintained. This method of loading is conducive to loads being loaded optimally and consistent load masses can be achieved .

Figure 3.5 Loose cane loaded onto stationary vehicle on a transloading zone

As in the case of loose cane, chain bundled stacked cane is transported from the field to transloading zones where the stacks are stockpiled. The sizes of chained stacks vary between three and eight tons (Meyer and Fenwick, 2003). Stacks are loaded into trucks using mobile cranes (*c.f.* Figure 3.6).

Figure 3.6 Mobile crane used to load chained bundled stacks

A considerable problem exists in relation to on-board weighing systems and bundled cane. Bundles vary in size but the average size is 5.58 tons for green cane and 6.56 tons for burnt cane (Meyer and Fenwick, 2003). Unlike with loose cane where small amounts of cane can be added to reach the maximum payload limit, with bundled cane under the payload limit, the addition of another bundle will most times push the payload beyond the maximum limit. Consequently trucks are either underloaded or overloaded and a wide variation in payloads occurs.

3.3.3 Lead distance

Lead distance is defined as the distance a truck has to travel from the point where the truck is loaded to where it is offloaded at the mill. The average lead distance in South Africa for sugarcane haulage trucks is 23 kilometres (Giles *et al.*, 2005), however, lead distances vary quite considerably from 1 kilometre at farms immediately surrounding the mill to distances as great as 110 kilometres such as on the Kwa-Zulu Natal South Coast (Kotze, 2006).

3.4 Discussion and Conclusion

Road transportation of sugarcane from grower to mill is a critical component of the sugarcane industry. 75% of sugarcane road transport in South Africa is done using articulated and rigid trucks which consist mainly of rigid drawbar and interlink configurations. The remaining 25% is done using a combination of rail and tractor trailer rigs.

It is envisaged that on-board weighing systems can be implemented on these articulated and rigid trucks in order to improve their utilisation and consequently reduce significantly the number of loads that these trucks are required to deliver in a season.

Articulated and rigid trucks are loaded by one of three commonly used methods with each method having an effect on the consistency of the mass of the loads delivered. The three methods are loose cane loaded infield, loose cane loaded on transloading zones and chain bundled cane loaded on transloading zones. Trucks loaded with loose cane on transloading zones are able to achieve the most consistent mass loads, while mass loads of infield loaded trucks can vary considerably depending on the topography of the field. Mass loads of bundled loaded trucks are difficult to optimise due to the constraint of bundle sizes.

4. EVALUATION OF ON-BOARD WEIGHING SYSTEMS IN SOUTH AFRICA

In the previous two chapters an understanding of how on-board weighing systems function was reviewed, the benefits and drawbacks of on-board weighing were discussed and an overview of the South Africa transport methods, as well as where on-board weighing fits into sugarcane transport in South Africa, was presented. This chapter evaluates on-board weighing systems that are currently being utilised in the sugarcane transport industry.

4.1 Introduction

On-board weighing is a technology that is widely used in timber transport in South Africa, while its use in sugarcane transport is limited. In this chapter three sugarcane transport operations using on-board weighing systems are assesed in an attempt to evaluate the effectiveness of these systems. Initially, the characteristics of each transport operation are presented, followed by an analysis of the data collected for each operation, followed by conclusions regarding the systems. The research approach followed in evaluating the on-board weighing systems is discussed below.

4.2 Research Approach

The proposed approach involved evaluating the use of on-board weighing systems currently operating in the South African sugarcane transport industry in the following manner. Data related to the payloads of trucks with on-board weighing would be collected from case studies during the study period and used to evaluate the on-board weighing systems. It was important that the field evaluations covered different loading scenarios within the sugarcane industry and that the trucks with on-board weighing systems could be evaluated against trucks without the on-board weighing systems, operating in the same vehicle fleet and under the same transport conditions.

The effectiveness of the on-board weighing systems would be evaluated according to the following main two criteria:

- the accuracy of the on-board weighing system, and
- the capacity of the system to improve vehicle utilization.

The proposed methodology involved three field evaluations, namely Unitrans Agriculture and Kevard Transport at Sezela and TSB Sugar in Malelane. The three operations function under different harvesting, loading and managerial structures which would enable on-board weighing to be evaluated under different operating conditions. Unitrans Agriculture and TSB Sugar are large transport companies wich have some trucks within their fleets operating with on-board weighing systems whereas Kevard Transport is a small privately owned grower cum transporter operation.

Unitrans and Kevard Transport vehicles operating with on-board weighing systems are loaded with loose cane by grab loaders on transloading zones and will be termed as zone loaded field evaluation. TSB Sugar vehicles are loaded infield and will be referred to as in-field evaluation.

The following specific objects were proposed in order to meet the overall object outlined on page 2 of evaluating the accuracy and consistency of on-board weighing systems under different loading scenarios.

Objective One: To evaluate the accuracy and measurement consistency of on-board weighing systems for zone loaded cane and infield loaded cane and to compare the two loading systems.

Objective Two: To determine if vehicle utilization was significantly improved for vehicles with on-board weighing systems.

Objective Three: To determine if external factors within the transport operation have an influence on the effectiveness of on-board weighing systems.

Objective Four: To determine if overloading of trucks is significantly reduced when using on-board weighing systems.

Figure 4.1 shows the location of the three field evaluation sites, Unitrans Agriculture at Sezela and Kevard Transport are located on the south coast of KwaZulu-Natal and TSB Sugar at Malelane is situated in the top Northeastern corner of Mpumalanga.

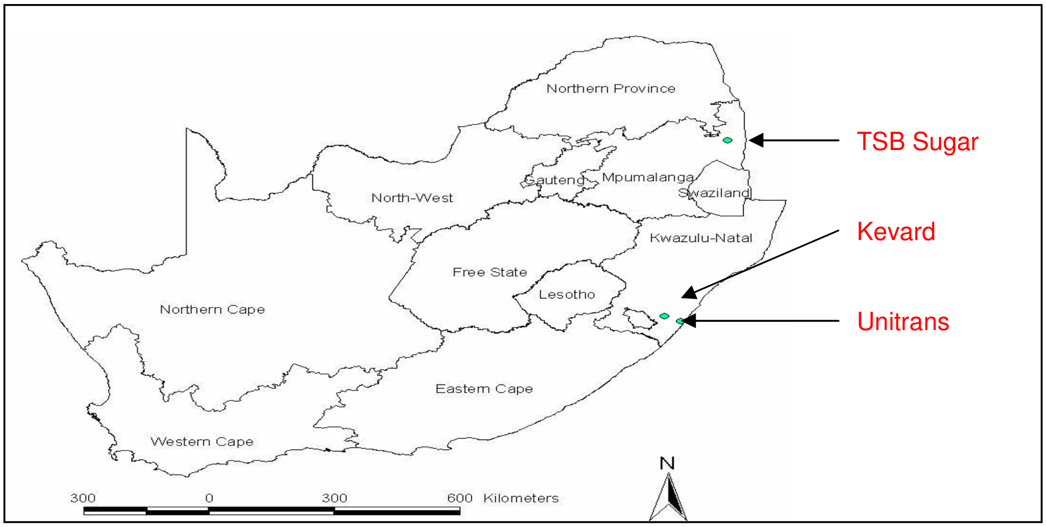

Figure 4.1 Location of field evaluation sites

4.3 Field Evaluation for Zone Loaded Cane

Unitrans and Kevard Transport operations both utilise articulated trucks that are loaded with loose cane by grab loaders on transloading zones. Firstly, the Unitrans operation is examined and then the Kevard Transport operation. The two operations are then compared at the end of this section.

4.3.1 Unitrans operation description and configuration

The Unitrans depot at Sezela (*cf.* Figure 4.1) is situated outside of the Sezela village and is approximately 2 km from the Sezela mill. Unitrans is the major haulier of cane into the Sezela mill, with its contribution being 57% of all sugarcane delivered to the mill in the 2007 season. Unitrans hauls sugarcane from various different private sugarcane farmers in and around the Sezela region. The operation consists of 26 trucks, with each truck hauling between 28 000 and 32 000 tons of sugarcane per season. The shortest lead distance required to be travelled by Unitrans trucks is approximately 20 km, with the longest lead distance being a considerable 110 km from the mill. The fleet is comprised of interlink and rigid drawbar trucks (*cf.* Figure 4.2 and 4.3) with all trucks having a maximum permissible GVM of 57 tons, the average tare mass of each vehicle is 23.7 tons which translates into a maximum payload of around 33.3 tons.

Figure 4.2 Unitrans Interlink

Figure 4.3 Unitrans Rigid Drawbar

Primarily due to the considerably long lead distances (up to 110km) LOADTECH on-board weighing systems were installed onto six vehicles in the fleet at the end of the 2005 harvest season. The reason behind the implementation of these systems was that the profitability of these trucks could be significantly improved if their payloads could be increased, especially when long haul distances were required. The six trucks were also to serve as experimental study to evaluate the use of on-board weighing systems as this was the first instance that Unitrans had implemented such a system. Figures 4.4, 4.5 and 4.6 are pictures of the LOADTECH on-board weighing system on the Unitrans trucks.

Unitrans trucks with on-board weighing systems are loaded with loose cane by a Bell three wheeled non-slewing grab loader, on transloading zones located on a private grower's farm for whom Unitrans hauls sugarcane.

Figure 4.4 Load cells at trailer body and axle point

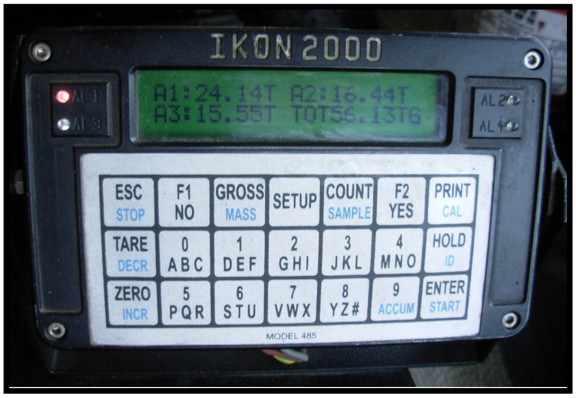

Figure 4.5 Interior display unit

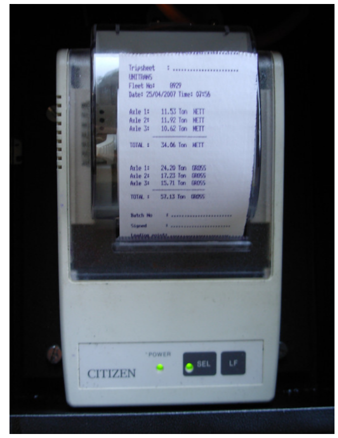

Figure 4.6 Printer unit

4.3.2 Data collection

At the Unitrans operation, data were collected at three points along the transport route. Data were recorded at the following points, as illustrated in Figure 4.6.

- Point1, GVM as shown by the on-board weighing system at the zone where the vehicle is loaded.
- Point 2, GVM as shown by the on-board weighing system at the mill yard, before the vehicle enters the mill to be offloaded.
- Point 3, GVM as recorded by the mill weighbridge

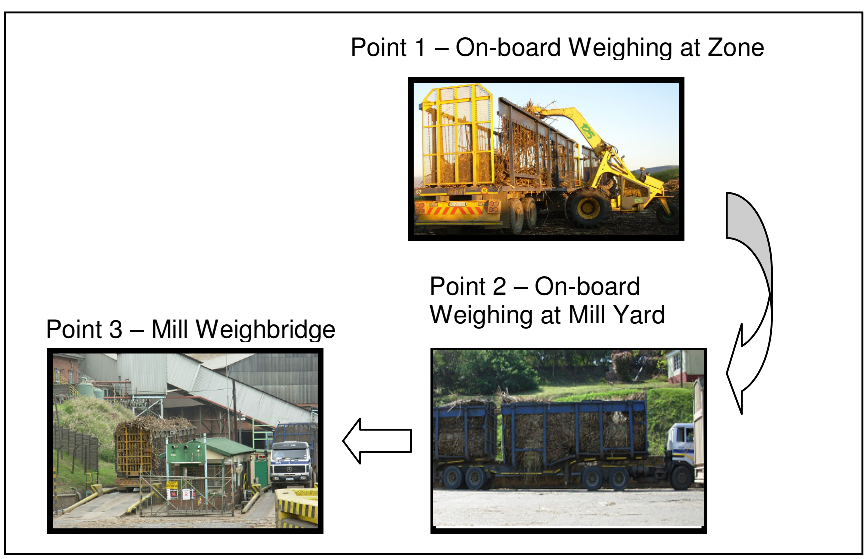

Figure 4.7 Points at which data was recorded

GVM's, as recorded from the on-board weighing system, were captured at the zone and at the mill yard in order to evaluate the consistency of the readings obtained from the on-board weighing system.

At the zone, while the three wheel loader is loading, the truck driver observes the weight reading displayed on the on-board weighing system. When the system indicates that the truck is loaded to its maximum permissible weight the truck driver will then indicate to the loader driver to stop loading. The truck driver then follows the following procedure:

- move the truck forward onto level ground if current position is not level,
- engage No.1 gear and switch off engine,
- release handbrake,
- print tripsheet.

Once the truck arrives at the mill yard (where the surface is level and flat) another tripsheet is printed. The two tripsheets and the weight from the mill weighbridge were then recorded for every load and captured into an Excel spreadsheet at the end of each day. The tare mass of the truck was subtracted from GVM to obtain the payload of each load delivered; Table 4.1 is an illustration of the captured data.

Table 4.1 On-board weighing data captured at Sezela depot

ON BOARD WEIGHING SYSTEM VERSUS MILL WEIGHTS						
2007 SEASON			TONS			
GROWER	DATE	FLEET NO	ZONE	MILL	WEIGHBRIDGE	ERROR
WOODBURN ESTATES	12.04.2007	8928	34.81	34.80	34.62	-0.19
PAUL SHEWAN/F TRUST	12.04.2007	8929	32.36	33.16	32.62	0.26
WOODBURN ESTATES	12.04.2007	8936	34.62	35.28	35.32	0.70
PONDEROSA	13.04.2007	8917	31.65	30.93	31.74	0.09
PAUL SHEWAN/F TRUST	13.04.2007	8928	33.77	34.56	34.04	0.27
PONDEROSA	13.04.2007	8928	35.67	35.64	35.54	-0.13
WOODBURN ESTATES	13.04.2007	8929	35.81	35.00	35.16	-0.65

The GVM (measured by the mill weighbridge) of all loads delivered by the Unitrans trucks without on-board weighing systems was also obtained for the duration of the study period. Table 4.2 is an illustration of this data.

Table 4.2 Data captured for all loads delivered by Unitrans at Sezela

Vehicle	Date & time	Grower	Cane Variety	Gross	Tare	Nett
S8735	2007/04/12 11:56	PAUL SHEWAN FAMILY TRUST	16	51.98	25.02	26.96
S8922	2007/04/12 12:06	WOODBURN EST. C.C.	1	58.30	24.40	33.90
S8929	2007/04/12 12:51	NHLANGWINI COMMUNITY INVESTMENT	16	55.58	22.96	32.62
S8914	2007/04/12 13:15	KNIGHT G J	1	56.64	25.14	31.50
S8187	2007/04/12 13:25	BOTHA RONALD FRANCOIS CLARKE	16	59.10	25.12	33.98
S8928	2007/04/12 13:33	NHLANGWINI COMMUNITY INVESTMENT	35	57.62	23.00	34.62
S8186	2007/04/12 14:04	LISTER H	47	49.74	24.62	25.12
S8921	2007/04/12 14:36	WOODBURN EST. C.C.	16	53.38	24.76	28.62
S2237	2007/04/12 14:50	PONDEROSA TRADING TRUST	16	55.38	24.28	31.10

4.3.3 Data analysis

The data was analyzed to assess: (i) the accuracy of the on-board weighing system compared to the mill weighbridge. (ii) The consistency of the on-board weighing system, (iii) factors affecting the GVMs of vehicles with on-board weighing systems, and (iv) the average GVMs of the trucks with on-board weighing compared to those without. The analysis of data and results follow.

4.3.3.1 Accuracy of the on-board weighing system

In all instances, the mill weighbridge is considered to be the control measurement as this is the weight on which payment for payload is made. The “best fit” simple linear regression was calculated for mill weighbridge weight (x) versus on-board scale weight (y) (*cf.* Figure 4.8). The standard deviation of this data set of differences (errors of the on-board scale from its regression value (denoted by line E(y) on Figure 4.8) is used as the measure of precision and defined as the “standard error of the estimate”. The percent standard error is the standard deviation of the data set of differences as a percentage of the mill weighbridge weight. On-board weighing scales are calibrated against the mill weighbridge on a regular basis.

From the graph it was assertained that the coefficient of determination, $R^2 = 0.9039$, and slope = 0.9569.

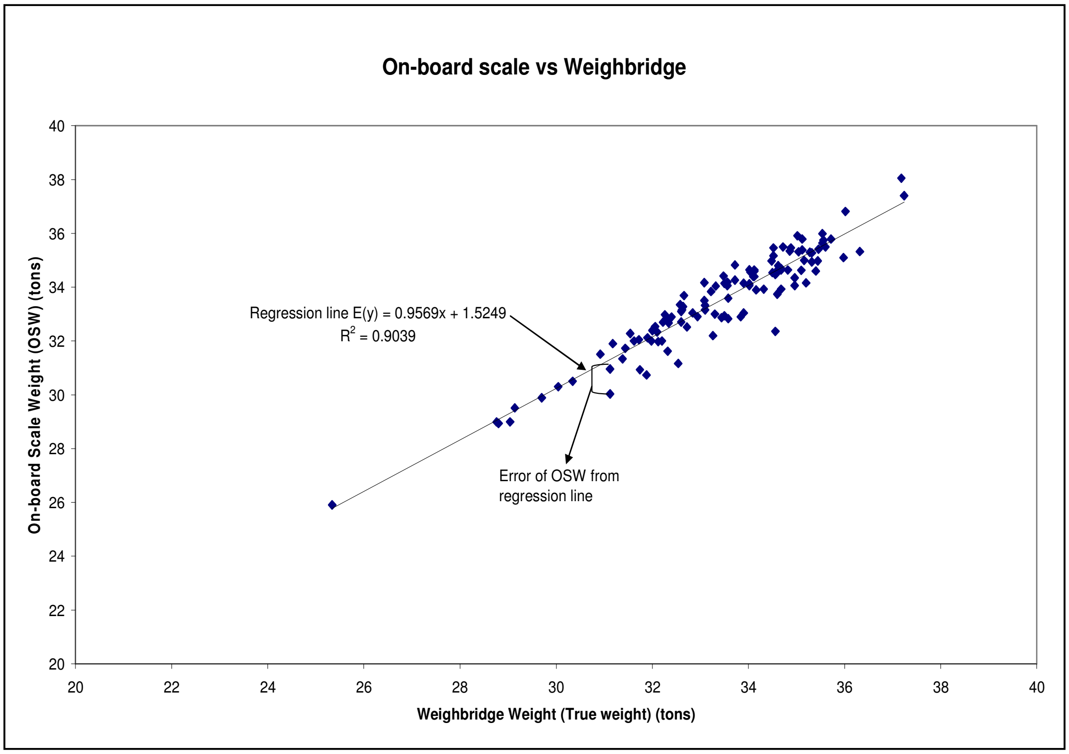

Figure 4.8 "Best Fit" simple linear regression

Mean Error (ME) and Root Mean Squared Error (RMSE) were calculated:

The Mean error is a indication of bias,

$$ME = \frac{1}{n}\sum_{i=1}^{n}(O_i - W_i) \quad \text{(t)} \qquad (4.1)$$

Where O_i and W_i represent the On-board weighing and mill Weighbridge weight series, respectively and S_o and S_w represent the standard deviations of the series O_i and W_i.

$O_{avg} = 33.507$ $S_o = 1.88174$

$W_{avg} = 33.421$ $S_w = 1.86951$

ME = 0.400678 tons

Error is positively biased which means that the on-board weighing systems tend to overweigh by 0.4 tons.

Root mean squared error gives the distance, on average, of a data point from the fitted line.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(O_i - W_i)^2 \tag{4.2}$$

$$RMSE = \sqrt{MSE}$$

$$= 0.595 \text{ tons}$$

Relative root mean squared error (RRMSE) gives the RMSE in terms of a percentage,

$$RRMSE = \frac{RMSE}{W_{avg}} \tag{4.3}$$
$$= 1.8\ \%$$

Therefore, the error that can be expected from an on-board weighing system is 1.8 %.

Disaggregation of the Error,

Theil's (1961) decomposition of mean squared error (MSE), elaborated by Mincer and Zarnowitz (1969), serves as a diagnostic check of the degree and sources of error.

As above,

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(O_i - W_i)^2$$

This can be expanded to,

$$MSE = (\overline{O} - \overline{W})^2 + (S_O - rS_W)^2 + (1 - r^2)S_W^2 \tag{4.4}$$

Where $\overline{O}$, $\overline{P}$, S_o, and S_W are the means and the standard deviations of the series O_i and W_i, and R^2 is their correlation coefficient.

Dividing both sides of the equation by MSE gives,

$$1 = \frac{(\overline{O} - \overline{W})^2}{MSE} + \frac{(S_O - rS_W)^2}{MSE} + \frac{(1 - r^2)S_W^2}{MSE}$$

$$= MC + SC + RC$$

Where MC = the mean component, or bias due to differences in the means of the on-board weighing and mill weighbridge data; SC = the slope component, or the error resulting from the slope deviating from unity; and RC = the residual component, or the proportion of MSE due to random error.

Perfect readings between the on-board weighing and weighbridge readings are highly unlikely to be obtained. The desired distribution therefore of the MSE over the sources is MC = 0, SC = O, RC = 1, indicating that the errors are not systematic but completely random. The following results were obtained:

MC = 0.020883

SC = 0.030731

RC = 0.948385

The majority of the error, 95 %, occurred due to the RC component which was desirable. Ninety – five percent of the error between the on-board weighing data and the mill weighbridge data can be attributed to random errors that occurred rather than systematic error between the two systems.

4.3.3.2 Consistency of the on-board weighing system

On-board weight readings were recorded at the zone, where the truck was loaded, and then again at the mill yard before crossing the mill weighbridge. This was done in order to assess whether there was any variation in the on-board weighing system during the trip from the zone to the mill. Theoretically, the mass of the load could decrease slightly from the zone to the mill (due to cane possibly falling off the top of the truck) but an increase in weight at the mill yard from the zone would be considered suspect unless it rained during the trip. The weights recorded at the zone were compared to those recorded at the mill yard to evaluate the consistency of the onboard weighing systems. Delta (Δ) is defined as:

$$\Delta = Zone\ weight - mill\ \ yard\ weight \tag{4.5}$$

The probability distribution of delta was plotted in order to evaluate if the distribution of the data contained any skewness. From the graph (see Figure 4.9) it can be seen that the right tail of the graph is longer and thus the distribution is positively skewed which means that the mass of the distribution is concentrated on the left of the figure. This fact supports the assumption that Delta values should be negative as in theory it is highly unlikely that the weight of the load will increase from the zone to the mill. However, there are a number of positive values and some concerning outliers with the largest of them being 1.99 tons. Upon investigating this particular value further it was found that the error between the on-board zone weight and the mill weighbridge weight was only 0.21 tons. The possible reason as to the much larger error between the on-board weighing zone weight and the on-board weighing mill yard weight could be attributed to the truck driver not having released his hand brake when recording the mill yard weight or some other related factor. Upon investigation as to why Delta values are not all zero, the manufactures of the on-board weighing system believe that some load redistribution occurs between the times that the truck leaves the zone and when it arrives at the mill weighbridge and this redistribution of the load accounts for the non-zero delta values. However, seventy five percent of the Delta values in the test sample were between -0.5tons and 0.5tons which is felt to be acceptable.

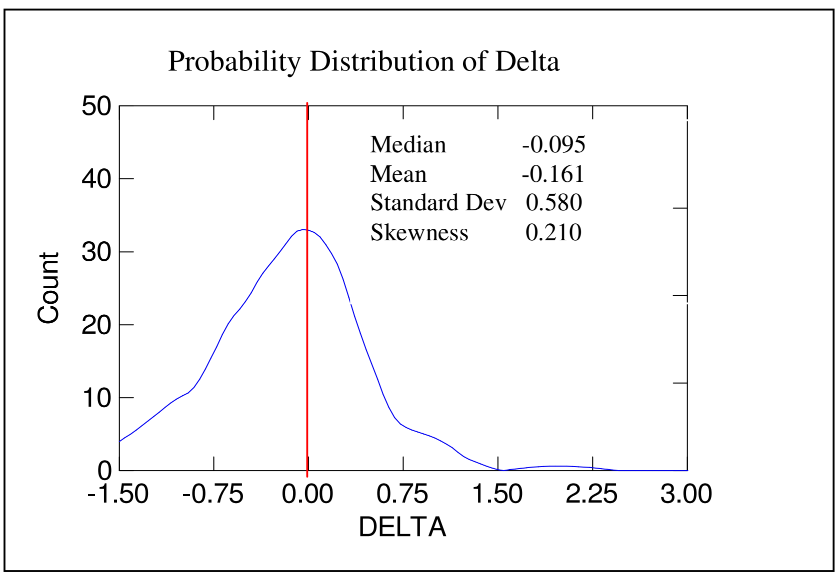

Figure 4.9 Probability distribution function of Delta

4.3.3.3 Factors affecting GVM of vehicles with on-board weighing systems

During the period in which data was recorded, the six trucks with on-board weighing systems hauled cane from 17 different zones that were all located in the Highflats region of Sezela. The data was analysed to assess whether there was a significant variation in GVM for loads delivered from the 17 zones and thereafter, if there was a significant difference, to establish what factors had impacted on causing this variation. The zones have been labelled A through to Q.

a) Test for significant variation between zones

Data for each zone is summarised in Table 4.3 where zones are arranged in descending order of GVM. Figure 4.10 is a graphical representation of the average GVM for all the loads that were delivered from each zone, the whiskers on each bar in the graph represents the standard deviation of GVM for each zone.

Table 4.3 Summary of data of GVM for each transloading zone

Zone	No. Loads	Average GVM (t)	Max (t)	Min (t)	Stdev (t)
M	28	58.42	61.54	56.46	1.36
O	80	57.75	65.28	53.6	1.56
H	134	57.16	59.9	49.58	1.55
B	174	57.15	61.76	49.68	1.61
I	64	57.07	60.38	54.28	1.36
E	74	56.72	60.16	52.28	1.59
N	100	56.61	64.16	46.18	2.59
D	82	56.46	61.38	48.22	2.66
F	148	56.45	61.52	34.56	1.74
G	126	56.30	60.26	46.62	2.02
L	61	56.10	61.06	46.42	2.67
A	31	55.83	60.04	51.62	2.02
J	75	55.70	59.46	48.78	2.17
P	39	55.12	59.58	47.84	2.37
K	83	53.72	60.56	46.60	2.59
C	162	53.29	58.46	47.48	2.21
Q	22	52.20	58.3	47.72	3.45

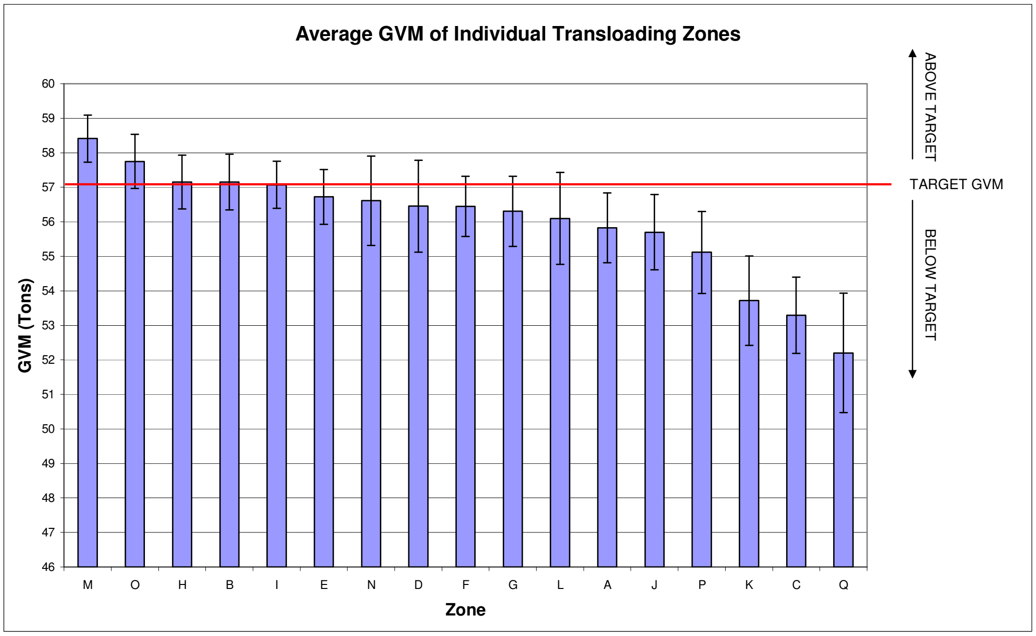

Figure 4.10 Average GVM of individual transloading zones

Visually, one can see that across the zones, there is a significant decrease in average GVM and a considerable variation in the standard deviation of each zone. All the zones were located in the same region and being serviced by the same trucks, therefore it was expected that the average GVMs of the zones would be similar to each other. Having also established that the standard error of the onboard weighing systems was 0.4 tons (see Section 4.3.3.1) it was no expected that the standard deviations of zones would vary as much as they did. Further investigation was done to establish if any of the following factors had an impact on the average payload: Fleet number (driver of the vehicle), sugarcane variety, the time of day in which the vehicle was loaded and the physical condition of each zone.

b) Test for significance of fleet number (driver of the vehicle)

The average GVM for the six individual trucks was established. The average GVM's of the vehicles did not differ by more than one ton from each other and the largest difference in standard deviation between two trucks was 0.6 tons. Table 4.4 contains a summary of the data related to each vehicle and Figure 4.11 graphically illustrates the average GVM of each vehicle for loads delivered during the study period.

Table 4.4 Summary of data of GVM for each individual vehicle

Vehicle Number	Total Tons	No. Loads	Average GVM (t)	Max (t)	Min (t)	Stdev (t)
8915	7302.25	227	55.86	62.81	45.70	2.71
8917	6427.34	200	56.16	63.20	47.20	2.43
8918	6618.64	206	55.27	62.19	48.12	2.22
8928	6675.15	207	56.58	60.70	46.29	2.71
8929	6198.97	193	55.98	60.10	46.88	2.23
8936	7207.3	224	55.59	60.30	40.70	2.82

The average standard deviation for the six trucks was 2.5 tons. This was considered to be high, considering that the standard error of the on-board weighing system was established as being only 0.4 tons. The high standard deviation, however, supports the large variation in average GVM for each individual zone.

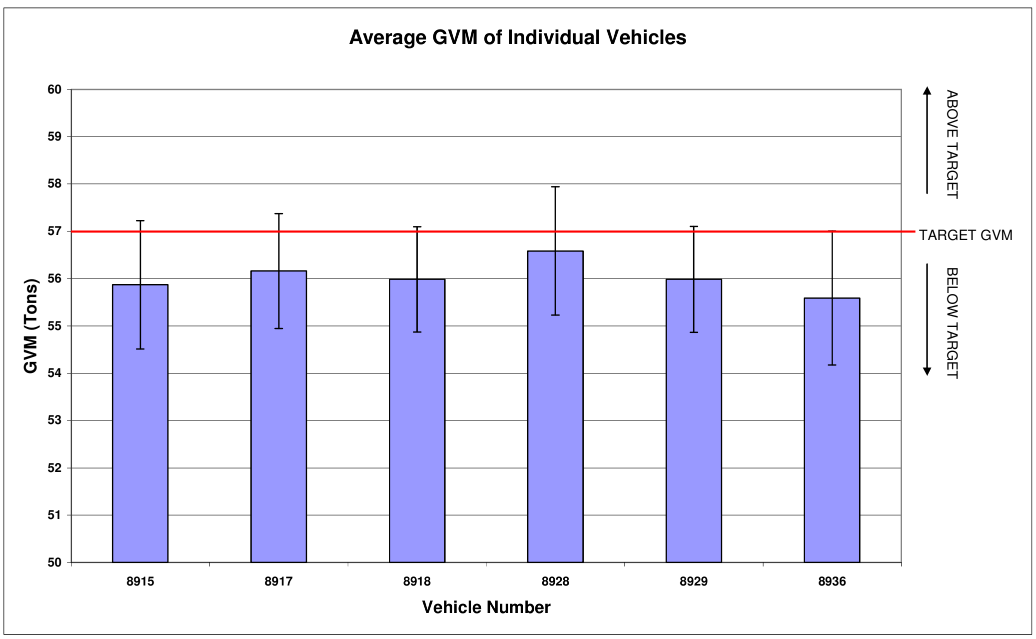

Figure 4.11 Graph of average payload for each vehicle

It was concluded that the vehicles (or drivers of the vehicle), did not cause the large variation in GVM for the individual zones as the average GVM of the vehicles did not differ greatly, however the average GVM for all six vehicles was below the target GVM of 57 tons.

c) Affect of cane variety on average GVM

The variety of sugarcane for each load was established and analysed to determine whether different varieties significantly affected the GVM of the vehicles with on-board weighing systems and consequently, if cane variety contributed to the large variation in average GVM for the individual zones. Different cane varieties have different bulk densities and consequently a truck could be filled to its capacity and yet still be below the desired target GVM. Table 4.5 contains a summary of the data for the different cane varieties. The majority of the loads that were delivered during the study period were N12 variety followed by N16 and then mixed variety loads. The average GVM of these varieties was 55.85, 56.61 and 56.49 tons respectively. The variety N31 however, had the lowest average GVM of 53.72 tons, although this variety constituted a relatively small number of loads (47 loads). The majority of these loads originated from Zone J which was shown to have a relatively low average GVM of 54. For this particular zone it was concluded that the cane variety contributed significantly to the low average GVM achieved by this zone, however for the rest of the varieties, they did not significantly affect the average GVMs of the individual zones. It is recommended that further investigation as to the effect of cane varieties be carried out in future research.

Table 4.5 Summary of data for average GVM for different cane varieties

Variety	**No loads**	**Average GVM (Tons)**
N12	779	55.85
N16	434	56.61
N29	8	56.74
N31	47	53.72
N35	4	56.08
N37	38	54.79
Mixed	107	56.49

d) Effect of delivery time on average payload

It was hypothesised that the time at which a truck was loaded would affect the GVM of the vehicle. If a vehicle was loaded late at night and drivers were tired they could possibly not pay the required attention to achieving the target GVM as they possibly would during the day or in the morning when they were still relatively fresh starting their shifts and.

The time at which each load was delivered to the mill was recorded. Delivery times were classified into four categories namely morning, mid-day, afternoon, and night time. Mornings were from 9am – 10am, mid-day 10am – 2pm, afternoon 2pm – 6pm, and night was from 7pm – 6am. Table 4.6 contains a summary of the average GVM for each time category and it was seen that the average GVM for the four time categories did not differ by more than one ton. Consequently, it was concluded that the time did not have a effect on average payload.

Table 4.6 Summary of data of average GVM for different delivery times

Delivery Time	**Loads**	**Average GVM (Tons)**
Morning	16	56.24
Mid day	403	55.75
Afternoon	302	55.25
Night	697	56.56

e) Physical condition of individual transloading zones

Further investigation was done to establish the physical condition of each loading zone in order to determine if the condition of the zone significantly impacted the average GVM of each zone. Each zone was investigated and rated good, average or poor. A zone was rated as good if it was flat and well maintained (no large potholes or excessively big bumps), average if the zone had a slight slope and was reasonably well maintained and poor if the zone sloped excessively and was in poor condition. Table 4.7 is a summary of the condition of each of the transloading zones. From Table 4.7 it can be seen that only zones A and C were rated as being bad, the corresponding average GVM of these two zones was 58.3 and 56.56 tons respectively. Zone A had the highest average GVM of all the zones evaluated and therefore, it was concluded that the zone condition did not affect the GVM of the vehicles.

Table 4.7 Physical condition of each transloading zone

ZONE	ZONE CONDITION GOOD	AVERAGE	POOR
A			X
I	X		
T	X		
E		X	
Q		X	
G		X	
O	X		
M		X	
C			X
L	X		
B	X		
F	X		
P			
S		X	
N		X	
K		X	
D			
J			
U		X	
H		X	
R		X	

4.3.3.4 Average GVM of vehicles with on-board weighing versus those vehicles without on-board weighing

One of the major objectives in evaluating the effectiveness of the on-board weighing systems was to establish if the utilisation of on-board weighing systems significantly increases the utilization of the vehicles. By comparing the average GVM of vehicles with the systems to those vehicles without the systems, this objective was assesed. The vehicles utilised in the comparative study hauled cane from the same zones and were therefore subjected to the same loading conditions.

Table 4.8 and 4.9 provide a summary of the average GVM for vehicles with on-board weighing and those without, respectively. It can be seen that the average GVM's of the vehicles were very similar and the on-board weighing systems did not increase the utilisation of the trucks in respect of increasing the average GVM of the vehicles.

Table 4.8 Average GVM of vehicles with on-board weighing

Vehicles with On-board weighing		
Fleet Number	**No. Loads**	**Average GVM (Tons)**
8915	227	55.86
8917	198	56.16
8918	205	55.27
8928	203	56.58
8929	192	55.98
8936	226	55.59

Table 4.9 Average GVM of vehicles without on-board weighing

Without On-board weighing		
Fleet Number	**No. Loads**	**Average GVM (Tons)**
8919	212	55.83
8914	207	56.01
8920	262	55.87
8921	192	56.27
8922	186	56.08
8923	276	56.27

From the results above it is evident that in this particular transport operation, it was possible to maintain the same average GVM with or without on-board weighing. However, in evaluating the two sets of GVM's further it was found that the variation in GVM for the vehicles with on-board weighing systems was much less than that for the vehicles without on-board weighing, this can be seen in Figure 4.13 and Figure 4.14. The distribution of GVM's for the two sets of trucks is shown in Figure 4.1. From Figure 4.12 it can be seen that the vehicles without on-board weighing systems have an even distribution of GVM's around the maximum point whereas the vehicles with on-board weighing systems had a sharper decrease in the number of vehicles that were in the overload range together with larger number of GVM's within the target GVM. Although the average GVM's of the two vehicles sets were similar, the large number of overloaded vehicles in the vehicle set with no on-board weighing compensated for the large number of underloaded loads thus enabling these vehicles to maintain a similar average as the vehicles with on-board weighing. From this analysis, it was concluded that the vehicle's utilisation is improved with the use of on-board weighing, as a considerably higher number of loads at the target GVM can be achieved.

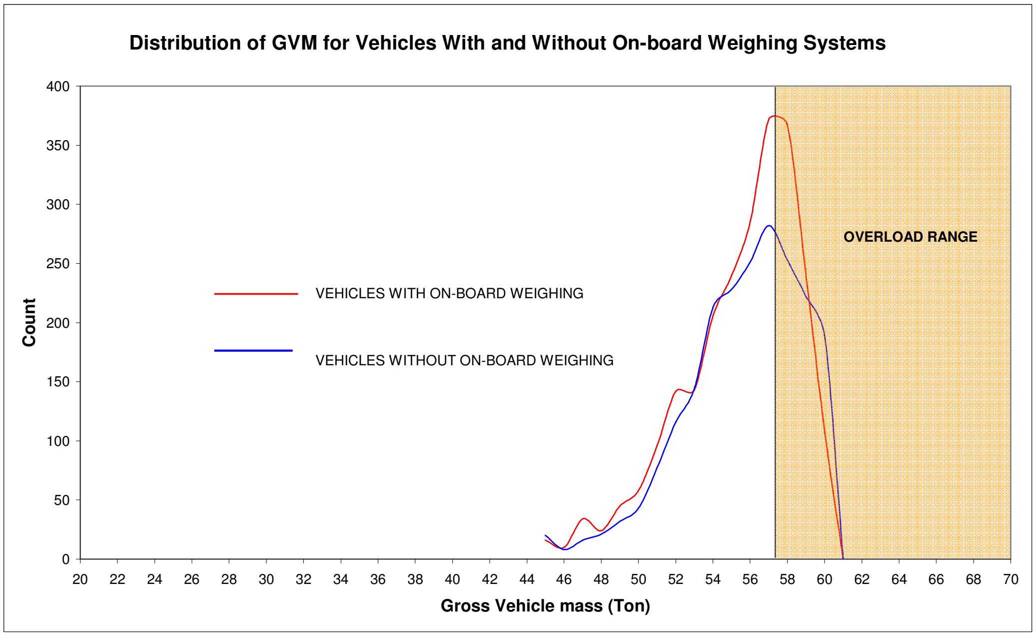

Figure 4.12 Distribution of GVM's for vehicles with and without on-board weighing systems

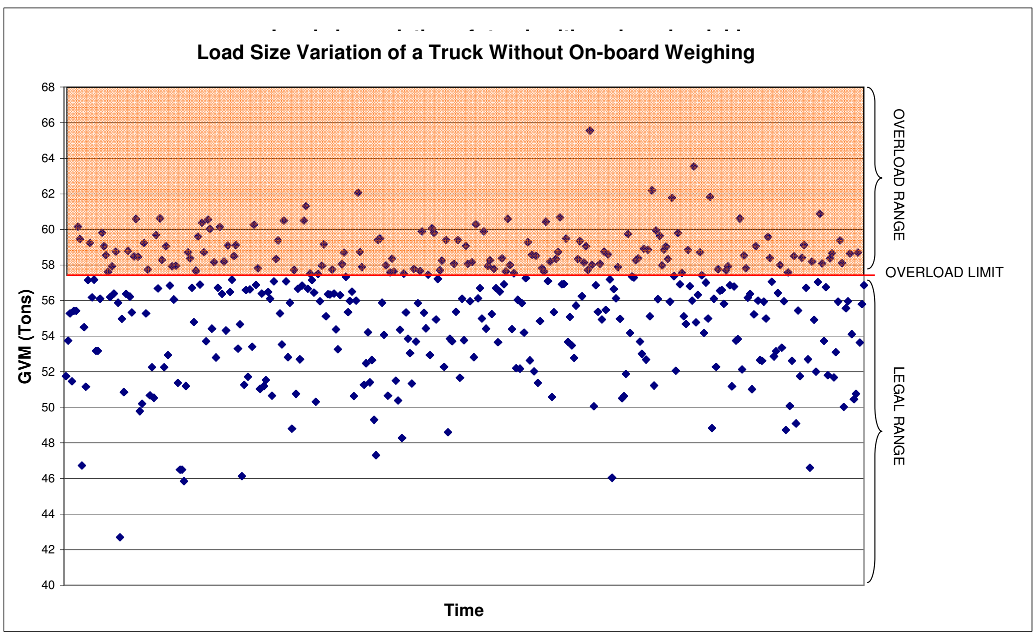

Figure 4.13 Variation of GVM for a vehicle with an on-board weighing system

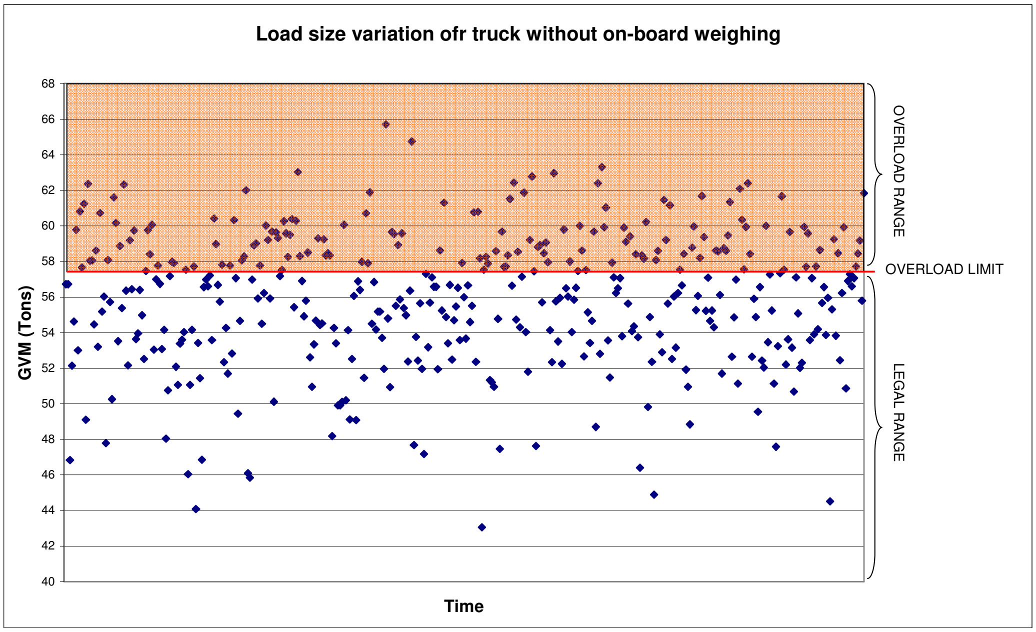

Figure 4.14 Graph of payload variation for vehicles without on-board weighing

4.3.3.5 Comparison of overloads

The legal gross vehicle weight for heavy duty trucks is 56 tons. The government allows a two percent leeway on this limit and therefore a truck is considered to be overloaded if its GVM exceeds 57.12 tons. 2460 loads from both vehicles with on board weighing and those without were evaluated, it was found that 790 of the 2460 (32%) and 1010 of 2460 (41%) loads exceeded the legal limit for vehicles with on-board weighing and those without respectively. These percentages are illustrated in Figure 4.15.

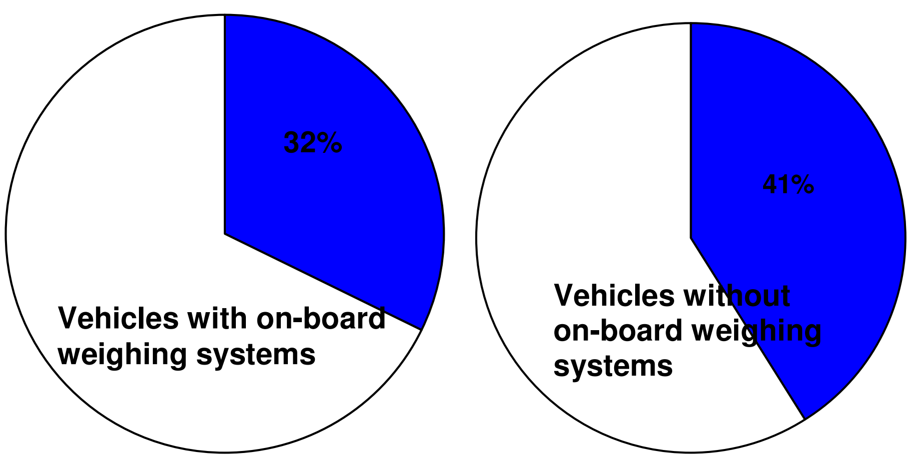

Figure 4.15 Number of overloads as a percentage of the total loads delivered

The overloading of trucks without on-board weighing occurred 9% more than with the trucks equipped with on-board weighing systems. The on-board weighing system was consequently seen to have an effect on reducing the overloading of trucks, however, the percentage of loads overloaded, 32% for vehicles with on-board weighing, is still seen to be a lot more than the desired level. This fact can be attributed to not enough management of the on-board weighing system.

The new Road Traffic Management System implemented within the sugar industry stipulates that only 4% of trucks total loads may be overloaded. Although the on-board weighing systems have contributed somewhat in assisting in reducing the number of overloads, a further considerable reduction in overloading is still required in order for this transport operation to meet the government regulations. With tighter management of the on-board weighing system it is envisaged that this can be achieved.

4.3.4 Kevard Sugar operation description and configuration

Kevard Sugar is a privately owned, grower cum transporter operation, situated on the south coast of Kwa-Zulu Natal (*c.f.* Figure 4.1). Kevard Sugar has two articulated trucks, both having a GVM of 56 tons. The vehicles are fitted with the same LOADTECH on-board weighing system as those utilised by Unitrans (*cf.* Figures 4.2, 4.3, and 4.4). The vehicles are loaded with loose cane on transloading zones by a Bell three wheeled loader. During the study period, Kevard Sugar hauled sugarcane from five different farms that are situated between 34 and 65 kilometres from Sezela mill.

Due to Kevard Sugar being a privately owned, relatively small operation (two trucks with on-board weighing), it was hypothesised that there would be tighter management and control of the on-board weighing systems than in a larger commercial haulage operation, which would result in there being less variation in the mass of the loads delivered. Therefore, the primary objective of this field evaluation was to determine the average GVM as well as the variation in GVM for all the loads delivered during the study period and to compare these two factors against the Unitrans operation, as well as assessing the extent to which the trucks were overloaded.

4.3.5 Data collection

The GVM's, as recorded by the mill weighbridge, for the two vehicles, (NX14214 and NX7789), for all loads delivered during the study period were collected. A summary of the data that was collected is shown in Table 4.10.

Table 4.10 Summary of load data collected for individual vehicles

	Vehicle	
	NX14214	NX7789
Number of loads	752	685
Average GVM (t)	55.32	55.93
Max GVM (t)	60.08	59.54
Min GVM (t)	49	51.64
Standard Deviation (t)	1.43	0.92
Total Tons Carried	23693	21806

4.3.6 Data Analysis

The data collected was analyzed to assess the following criteria pertaining to the Kevard Sugar operation:

- The average GVM of the two vehicles over the period in which the data was collected
- The variation in GVM for all the loads delivered by Kevard Sugar during this period
- Percentage of loads overloaded

4.3.6.1 Average payloads and payload variation

The legal gross vehicle mass for the two vehicles operated by Kevard Sugar is 56 tons. The target payload therefore, when loading the vehicles was 56 tons. From Table 4.9 above, it can be seen that the average GVM was 55.32 and 55.93 tons for vehicle NX14214 and NX7789 respectively. Vehicle NX14214 delivered 752 loads during the study period and had a standard deviation in GVM of 1.43 tons whereas vehicle NX7789 delivered 685 loads and had a standard deviation of 0.92 tons. All loads delivered by the two vehicles were plotted on graphs to assess the variation in GVM for the two vehicles. Figure 4.16 shows the variation in GVM for vehicle NX14214 and Figure 4.17 is for vehicle NX7789.

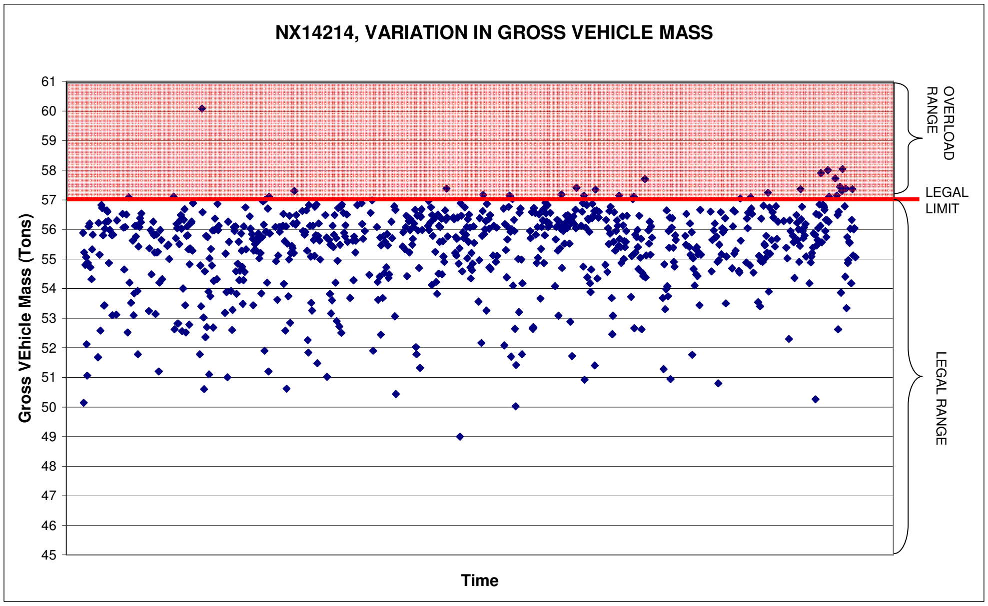

Figure 4.16 Variation in GVM

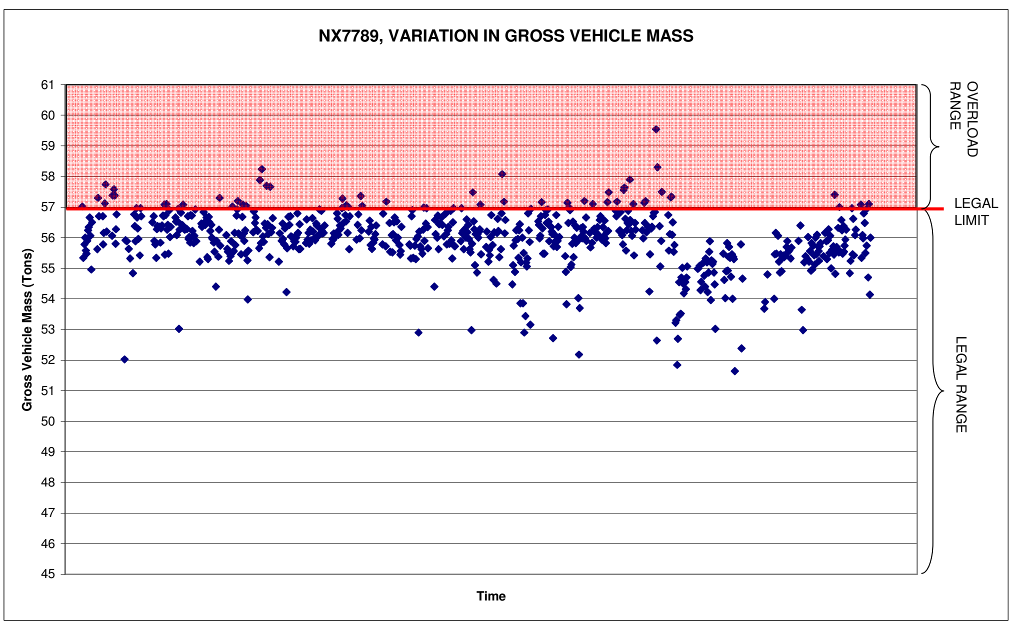

Figure 4.17 Variation in GVM

From the graphs above it is evident that the majority of vehicle weights were between 55 and 57 tons with vehicle NX7789 having a smaller variation in GVM's to vehicle

NX14214. This supports the difference in standard deviation between the two vehicles. In investigating why there was a difference between the vehicles, as both vehicles hauled cane from the same zones, it was suggested that the driver of vehicle NX7789 had a greater level of experience in using the on-board weighing system compared with the driver of vehicle NX14214 and this greater level of experience had a significant bearing on the effectiveness of the weighing system.

4.3.6.2 Percentage of loads overloaded

As above-mentioned, a vehicle was considered to be overloaded if the GVM exceeded 57.12 tons. For vehicle NX14214 2.9 % of the loads delivered were overloaded and 5 % of loads delivered by NX7789 were overloaded. Table 4.11 below summarises the percentage of loads that were overloaded in proportion to the total loads delivered during the study.

Table 4.11 Percentage of total loads overloaded

Vehicle	**NX41214**	**NX7789**
Total number loads delivered	752	685
No of loads exceeding 57.12 tons	22	34
Percentage of total loads overloaded (%)	2.93	4.96

4.3.7 Comparison between the commercial haulier and grower cum transporter

The average GVM of vehicles in the Commercial Unitrans operation and the private grower cum transporter Kevard Sugar operation were similar with average GVM's of 55.9 and 55.6 tons respectively. However, the standard deviation and variation in GVM for the grower cum transporter operation was much less than that of the commercial haulier. Trucks in the private operation were also only overloaded on average 4% of their total loads, whereas trucks in the commercial operation were overloaded 32% percent of the time. Therefore, it can be seen that much better results were obtained from the use of the on-board weighing system in the private operation where greater management and control of the system was implemented. This point was proven by the results achieved by Cole (2005).

4.4 Field evaluation of in-field loading

The site used to evaluate the use of on-board weighing systems under in-field loading conditions was at TSB Sugar in the South – Eastern Lowveld of Mpumalanga, South Africa (*cf.* Figure 4.1). TSB Sugar's core business activity is the production of refined and raw sugar. They grow their own sugarcane which they then transport to their two mills namely Malelane and Komati.

4.4.1 Operation Description and Configuration

At Malelane, Tsb have a fleet of 37 trucks which haul cane from the surrounding areas around the mill. Haulage distances range from being very short (areas immediately surrounding the mill) to the longest haul distances being approximately 40km from areas further away from the mill. The haulage trucks are rigid drawbar trucks with a maximum gross weight of 56 tons and all loads are loaded in-field by three-wheeled grab loaders or push pile grab loaders.

In the past Tsb Sugar have had a considerable problem with their cane trucks being overloaded. The good growing conditions combined with availability of water in the Malelane region encourages large sugarcane with a high bulk density to be grown. These factors contribute to trucks being constantly overloaded. Despite Tsb Sugar being conscious that extensive vehicle and road damage is caused by overloading, a large number of fines have been incurred when trucks were weighed at government weighbridges and found to be overloaded.

At the end of the 2006 season, measures were sought to combat the constant overloading of trucks. Nine trucks within the fleet were consequently fitted with LOADTECH on-board weighing systems. The LOADTECH systems are the same as those used in the previous two field evaluations. These nine trucks were to serve as a test to evaluate whether the use of on-board weighing could eliminate the problem of overloading.

The objectives of the case study were:

- To evaluate the accuracy of on-board weighing when operating in infield loading conditions,
- Determine whether overloading had been reduced in the trucks with on-board weighing installed, compared with the other trucks in the fleet without on-board weighing systems.

4.4.2 Data collection

Over the study period, daily weighbridge data for all twenty five trucks was collected. The data included the vehicle number, grower name, gross mass, and tare mass for every load. An illustration of the collected data is shown in Table 4.12. Tripsheets as printed by the on-board weighing systems in the field were also collected for each load during the same period. The tripsheet data was collected in order to compare the on-board weight reading in the field to the weighbridge weight and ultimately assess the accuracy of the on-board weighing system when operating in-field.

Table 4.12 Illustration of data collected for infield loading evaluation

Date	Vehicle	Grower Name	Gross Mass	Tare Mass	Nett Mass
06-Jun	629	SEEKOEIGAT	54.28	25.18	29.10
06-Jun	629	SEEKOEIGAT	54.32	25.10	29.22
06-Jun	629	MHLATI	53.66	25.20	28.46
06-Jun	629	MHLATI	55.46	25.18	30.28
06-Jun	629	MHLATI	56.58	25.22	31.36
06-Jun	630	SEEKOEIGAT	55.78	25.10	30.68
06-Jun	630	SEEKOEIGAT	53.72	25.06	28.66
06-Jun	630	SEEKOEIGAT	55.26	25.16	30.10
06-Jun	630	MHLATI	52.42	25.22	27.20
06-Jun	630	MHLATI	56.36	25.34	31.02
06-Jun	631	SUSPENSE SOWIL	54.84	25.06	29.78
06-Jun	631	SEEKOEIGAT	55.98	24.90	31.08
06-Jun	631	MHLATI	56.42	25.10	31.32
06-Jun	631	MHLATI	52.80	25.20	27.60

4.4.3 Data analysis

The data collected was analysed to assess firstly the accuracy of the on-board weighing system when operating in-field and secondly, to determine if overloading of the vehicles had been reduced due to the implementation of the on-board weighing system. The analysis and results of the two objectives are shown below.

4.4.3.1 Accuracy of the system

As done in the zone-loaded field evaluation, the on-board weighing system was measured against the mill weighbridge to determine accuracy. The 'best fit' simple linear regression was calculated for mill weighbridge versus on-board weighing system. The standard deviation of the data set of differences between the two measures is used as the measure of precision and is defined as the 'standard error of the estimate'.

Figure 4.18 shows the calculated linear regression with mill weighbridge on the X-axis and on-board weighing on the Y-axis. Errors of the on-board weighing system from its regression value are denoted by the line E(y) in Figure 4.18.

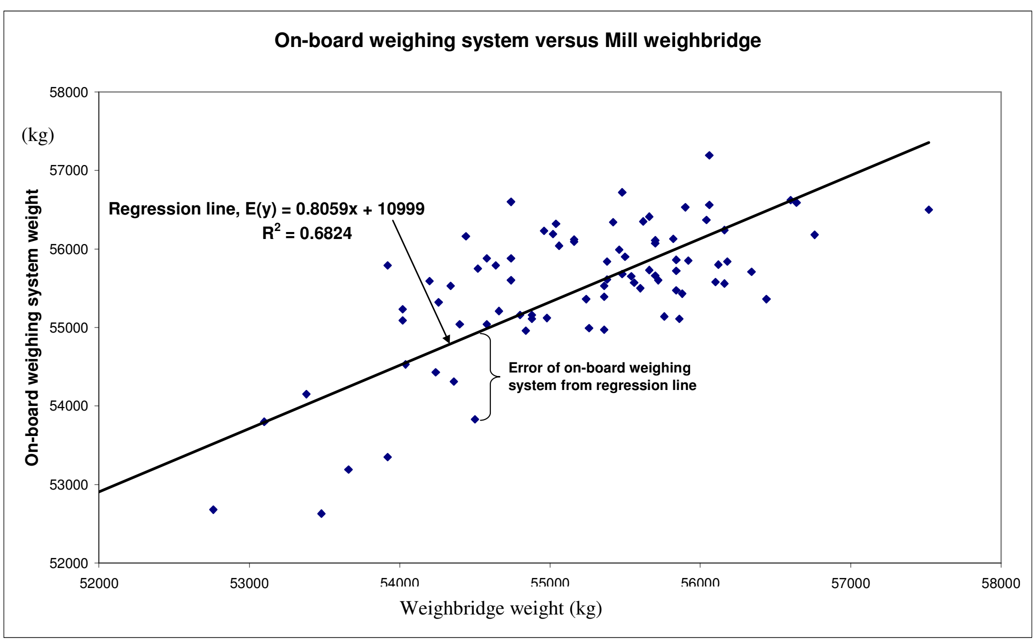

Figure 4.18 'Best fit" linear regression of On-board weigh vs Mill Weighbridge

From the graph above it was shown that the coefficient of determination (R^2) for the data set was 0.68 and that slope of the regression line was 0.81.

The mean error (ME) and root mean squared error (RMSE) of the data set was calculated. ME shows the bias of the error and RMSE gives an indication (on average) of the distance of a data point from the fitted line.

Mean error (ME) and root mean squared error (RMSE)

Using Eqn. 4.1, Mean error:

$$ME = 0.308 \text{ tons}$$

Error is positively biased which means that the on-board weighing systems tend to overweigh by 0.308 tons.

Root mean squared error gives the distance, on average, of a data point from the fitted line.

Using Eqn. 4.2 $\qquad MSE = 0.803 \text{ tons}$

Relative root mean squared error (RRMSE) gives the RMSE in terms of a percentage,

$$RRMSE = \frac{RMSE}{W_{avg}}$$

and, $\qquad W_{avg} = 55387.53$

$$RRMS = 0.01457 \text{ tons}$$

Therefore, the error that can be expected from an on-board weighing system, relative to the mill weighbridge is 1.5%.

As done for the data pertaining to zone loading, the decomposition of mean squared error was performed as a diagnostic check of the degree and sources of error.

Results calculated,

MC = 0.147241

SC = 0.057856

RC = 0.812225

The majority of the error, 81%, still occurred due to the RC component and 14% of the error was attributed to the difference in the means of the two data sets.

A comparison between statistics pertaining to vehicles loaded on zones and those loaded in field is shown in Table 4.13.

Table 4.13 Comparison of statistics pertaining to the accuracy of an on-board weighing system when used in loading environments of transloading zones and in-field

STATISTIC	TRANSLOADING ZONES	IN-FIELD
Mean Error (ME)	0.400678	0.308
Root mean Square Error (RMSE)	0.595	0.803
Relative Root Mean Square Error (RRMSE)	1.8%	1.5%
Decomposition of Error		
Mean Component (MC)	0.020883	0.147241
Slope Component (SC)	0.030731	0.057856
Random Component (RC)	0.948385	0.812225

From Table 4.13 it can be seen that under in-field loading conditions the on-board weighing system was slightly more accurate than when the system was used under transloading zone conditions. In evaluating the decomposition of the error, the MC component was smaller under zone conditions. This was attributed to a much better fit of the linear regression line to the zone data set than in-field data set, (i.e. R^2 for zone conditions was 0.9039 whereas in-field condition R^2 was 0.68).

4.4.3.2 Comparison of overloads

As in the previous two field evaluations, the maximum gross legal vehicle weight for the trucks in the TSB operation is 56 tons. A vehicle is consequently considered to be overloaded if its GVM exceeds 57.12 tons. The vehicles with on-board weighing systems delivered a total of 8866 loads during the study period with 559 of these loads being overloaded which translates into 6.3% of the total number of loads delivered. The rest of the fleet without on-board weighing systems delivered 14 982 loads with 10.6% percent of these loads being overloaded. The implementation of the on-board weighing systems reduced the extent of overloading by 4.3%. Table 4.14 below summarises the data pertaining to the overloading of the TSB vehicles and Figure 4.19 illustrates this data

Table 4.14 Summary of data pertaining to the overloading of vehicles with and without on-board weighing systems

	With On-board weighing	**Without On-board weighing**
No of vehicles	9	28
No of loads	8866	14982
No of overloads	559	1600
Percent of total loads overloaded	6.30%	10.60%

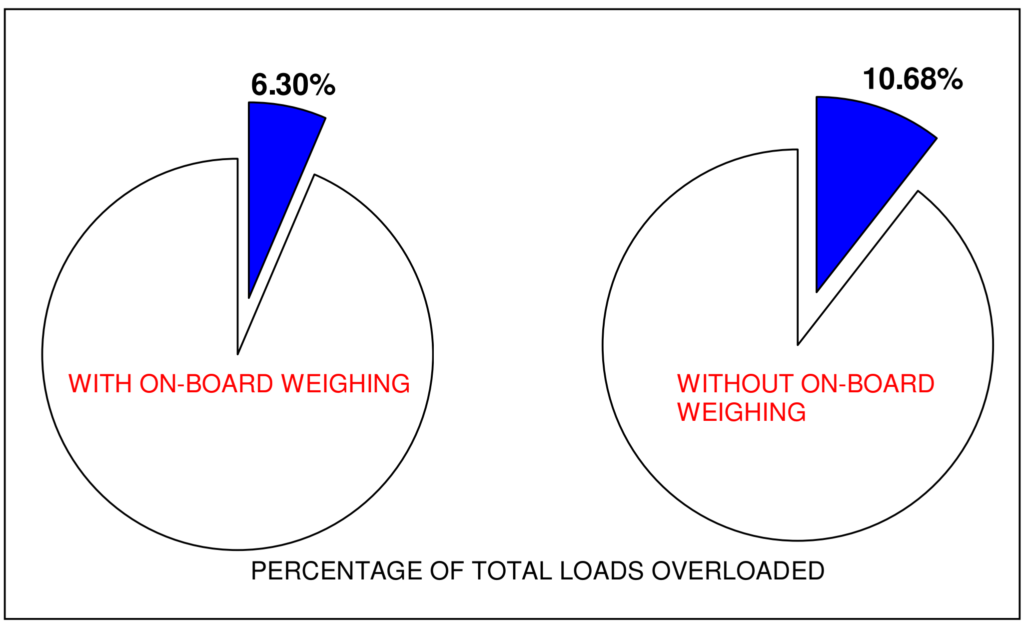

Figure 4.19 Illustration of the percentage of vehicles overloaded for vehicles with and without on-board weighing systems

In the TSB field evaluation, as in the Unitrans evaluation, it was seen that the implementation of on-board weighing systems reduced the number of times that trucks were overloaded. TSB trucks did show less overloading than the Unitrans trucks and this can be attributed to two reasons namely that there is a government weighbridge on the road to the mill which discourages overloading because of the fear of getting fines and the construction of TSB trucks doesn't allow the same volume of sugarcane to be loaded as in the Unitrans tucks. However further reduction in overloading is required in order to meet the new government RTMS regulations.

4.5 Discussion and conclusion

The evaluation of three field studies was shown in this chapter. The field studies evaluated the current use of on-board weighing systems in the South African Sugarcane industry under different transport operations. The first evaluation was for a commercial transporter operating a fleet of twenty six trucks with six of the trucks having on-board weighing systems. The second evaluation was of a private grower cum transporter operating two trucks with on-board weighing systems and the third evaluation was of a commercial transport operation of thirty six trucks, of which nine trucks were equipped with on-board weighing systems. The first two evaluations were for transport operations where trucks are loaded with loose cane on transloading zones and the third evaluation was for an operation where trucks are loaded with loose sugarcane in-field.

In the first field evaluation, the data collected was evaluated to assess the accuracy of the on-board weighing systems, the consistency of the systems, establish factors that affected the operation of the systems, determine if vehicle utilization was improved when using the system and compare the percentage of trucks overloaded when using the systems and when not using the systems. The on-board weighing system was measured against the mill weighbridge to determine accuracy and it was established that the mean error between the mill weighbridge and the on-board weighing system was 0.4 tons. As the mill weighbridge was the control measure, it was concluded that the on-board weighing systems in this field evaluation tended to overweigh by 0.4 tons. The relative mean squared error for the data set was 1.8%. The error between the mill weighbridge and the on-board weighing system was also disaggregated to determine the source of and degree of error. It was established that the majority of the error, 95%, occurred due to random errors and not systematically generated errors. In evaluating the consistency of the measurements of the on-board weighing system it was found that 75% of the measurements taken were within 0.5 tons of each other and therefore, it was concluded that the on-board weighing systems were reasonably consistent in their measurements. Various factors, including drivers of vehicles, cane variety and quality, delivery time and physical condition of loading zones were evaluated to assess if they influenced the effectiveness of the on-board weighing systems. It was found that drivers, time of day and physical condition of zones did not have an impact but that cane variety and quality had an influence on the effectiveness of the systems. In determining if vehicle utilisation was increased within the vehicles operating with on-board weighing systems it was seen that the average GVM of vehicles did not increase for the vehicles with on-board weighing systems. However the variation in GVM was significantly reduced and hence it was concluded that vehicle utilisation was improved through the use of the systems. Lastly, the number of overloads as a proportion of the total loads delivered by vehicles with and without on-board weighing systems during the study period was compared. Vehicles with on-board weighing systems were overloaded 32% percent of the time whereas vehicles without the systems were overloaded 41% of the time. The implementation of the systems was seen to reduce overloading, but a much larger reduction is needed in order to meet the government regulation of 4%. It is envisaged that through greater management of the on-board weighing systems a greater reduction in overloads can be achieved.

In the second field evaluation the data that was collected was evaluated to assess the average GVM of the vehicles, the variation in GVM and the percentage of loads overloaded. As this field evaluation was of a private grower cum transporter operation with only two trucks having on-board weighing systems it was envisaged that there were would be better management of the on-board weighing systems and consequently when compared to the previous commercial operation there would be an improvement in the results obtained from using the on-board weighing systems. In comparing the two field operations it was found that the private operation had a slightly higher average GVM than the commercial operation but the variation in GVM was significantly reduced in the private operation with a much larger percentage of loads being at the target GVM. The number of times the trucks were overloaded as a proportion of the total loads delivered was on average 4% for the two trucks which was significantly smaller than for the commercial operation. This supported the fact that overloading in the commercial operation could be reduced further if the on-board weighing systems were managed better.

Calibration of the systems was done by reconciling the weights obtained from the on-board weighing system with the weights obtained from the mill weighbridge. The mill weighbridges are calibrated regularly using recognised methods and were taken to be the correct weight.

The last field evaluation was for a large transport operation where trucks were loaded in-field. The data that was collected was evaluated to determine the accuracy of the system when operating under in-field conditions and secondly to compare the overloading of vehicles for trucks with on-board weighing systems and those without systems. In establishing the accuracy of the system it was calculated that the mean error between the mill weighbridge and the on-board weighing systems was 0.308 tons with a relative root mean squared error of 1.5%. As in the zone loaded field evaluation the on-board weighing system tended to overweigh by 0.3 tons. In comparing the overloading of the trucks, vehicles with on-board weighing were overloaded 6.3% and those without were overloaded 10.7% of the time. Once again the on-board weighing system reduced overloading but further reduction is needed to be within government regulations.

From the three field evaluation it can be concluded that on-board weighing systems are fairly accurate (to within 0.4 of a ton) compared to mill weighbridges and their measurements are consistent. The utilisation of a vehicle is improved through reducing the variation in mass loads enabling a greater number of loads at the target mass to be achieved. However, better the management of the system the more effectively the system operates. The effectiveness of the on-board weighing system is also affected by the variety and quality of the cane. Overloading of vehicles is reduced when on-board weighing systems are utilised and with close management of the system, overloading can be reduced so that vehicles comply with government regulations.

5. ECONOMIC EVALUATION

In the previous chapter it was concluded that vehicle utilization could be improved with the implementation of on-board weighing systems and good management practices. This chapter contains an assessment of whether economic benefits could be realised beyond the cost of the on-board weighing systems within the South African Sugarcane industry.

5.1 Introduction

Transport in the South African sugarcane industry is done by one of two parties, either grower cum transporters or commercial hauliers. Grower cum hauliers are defined as cane growers who haul their own cane and possible other growers' cane but not for a profit, whereas commercial hauliers haul cane as a profit making business (Giles, 2007). This economic evaluation is applicable to grower cum transporters.

The implementation of an on-board weighing system requires a considerable capital investment. The system then needs to increase vehicle utilization and reduce transport costs significantly to warrant the investment. An increase in vehicle utilisation can result in a reduction in the number of loads a transporter delivers annually while still delivering the same tons of sugarcane. The reduced number of loads needed to be delivered in a season will result in a direct saving in transport costs. This chapter attempts to establish the payback period of the investment required for an on-board weighing system for different transport scenarios.

5.2 Method

As mentioned above, the implementation of an on-board weighing system requires capital investment. The capital budget system is a technique of accounting for investments made and cost saving achieved through those investments over a number of years. The methodology used to evaluate the economic feasibility of implementing an on-board weighing system involved developing a capital budget for the investment required and using the capital budget to determine the payback period for the investment for different transport scenarios. The specific methodology was as follows:

- Development of a generic capital budget,
- Determine transport costs for different lead distances,
- Determine transport cost saving due to the implementation of an on-board weighing system for different scenarios,
- Substitute transport cost saving into the developed capital budget to determine the payoff period of the investment for the different scenarios.

An on-board weighing system reduces transport cost due to improved vehicle utilisation by increasing the payload of a truck. The scenarios evaluated involved determining the transport cost saving for increasing the payload by 2, 3 and 4 tons for lead distances of 20, 40, 60, 80 and 100 kilometres.

5.2.1 Development of a capital budget

A capital budget accounts for depreciation of capital, discount rates and tax rates. A capital investment depreciates over a time period; the depreciation is dependent on the asset purchased. The discount rate comprises risk and an opportunity cost, where the opportunity cost is the rate of return that could be achieved if the money was invested elsewhere and an element of risk is included to account for fluctuations of interest in the future. Because all values are expressed in real terms, all cost savings are calculated using present input costs which removes the need to account for inflation. Cost savings and investment values that occur in the future are discounted back to present values *(PV)* by applying equation 5.1.

$$PV = FV(1+i)^{-n} \tag{5.1}$$

Where, FV is the future value, n is the number of years being discounted back and i is the discount rate in decimals.

The economic parameters that were assumed for the development of the capital budget are summarised in Ttable 5.1.

Table 5.1 Economic parameters used for the development of the capital budget

VARIABLE	VALUE
Depreciation of Capital	
Year 1	50%
Year 2	30%
Year 3	20%
Discount Rate	
Opportunity Cost	5%
Risk	2%
Tax on Revenue	40%

The first step in developing the capital budget was to establish the capital investment required for implementing an on-board weighing system. As the cost of a system varies with different truck, trailer and suspension configurations, the cost for a rigid truck and trailer with front and rear dual axe spring suspension was used throughout this economic analysis. From chapter two (overview of on-board weighing systems) it was established that the capital investment required for this configuration is R 89 500 (see Section 2.5.1). Table 5.2 contains the development capital budget; the next steps in the analysis involved calculating the transport cost and cost saving for the different scenarios.

Table 5.2 Outline of the development capital budget

Step	Year	0	1	2	3	4	5
1	Investment (-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving						
4	Total Annual Cost Saving (Real)						
5	Change in Taxable Income						
6	Change in Tax (40%)						
7	Change in Net Cash Flow						
8	PV of Δ Net Cash Flows (I = 7%)						
9	Accumulative Net Income						
10	Percentage of Investment Returned						

5.2.2 Transport costs

Transport cost is a function of the lead distance that is required to be travelled. Lusso (2005), while developing an optimum road upgrading model for the timber industry, established that when lead distances are relatively short, generally less than 10 km, a large portion of the truck's life is spent idle as a lot of time is spent loading and off loading. The longer the lead distance, the larger the portion of time spent moving timber rather than idling while loading and off-loading (*cf.* Figure 5.1). The same principles apply to sugarcane transport with the result being that the cost of transport (per km) for longer lead distances is less than that for short lead distances.

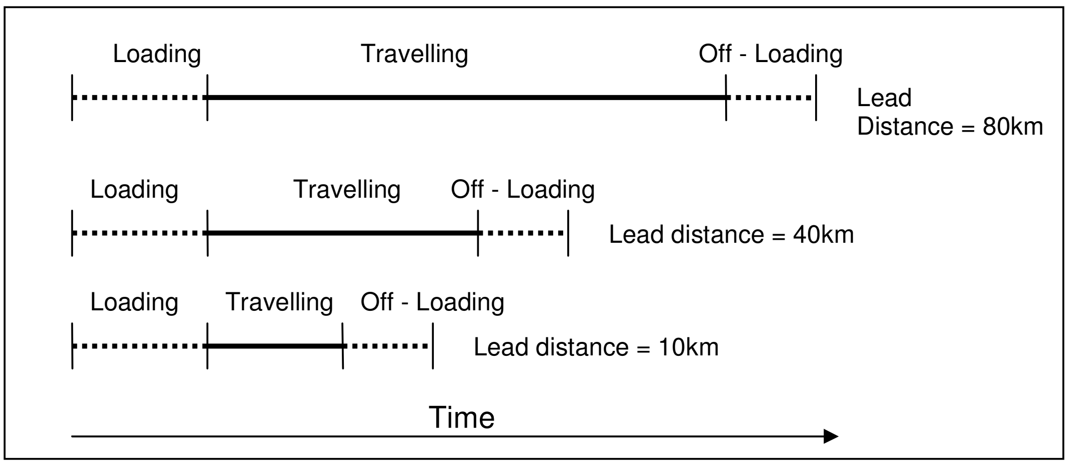

Figure 5.1 Breakdown of machine life into loading, travelling and off-loading over different lead distances (Lusso, 2005)

Meyer (2005) established a reference of transport costs for annual kilometres travelled by a vehicle in the sugarcane industry. These benchmark costs are shown in Figure 5.2 and it is evident that there exists a non-linear relationship between lead distance and cost per kilometre of transport. From the graph it can be seen that if a truck travels 80 000 kilometres in a season the cost per kilometre is R10.50. If the distance travelled is only 20 000 kilometres, the cost increases considerably to approximately R25 per kilometre. The considerable variation in cost, related to lead distance is due to transport cost being comprised of a fixed and variable cost component.

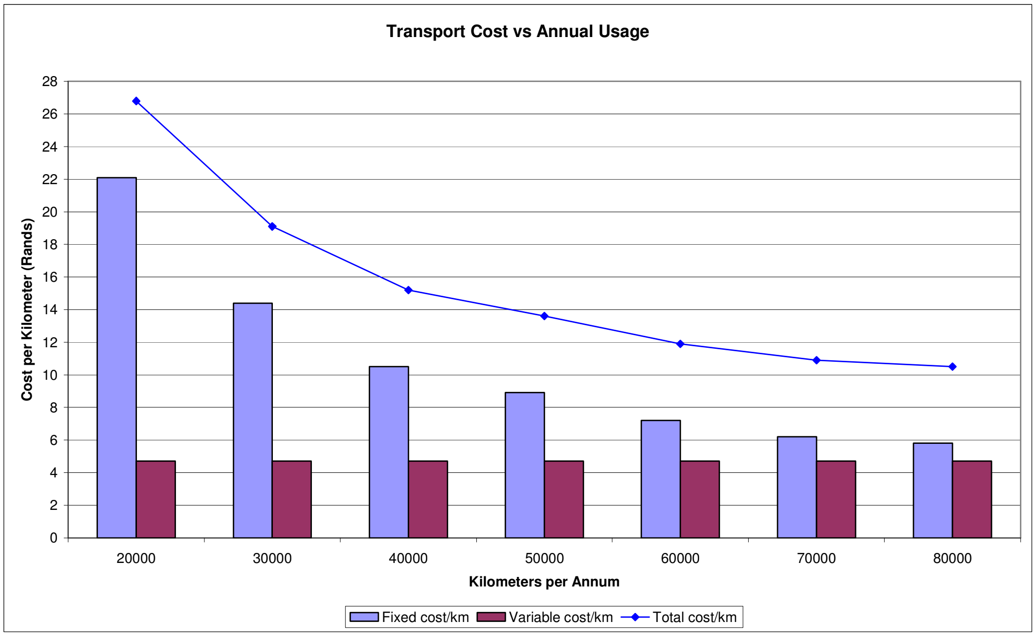

Figure 5.2 Benchmark of transport costs (Meyer, 2005)

As shown in Figure 5.2, transport costs consist of fixed and variable costs. Fixed costs consist of capital cost of buying the truck, tractor and trailer and associated interest, driver wages, insurance fees, licensing fees and overheads costs. Variable costs include fuel, lubricants, tyres and maintenance (Giles, 2007). Variable costs remain constant for different lead distances, however, fixed costs decrease considerably as the lead distance increases. This is due to the principle mentioned above where more of a vehicle's time is spent travelling rather than idling resulting in reduced fixed costs.

The total cost of transport will vary with every different haulier as fixed and variable costs will differ with different makes of trucks, tyres, maintenance schedules etc. The benchmark costs per kilometre for annual usage of a truck, established by Meyer (2005) (*cf.* Figure 5.2) were used in this economic analysis.

In Table 5.3 the transport cost (used in this study) for different lead distances as derived from Figure 5.2 are shown. Referring to Table 5.3, cycle times, number of loads delivered per day for each lead distance, number of days worked per week and weeks per season were based on parameters obtained from the Sezela mill on the KwaZulu-Natal south coast. Total available delivery hours per day were assumed to be 22 hours.

Table 5.3 Cost per kilometre for different lead distances
(Derived from Meyer, 2005)

Lead Distance (km)	**20**	**40**	**60**	**80**	**100**
Cycle Times (hrs)	4	4.5	5.5	7	8
Loads per day	5	5	4	3	3
Days per week	6	6	6	6	6
Weeks per season	38	38	38	38	38
Annual Usage (km)	22800	45600	54720	58320	68400
Cost per km ($R.km^{-1}$)	**25.2**	**14.1**	**13**	**12.8**	**11.5**

Transport cost per kilometre for different lead distance was calculated as follows:

$$\frac{Delivery\ hours\ available\ per\ day}{Cycle\ times} = Loads\ per\ day$$

$$Loads\ per\ day \times Days\ per\ week \times Weeks\ per\ season = Loads\ per\ season$$

Loads per season x *Lead distance = Annual usage (km)*

From the annual usage calculated, transport cost was determined from Figure 5.2.

5.2.3 Transport cost saving

Transport cost saving (due to the implementation of an on-board weighing system) was determined by calculating the saving in the number of loads required to be delivered by a truck, in a season, if the average payload of the truck was increased by 2, 3 or 4 tons. As this evaluation is for a rigid drawbar truck/trailer configuration, the cost saving that can be achieved by increasing the average payload of the truck from 30 tons to 32, 33 and 34 tons was calculated. The average payload of a rigid drawbar truck in the South African sugarcane industry is 30 tons (Giles, 2007). The steps followed in calculating transport cost saving were:

- Calculate the number of loads delivered per season if the payload is 30 tons. Number of loads delivered per season was determined by dividing the annual usage of a truck (as determined in Table 5.3 by the lead distance for each scenario,

- Calculate the cost per load due to the lead distance and the resulting total cost per season. The cost per load is a function of the cost per kilometre for specific lead distances,
- Determine the reduction in number of loads from the original number if payload was increased by 2, 3 or 4 tons,
- Calculate the cost saving due to the number of loads saved.

A sample calculation of cost saving for a scenario where the payload is increased by 3 tons and the lead distance is 60 km shown in table 5.4.

Table 5.4 Sample calculation of cost saving per season for scenario where average payload was increased by 3 tons and lead distance is 60 km

Scenario: 3 ton increase in payload for 60km lead distance	
For 30 ton average payload	
Lead distance (km)	60
Loads per season	912
Tons per season	27360
If average payload is increased by 3 tons - 33 ton payload	
Loads per season	829
Loads saved per season	83
Cost per load (R)	780
Total saving per season (R)	64669

The cost saving per season, calculated for each scenario is shown in Table 5.5.

Table 5.5 Cost saving per season for an increase in payload of 2, 3 and 4 tons for lead distances of 20, 40, 60, 80 and 100 km

		Lead Distance (km				
		20	**40**	**60**	**80**	**100**
Payload increase (t)	**2**	35 910	40 185	44 460	43 776	32 775
	3	52 233	58 451	64 669	63 674	47 673
	4	67 595	75 642	83 689	82 402	61 694

5.2.4 Results

The transport cost saving calculated for each scenario, shown in Table 5.5, was substituted into the capital budget and the percentage of the investment returned per year was calculated. Tables 5.6, 5.7 and 5.8 contain the capital budgets for the scenarios where lead distance is 60 km and the payload increase was 2, 3, and 4 tons respectively. Capital budgets for the other twelve scenarios are shown in Appendix A.

For the scenario shown below, 100% of the investment was paid off in the third year when the payload was increased by two tons, and for a payload increase of three and four tons the investment was paid off n the second year. In each scenario a considerable return in investment can potentially be realised by the sixth year with a 179%, 250%, and 330% return in investment for two, three and four ton increase in average payload respectively.

Table 5.6 Capital budget for a two ton increase in average payload and a lead distance of 60km. (PV of Δ Net Cash Flow reflects the change in net cash flow expressed in present value terms. Values are expressed in Rands.)

Step	Year	0	1	2	3	4	5
1	Investment (-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	44460	44460	44460	44460	44460	44460
4	Change in Taxable Income	64669	-290	17610	26560	44460	44460
5	Change in Tax (40%)	25868	-116	7044	10624	17784	17784
6	Change in Net Cash Flow	-70908	44576	37416	33836	26676	26676
7	PV of Δ Net Cash Flows (I = 7%)	-70908	41660	32681	27620	20351	19020
8	Accumulative Net Income	-70908	-29248	3433	31053	51404	70424
9	**Percentage of Investment Returned**	**21%**	**67%**	**104%**	**135%**	**157%**	**179%**

Table 5.7 Capital budget for a three ton increase in average payload and a lead distance of 60 km. (PV of Δ Net Cash Flow reflects the change in net cash flow expressed in present value terms. Values are expressed in Rands.)

Step	Year	0	1	2	3	4	5
1	Investment (-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	64669	64669	64669	64669	64669	64669
4	Change in Taxable Income	64669	19919	37819	46769	64669	64669
5	Change in Tax (40%)	25868	7968	15128	18708	25868	25868
6	Change in Net Cash Flow	-50699	56701	49541	45961	38801	38801
7	PV of Δ Net Cash Flows (I = 7%)	-50699	52992	43271	37518	29601	27665
8	Accumulative Net Income	-50699	2293	45565	83083	112685	140349
9	**Percentage of Investment Returned**	**43%**	**103%**	**151%**	**193%**	**226%**	**257%**

Table 5.8 Capital budget for a four ton increase in average payload and a lead distance of 60 km.(PV of Δ Net Cash Flow reflects the change in net cash flow expressed in present value terms. Values are expressed in Rands.)

Step	Year	0	1	2	3	4	5
1	Investment (-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	83689	83689	83689	83689	83689	83689
4	Change in Taxable Income	64669	38939	56839	65789	83689	83689
5	Change in Tax (40%)	25868	15576	22736	26316	33476	33476
6	Change in Net Cash Flow	-31678	68114	60954	57374	50214	50214
7	PV of Δ Net Cash Flows (I = 7%)	-31678	63658	53239	46834	38308	35802
8	Accumulative Net Income	-31678	31979	85219	132053	170360	206162
9	**Percentage of Investment Returned**	**65%**	**136%**	**195%**	**248%**	**290%**	**330%**

The percentage of the investment returned per year for the investment in an on-board weighing system for a rigid drawbar truck for all fifteen scenarios analysed is shown in Figures 5.3, 5.4 and 5.5. Figure 5.3 shows the return in investment for a two ton increase, Figure 5.4 is for a three ton increase and Figure 5.5for a four ton increase in average payload. From the respective figures it can be seen that the time taken to pay off the investment decreased with an increase in lead distance with a significant increase in payoff time between lead distances of 80 km and 100 km. The shortest pay off period was two years and occurred when the lead distance was 60 km in all three payload increase cases. The longest pay off period was four years and was shown to occur when the lead distance was 100 km. It was assumed that this is due to the small number of loads delivered annually when the lead distance is 100 km in comparison to the shorter lead distances.

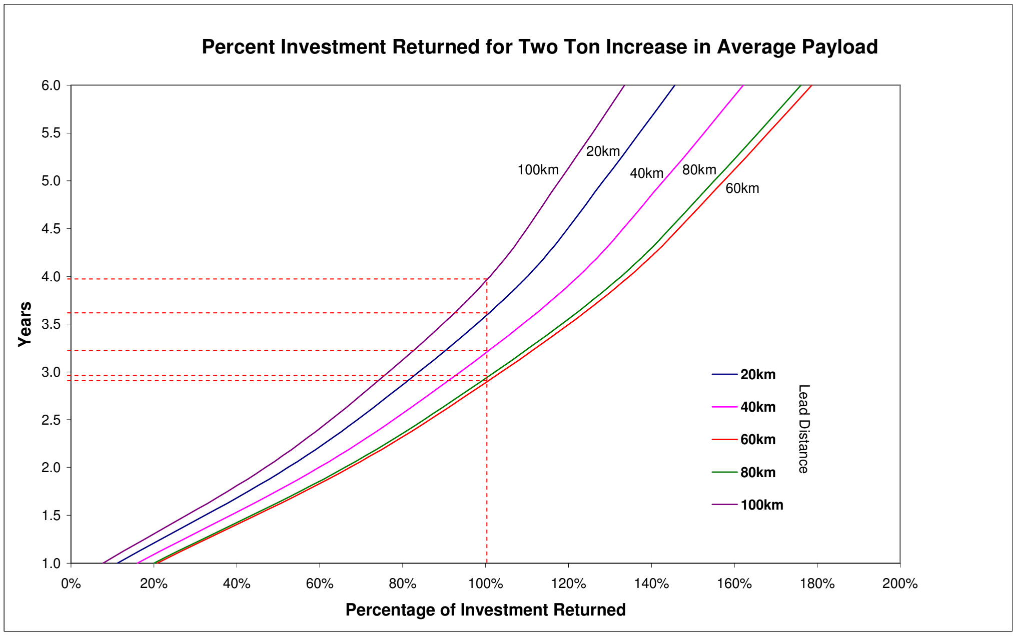

Figure 5.3 Percentage of investment returned per year for an average payload increase of two tons.

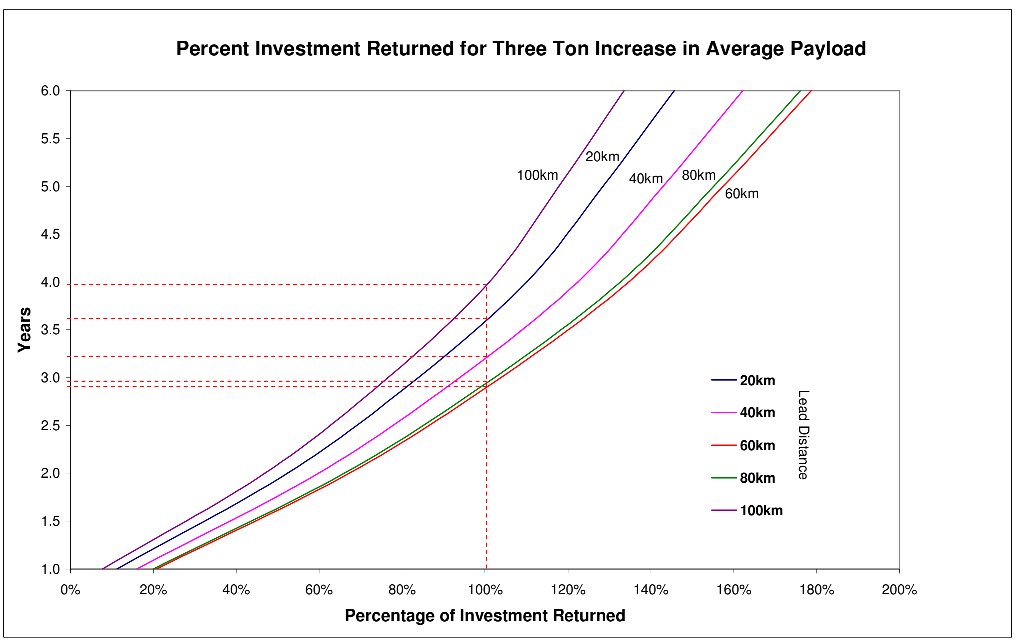

Figure 5.4 Percentage of investment returned per year for an average payload increase of three tons.

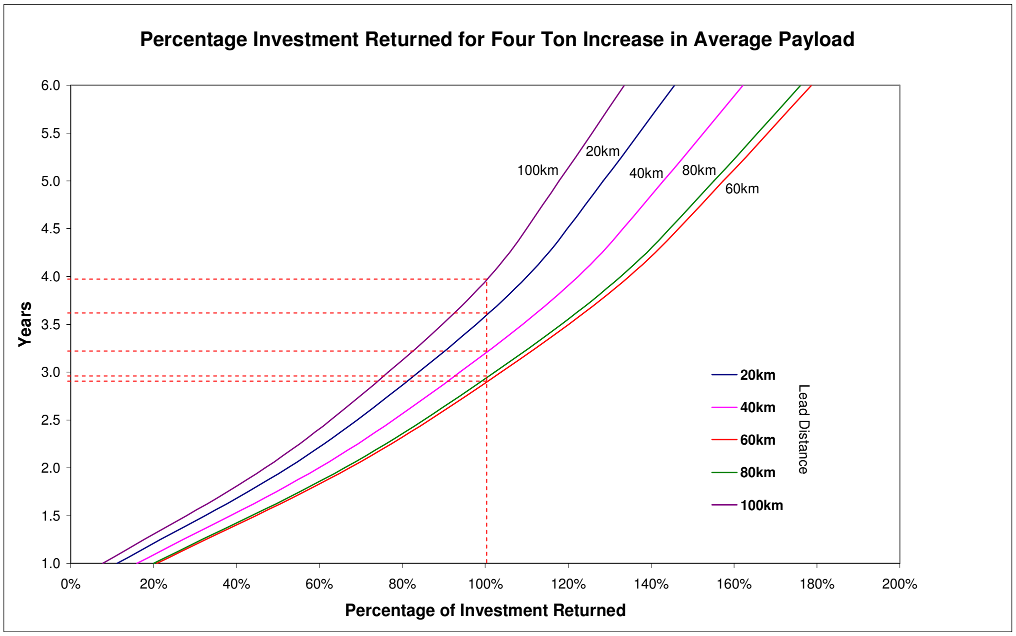

Figure 5.5 Percentage of investment returned per year for an average payload increase of four tons.

5.2.5 Discussion and conclusion

The application of a capital budget to evaluate the investment in an on-board weighing system (for a rigid drawbar truck/trailer configuration) for fifteen different transport scenarios was demonstrated in this chapter. The cost of transport was based on benchmark costs established within the industry and parameters used to determine annual usage of a sugarcane haulage truck were derived from current industry norms in the South African sugarcane industry presently.

The transport scenarios analysed were for the increase in average payload of a rigid drawbar truck by 2, 3 and 4 tons for lead distances of 20, 40, 60, 80 and 100 kilometres. It was shown that the investment in an on-board weighing system was feasible for all the different scenarios analysed, with the shortest payoff period of $1^1/_2$ years being realised when the payload was increased by four tons and the lead distance was 60 kilometres. The scenario with the longest payoff period was when the payload increase was two tons and lead distance was 100 kilometres and the payoff period was four years.

For an increase in average payload of 2, 3 and 4 tons the shortest payoff period was realised for a lead distance of 60 km followed by 80 km, thereafter there was a considerable increase in the payoff period with the longest payoff period being for 100 km. It was concluded that this was due to the relatively small number of loads that a truck is able to deliver per day when lead distances are 100 km and above. The optimum lead distance for the investment in an on-board weighing system is 60 km. However, the investment was still seen to be economically feasible for all the scenarios analysed with a considerable return on the investment (up to 250 %) being achieved by the fifth year of using the system.

Although this economic evaluation was applied to a rigid drawbar truck/trailer configuration, it can be assumed that it is economically feasible to implement an on-board weighing system on other truck/trailer configurations. The cost of an on-board weighing system for a rigid drawbar truck/trailer is more expensive than for any other truck/trailer configuration commonly used within the South African sugarcane industry and therefore if it has been shown that it is economically feasible for a rigid drawbar truck/trailer then it can be assumed that it is feasible to implement a system on other truck/trailer configurations where the required initial investment is less.

This economic evaluation of on-board weighing systems was based solely on the reduction in transport cost due to improved vehicle utilisation. There are however, other cost benefits related to using an on-board weighing system that have not been included in this evaluation. Other cost benefits include the elimination of overloading fines and a reduction in maintenance costs. Preventing overloading through the monitoring of payloads with an on-board weighing system will ensure that no overloading fines are incurred and that a truck operates within its design limits, reducing any stress and strain that is placed on the vehicle when overloaded which can result in vehicle breakdowns and an increase in truck maintenance.

6. GUIDELINES FOR IMPLEMENTATION

It was concluded in the previous chapter that on-board weighing systems are an economically feasible investment and that considerable returns, over and above the cost of the system, are able to be realised. This chapter serves to provide practical guidelines for implementing and thereafter the operational use of an on-board weighing system.

6.1 Introduction

The adoption of new technologies is often the key to maintaining a profitable agricultural operation (Miller and Cox, 2006). However, stated that the adoption of a new technology is significantly affected by the consumer's perceptions of the product's attributes and some adoption studies have included farmers' subjective assessment of the technology attributes as explanatory variables in the slow adoption of a technology (Jabbar *et al.,* 1998, Adesina and Zinnah, 1993). A farmer's subjective assessment is largely based upon existing knowledge about the technology and the slow adoption of technologies in agriculture is often attributed to a lack of knowledge. This chapter attempts to provide information pertaining to the use of an on-board weighing system (under three different loading scenarios), maintenance of the system and management requirements for implementing the system optimally in grower cum transporter operations. The information provided is based upon observations that were made while carrying out the field evaluations in this study and from information obtained from current users of on-board weighing systems in the South African sugarcane industry.

Guidelines associated with operational procedures will be discussed for three different loading environments. Thereafter, the management and maintenance of the system will be discussed.

6.2 Loading environments

Within this study, the use of on-board weighing systems on interlink and rigid drawbar trucks was analysed. Interlink and rigid drawbar trucks are loaded by three primary methods, these methods being (i) loose cane on zones, (ii) bundled cane on zones and (iii) loose cane infield (Meyer, 2005). The use of on-board weighing systems in these three loading environments are considered.

Load cell on-board weighing systems, such as the LOADTECH system, function optimally when the truck is on a level surface (Cole, 2007). The system has also been designed as such to operate on a level surface. Load cells are located at all the critical load bearing points on a truck and if the vehicle is not level, there is uneven distribution of the load over the various load cells. Some degree of load distribution from one load cell to another occurs which leads to an incorrect gross vehicle mass being indicated by the system Figure 6.1 illustrates this point. The topography of the loading environment is therefore very important to the successful operation of on-board weighing systems.

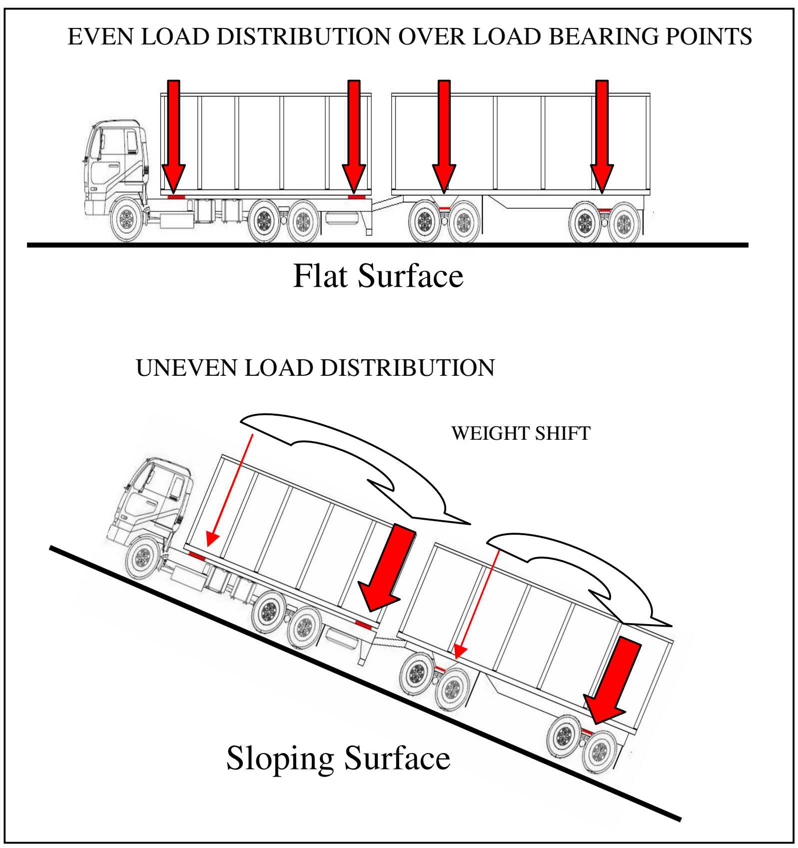

Figure 6.1 Illustration of weight shift when truck is on a sloping surface

6.2.1 Loose cane loaded on transloading zones

Loose cane that is stockpiled on transloading zones and thereafter loaded onto a stationary truck with the use of a grab loader provides an optimum loading environment for on-board weighing systems (see Section 3.3.2 for description of loading method). The majority of transloading zones are flat and reasonably well maintained and therefore provide a level surface on which to operate the on-board weighing system. A truck should able to carefully monitor the digital display of the on-board weighing system while loading is taking place and is then able to halt the loading process when the system indicates that the truck is loaded to its legal limit.

6.2.1.1 Recommended procedures

When the truck has been loaded to the legal limit as indicated by the on-board weighing system, the following steps should be followed:

- Move the truck onto the most level section of the zone,
- Switch off the truck, engage first gear and remove the handbrake,
- Re-check the weight of the vehicle, if it is below the legal limit top up further, if above the limit remove some cane until the legal limit is reached,
- Print the tripsheet from the on-board weighing system and proceed to mill.

If the handbrake of the truck is engaged, there is tension on the load cells created by the truck brakes which is unrelated to the load that is on the truck giving an incorrect mass load reading. Therefore, it is recommended that the vehicle be moved to an area on the zone where it is level enough for so that when the engine is switched off and the truck is in first gear, the truck will not roll away if the handbrake is removed. An accurate reading that is not distorted by tension created by brakes being engaged can then be obtained.

6.2.1.2 Critical factors

For loose cane loaded on zones three factors are considered critical to the successful operation of the on-board weighing systems. These factors are:

Reasonably level transloading zones:
As mentioned above it is important that a zone be level enough to allow a truck to be parked with first gear engaged and the handbrake off.

Availability of cane on the zone:
If the stockpile of cane on the zone runs out before the truck is fully loaded, the on-board weighing system is not used and the technology is totally wasted. In order for the system to operate as designed and provide benefit to the user it is imperative that there is enough cane on the zone to load the truck to its maximum legal capacity. This factor is also related to managerial requirements for an on-board weighing system and will be discussed later.

Effective communication and co-operation between the grab loader driver and the truck driver**:**
When loading takes place, the truck driver observes the digital display of the on-board weighing system and indicates to the grab loader driver when to stop loading. It is often required that small amounts of cane are added to 'top up' the truck to the desired level. This requires the truck driver to communicate to the grab loader driver how much cane needs to be added or removed. However, some grab loader operators are resistant to being told by the truck driver what to do, as they believe that they know their jobs and can judge for themselves whether the truck is full or not. It is therefore important that there is a good relationship between the truck drivers and the grab loader drivers in order that they communicate and co-operate with each other to load the truck to the desired limit.

6.2.2 Chain bundled cane loaded on transloading zones

As mentioned in Chapter Three (see Section 3.3.2) problems exist in relation to on-board weighing systems and chain bundled cane. Bundles vary in size between 3 and 8 tons with the average size being 6 tons for burnt cane. If the on-board weighing system indicates that the truck is underloaded the addition of another bundle to the truck will often cause the truck to be overloaded. This defeats the purposes of the on-board weighing system as one of its main purposes is to prevent overloading.

Cole (2005) showed that the problem of bundled cane can be solved by using a grab loader to ‘top up’ a truck with loose cane once the bundles have been loaded. This requires a chain bundled stack to be broken on the zone so that the grab loader has loose cane with which to top up the truck to the desired payload. The constraint, however, is the extra capital investment required if a grab loader needs to be bought over and above the cost of the on-board weighing system. An economic evaluation to asseses the feasibility of this extra investment is shown below.

6.2.2.1 Economic feasibility of investing in a grab loader for bundled cane

The capital budget system (see Chapter 5) was used to evaluate the payback period for investing in a grab loader over and above the investment of an on-board weighing system. As the grab loader is required to do a relatively small amount of work in this scenario (merely topping up the truck) it is assumed that the purchase of a second hand grab loader would be sufficient to carry out such a job. A commonly used grab loader in the South African industry is the Bell three wheeled loader at an estimated cost of R 140 000 (Price Obtained from Bell Equipment, 2007) such a machine was utilised in the evaluation. Figure 6.2 below shows the variation in GVM of loads delivered by the haulier to Sezela mill where the trucks were loaded with chain bundled cane using a crane. It is evident from the Figure 6.2 that a wide variation in GVM occurred with no consistency at the target GVM of 56 tons being achieved. The average GVM for the 660 loads that were evaluated was 53.07 tons, which is 3 tons below the target GVM.

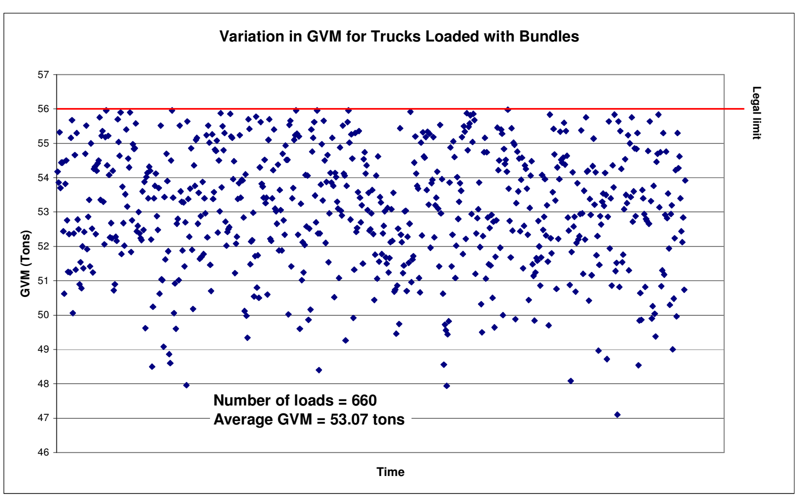

Figure 6.2 Distribution of GVM for trucks loaded with bundled cane

Based on the results above, this economic evaluation was calculated on increasing the average payload by 3 tons. Using the same methodology as in Chapter 5, the payback period for investing in an on-board weighing system at a cost of R 89 500 and a grab loader at a cost of R 140 000 was calculated. Figure 6.4 shows the results of the evaluation. It can be seen that the shortest payoff period is 4.2 years which can be realised if the lead distance is 60 km and 80 km, The payoff period if lead distance is 40 km is 4.8 years, 5.7 years for 20 km and over 6 years if the lead distance is 100 km or greater. The capital budgets used to derive these graphs are shown in Appendix A.

Judging by the time required to pay off the investment of an on-board weighing system as well as a grab loader, the investor may consider the investment not to be worthwhile. Other cost benefits associated with the use of on-board weighing systems such as the prevention of overloading fines could however make the investment more feasible.

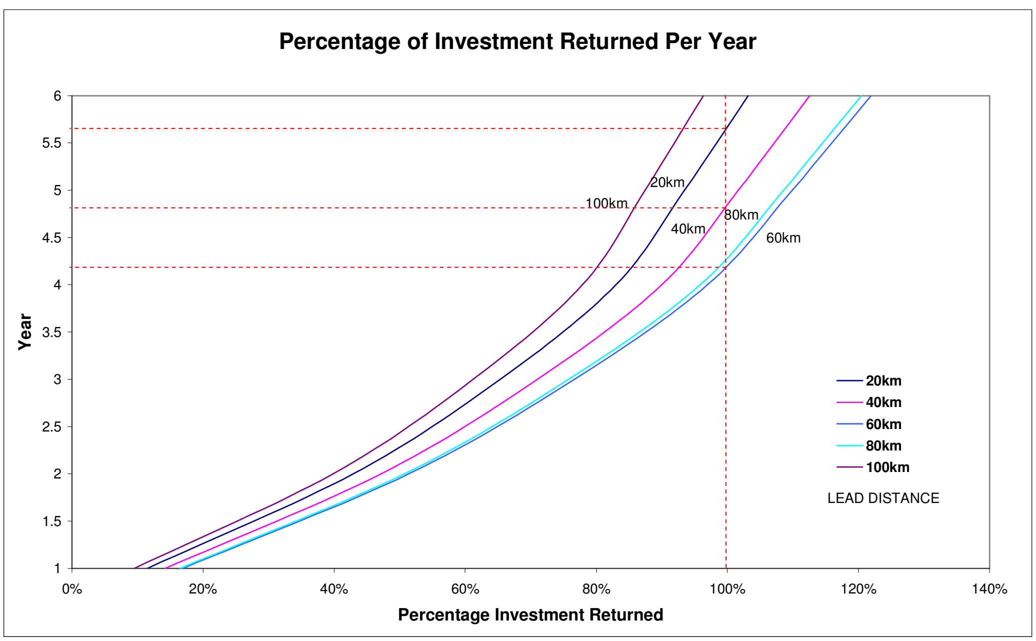

Figure 6.3 Percentage of investment returned per year for an investment in an on-board weighing system and a grab loader

6.2.2.2 Recommended procedures and critical factors

Recommended procedures and critical factors for chained bundled cane on transloading zones (with a grab loader for topping up) are the same as those stated for loose cane loaded on transloading zones.

If a grab loader is not available and an on-board weighing system is being used, it is envisaged that some degree of improved vehicle utilisation can be achieved through grading the sizes of the stacks. When stacks are stockpiled on the transloading zone they need to be graded according to size and stacked accordingly. When a truck is loaded the larger stacks are loaded first and when the truck is nearing its weight limit smaller stacks can be added to get as close as possible to the desired load mass.

6.2.3 Infield loading

As in the case of loose cane loaded on transloading zones, infield loading is conducive to trucks being loaded accurately according to the weight displayed by the on-board weighing system. A problem can occur however, due to the uneven topography of sugarcane fields. In the Northern regions such as Komati in Mpumalanga this is much less of a problem as the land is relatively flat in comparison to areas such as the Kwazulu Natal South Coast where the terrain is very hilly and/or steep. As explained earlier, load cell on-board weighing systems work optimally when the truck is on a level surface and the load is evenly distributed over all the load cells located at the load bearing points of the truck. The situation can occur where a truck is loaded on a steep slope and the nearest flat area (where the on-board weighing reading can be checked) is too far away for the loader to travel to top up the vehicle, if required. Potholes and excessively big bumps in the field can also cause the on-board weighing reading to be inaccurate.

6.2.3.1 Recommended procedures

Similar procedures as done when loading loose cane on transloading zones should be carried out infield.

- When the truck is full, the truck must be moved onto the most level surface available. If the truck is able to remain stationary when switched off with first gear engaged and the handbrake off, then the surface is considered to be level enough to get an accurate reading from the on-board weighing system. The truck driver should also check that there are no truck or trailer wheels in potholes or on excessively big bumps such as ant hills,
- Once on a reasonably level surface, topping up of the truck can be done. Thereafter the on-board weighing tripsheet should be printed before proceeding to the mill.

6.2.3.2 Critical factors

Once again the critical factors with respect to loading environments are, firstly, the topography of the loading environment and, secondly, communication and co-operation between the truck driver and the loader driver. In the case of infield loading, the truck does not remain stationary while loading, but rather moves along the rows of windrowed cane. Communication between the truck driver and the loader driver becomes more difficult and therefore close co-operation between the two drivers becomes imperative.

6.3 Managing the system

The managerial procedures outlined in this section are based on observations of the management of the different on-board weighing systems that were evaluated in this study. The managerial procedures are generic to trucks loaded on zones as well as those loaded infield. The two areas related to the management of an on-board weighing system are the truck drivers' experience and their acceptance of the system with the continuous monitoring of the system.

6.3.1 Driver experience and acceptance

The operator's experience and skill in using the system, and the operator's acceptance of the system, play important roles in the effectiveness of on-board weighing systems

(Phillips, 1989). Kopp (2007) using on-board weighing systems in the South African timber industry, stated that the difference in payloads for drivers that had been using the system for some time and drivers that were new to the system, was remarkable. Proper training of drivers as to how the system works and how the system should be operated is very important. An illustration of the location of the different load cells at the load bearing point of the truck will help the driver to understand the importance of the truck being on level ground when reading the weight from the on-board weighing system. A printout of the procedures needed to be followed by the driver should be stuck up in the cab of the truck which can assist the drivers in remembering the procedures needed to be followed. Figure 6.7 is an illustration of what such a procedure list could look like.

Training of loader drivers is also important in order that they co-operate and communicate with the truck drivers. The loader driver needs to understand how the system works so that he reacts accordingly when the truck driver indicates that the truck is nearing its limit when he can then load small amounts of cane into the truck until the exact desired load mass is achieved. Good understanding between the loader driver and the truck driver is very important in order to achieve accurate and consistent mass loads.

LOADING PROCEDURE

1] LOAD TILL AXLE WEIGHTS ARE:

AXLE 1 = 24 000 KG
AXLE 2 = 17 000 KG
AXLE 3 = 16 000KG

TOTAL = 57 000KG

2] AFTER LOADING MOVE TRUCK FORWARD ONTO LEVEL GROUND

3] ENGAGE NO.1 GEAR AND SWITCH OFF ENGINE

4] REMOVE HANDBRAKE

5] CHECK WEIGHT AGAIN AND LOAD/UNLOAD IF NECCESSARY

6] PRINT TRIPSHEET AND PROCEED TO MILL

Figure 6.4 Illustration of a loading procedure list

6.3.2 Continuous monitoring of the system

In order to continuously manage the on-board weighing systems, tripsheets (printed from the on-board weighing system) need to be printed for every load that is delivered to the mill. The printing of tripsheets not only allows a manager to monitor the system but also forces the driver of the truck to recognise and make use of the system. Tripsheets can be collected on a daily or weekly basis and entered into an Excel spreadsheet which can then be used to easily monitor the performance of the system as well as the performance of drivers. The tripsheet data also enables the weights from the on-board weighing system to be compared to the weights recorded by the mill weighbridge and if a discrepancy occurs, the manager will know the system needs to be recalibrated or that there is a fault with the system.

6.4 Routine maintenance

The routine maintenance of cleaning the system and recalibrating (when necessary) is absolutely necessary to achieve acceptable reliability and accuracy from the system.

6.4.1 Calibration

Recalibration of the system may be required periodically. From Chapter Four (see Section 4.3) it was established that the standard error between on-board weighing systems and the mill weighbridge is 0.4 tons. By continuously comparing the truck weights recorded by the on-board weighing system tripsheets and the weights recorded at the mill weighbridge, it can be determined if the system needs to be recalibrated. If the error between the on-board weighing system and the mill weighbridge is consistently greater than 0.4 tons then the system should be recalibrated.

Recalibration is done by technicians from the suppliers of the on-board weighing system and the system is calibrated to whichever mill weighbridge that particular truck delivers.

6.4.2 Cleaning

The on-board weighing system works via cables that connect the loads cells located on the trailers of the truck to the tractor part of the truck. Cables are connected between the trailers and the tractor with connectors. These connectors should be checked, cleaned and lubricated regularly and any wear points on the cables should be shielded. The loads cells located at different points between the trailer chassis, axles and the trailer should also be cleaned and kept free of dirt.

6.5 Discussion and conclusion

The successful operation of an on-board weighing system depends on the loading environment, the management of the system as well as the maintenance of the system. An optimum loading environment is determined by topography of the environment and the method of loading with loose cane that is loaded on a flat level surface is considered to be most conducive to achieving accurate and consistent mass loads. Areas of the system that require management are driver training and continuous monitoring. Drivers need to be trained to become skilled in using the system as well as ensuring acceptance of the system. Continuous monitoring of the system is required to ensure the system is functioning correctly and when recalibration is required. Finally, routine maintenance which involves cleaning and lubricating the system should be done to ensure that accurate payloads are achieved consistently.

7. DISSCUSSION, CONCLUSION AND RECOMMENDATIONS

7.1 Discussion and Conclusion

An evaluation of on-board weighing systems for articulated haulage trucks in the South African sugarcane industry was conducted. Different types of on-board weighing systems are available for different configurations of trucks and trailers as well as different suspension types. Truck/trailer configurations with traditional mechanical suspensions are suited to load cell type on-board weighing systems and trailers with air suspension make use of pneumatic sensor type on-board weighing systems. It is envisaged that the benefits that can be realised from implementing an on-board weighing systems' include improved vehicle utilization reduced transport cost through increasing the payloads of vehicles, prevention of vehicle breakdowns and decreased downtime due to the prevention of overloading which causes structural damage, improved driver and vehicle safety through the prevention of overloading, elimination of legal infringements by preventing overloading, reduction in time between deliveries due to not needing to be weighed at government weigh stations, reduced weight disputes between the transporter and the receiver, increased road safety due to the prevention of overloading and preventing road damage which is largely caused by overloaded heavy duty trucks. The negative aspects of implementing on-board weighing systems are the initial capital investment that is required to install such a system together with the increase in managerial duties due to the on-board weighing system and good management in order to perform effectively. Initial studies conducted on the use of on-board weighing systems showed that vehicle utilisation can be improved and that the negative aspects of the system were outweighed by the return that the investment produced.

Various different transport methods exist within the South African sugarcane industry. The majority of road transport however, is effected by articulated trucks. It is envisaged that on-board weighing will be implemented on these trucks to improve their utilisation and reduce the overloading of these trucks which causes damage to roads. Articulated trucks are loaded by three primary methods, these being with loose cane on transloading zones by grab loaders, chain bundled cane on transloading loaded by cranes, and loose cane loaded infield by grab loaders. The methods of loading loose cane onto the trucks suits on-board weighing systems as very accurate payloads can be achieved whereas problems are realised when loading bundled cane as the size of the bundles limits the accuracy that can be achieved.

Three field operations using on-board weighing systems in the sugar industry were evaluated. The field operations were evaluated to determine the accuracy of on-board weighing systems when loading loose cane on transloading zones and when loading loose cane in-field, in order to determine the consistency of the measurement of the systems; to assess whether vehicle utilisation was improved when using the systems; to establish what factors relating to a transport operation have a significant effect on the effectiveness of the on-board weighing system, to compare the use of an on-board weighing system in a commercial transport operation and a smaller private operation and lastly to determine if overloading was reduced when on-board weighing systems were utilised.

In evaluating the accuracy of the on-board weighing systems, the mill weighbridge was used as the control measure. In the case where trucks were loaded on transloading zones with loose cane, the on-board weighing systems tended to overweigh by 0.4 tons (mean error = 0.4) and when trucks were loaded in-field the on-board weighing systems tended to overweigh by 0.3 tons (mean error = 0.3). The measurements were found to be reasonably consistent with 75% of values compared being within 0.5 tons.

In assessing whether vehicle utilisation was improved when on-board weighing systems were used it was established that the average GVM of vehicles with and without the systems were very similar. However the variation in GVM of loads was less when on-board weighing systems were used, hence enabling more loads to be at the targeted GVM and it was concluded that vehicle utilisation was improved.

Various different factors relating to the transport operation were evaluated to assess if they influenced the effectiveness of the on-board weighing systems. Factors evaluated included the drivers of the trucks, the cane variety and quality, the time of day at which deliveries were made, and the physical condition of the different transloading zones. It was established that different drivers, time of day and zone condition did not have an effect but cane variety and quality directly affected the average GVM of vehicles and consequently the effectiveness of the on-board weighing systems.

In comparing the use of on-board weighing systems in a large commercial transport operation to a relatively smaller private grower cum transporter operation it was found that the average GVM of the vehicles in the private operation was slighter higher but the variation in GVM of loads was significantly less than that for the large commercial transport operation. It was concluded that the smaller private operation was managed better with closer supervision of the on-board weighing system and thus the on-board weighing systems were used more effectively.

In all three field evaluations the proportion of loads overloaded as a percentage of the total loads delivered in case was calculated. In the case of the commercial haulier where trucks were loaded with loose cane on zones, trucks with on-board weighing systems were overloaded 32% of the time and trucks in the same fleet without on-board weighing were overloaded 41% of the time. In the private grower cum transporter operation only 4% of loads were overloaded and in the operation where trucks were loaded in-field, trucks with on-board weighing were overloaded 6.3% of the time and trucks in the same fleet without on-board weighing were overloaded 10.4%. In the two field evaluations where there were trucks with and without on-board weighing systems it was seen that overloading was reduced in the trucks with on-board weighing. However, further reduction is needed to reach the government regulation of 4% overloads which was achieved in the private grower cum transporter operation.

An economic evaluation using a capital budget system was conducted to determine the feasibility of the investment in an on-board weighing system for a grower cum transporter operation. The cost of transport and the related transport cost saving through increased vehicle utilisation is dependent on the lead distance that a truck has to travel. The economic evaluation was applied to different transport scenarios to ascertain the pay off period required for different lead distances. The shortest payoff period was realised when the lead distance was 60 km which was 1 year for a payload increase of 4 tons, 2 years for a payload increase of 3 tons and 3 years for an increase of 2 tons. Thereafter, by the fifth year of the investment, considerable returns can be realised for payload increase of 2, 3 and 4 tons.

To conclude, the implementation of an on-board weighing system on an articulated sugarcane haulage truck is an economically viable investment that enables the payload of a vehicle to be increased, while it reduces the variation in GVM for loads and prevents trucks from being overloaded. In order to achieve maximum effectiveness from the on-board weighing system it needs to be managed closely and be maintained through regular maintenance.

7.2 Recommendations for further research

The overloading of trucks beyond the government regulations was seen to occur consistently throughout the study. With the new government RTMS regulation it is going to become more imperative that hauliers reduce the number of loads that are overloaded. On-board weighing systems have been shown to reduce the extent of overloading however further reduction is needed. It is recommended that management methods employed in the utilisation of on-board weighing systems to reduce overloading be researched together with investigating other methods of reducing overloading while still maintaining profitable payloads.

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9. APPENDIX

Appendix A. Capital Budgets for Payload Increase of Two Tons

Lead distance = 20 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	35910	35910	35910	35910	35910	35910
4	Change in Taxable Income	35910	-8840	9060	18010	35910	35910
5	Change in Tax (40%)	14364	-3536	3624	7204	14364	14364
6	Change in Net Cash Flow	-67954	39446	32286	28706	21546	21546
7	PV of Δ Net cash Flows (I = 7%)	-67954	36865	28200	23433	16437	15362
8	Accumulative Net Income	-67954	-31089	-2889	20544	36981	52343
9	**Percentage of Investment Returned**	**24%**	**65%**	**97%**	**123%**	**141%**	**158%**

Lead distance = 40 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	40185	40185	40185	40185	40185	40185
4	Change in Taxable Income	40185	-4565	13335	22285	40185	40185
5	Change in Tax (40%)	16074	-1826	5334	8914	16074	16074
6	Change in Net Cash Flow	-65389	42011	34851	31271	24111	24111
7	PV of Δ Net cash Flows (I = 7%)	-65389	39263	30440	25526	18394	17191
8	Accumulative Net Income	-65389	-26126	4314	29840	48234	65425
9	**Percentage of Investment Returned**	**27%**	**71%**	**105%**	**133%**	**154%**	**173%**

Lead distance = 80 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	43776	43776	43776	43776	43776	43776
4	Change in Taxable Income	43776	-974	16926	25876	43776	43776
5	Change in Tax (40%)	17510	-390	6770	10350	17510	17510
6	Change in Net Cash Flow	-63234	44166	37006	33426	26266	26266
7	PV of Δ Net cash Flows (I = 7%)	-63234	41276	32322	27285	20038	18727
8	Accumulative Net Income	-63234	-21958	10364	37649	57687	76414
9	**Percentage of Investment Returned**	**29%**	**75%**	**112%**	**142%**	**164%**	**185%**

Lead distance = 100 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	32775	32775	32775	32775	32775	32775
4	Change in Taxable Income	32775	-11975	5925	14875	32775	32775
5	Change in Tax (40%)	13110	-4790	2370	5950	13110	13110
6	Change in Net Cash Flow	-69835	37565	30405	26825	19665	19665
7	PV of Δ Net cash Flows (I = 7%)	-69835	35107	26557	21897	15002	14021
8	Accumulative Net Income	-69835	-34728	-8171	13727	28729	42750
9	**Percentage of Investment Returned**	**22%**	**61%**	**91%**	**115%**	**132%**	**148%**

Appendix B. Capital Budgets for Three Ton Payload Increase

Lead distance = 20 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	52233	52233	52233	52233	52233	52233
4	Change in Taxable Income	52233	7483	25383	34333	52233	52233
5	Change in Tax (40%)	20893	2993	10153	13733	20893	20893
6	Change in Net Cash Flow	-58160	49240	42080	38500	31340	31340
7	PV of Δ Net cash Flows (I = 7%)	-58160	46019	36754	31427	23909	22345
8	Accumulative Net Income	-58160	-12142	24612	56040	79949	102294
9	**Percentage of Investment Returned**	**35%**	**86%**	**127%**	**163%**	**189%**	**214%**

Lead distance = 40 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	58451	58451	58451	58451	58451	58451
4	Change in Taxable Income	58451	13701	31601	40551	58451	58451
5	Change in Tax (40%)	23380	5480	12640	16220	23380	23380
6	Change in Net Cash Flow	-54429	52971	45811	42231	35071	35071
7	PV of Δ Net cash Flows (I = 7%)	-54429	49505	40013	34473	26755	25005
8	Accumulative Net Income	-54429	-4924	35089	69561	96317	121321
9	**Percentage of Investment Returned**	**39%**	**94%**	**139%**	**178%**	**208%**	**236%**

Lead distance = 80 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	63674	63674	63674	63674	63674	63674
4	Change in Taxable Income	63674	18924	36824	45774	63674	63674
5	Change in Tax (40%)	25470	7570	14730	18310	25470	25470
6	Change in Net Cash Flow	-51296	56104	48944	45364	38204	38204
7	PV of Δ Net cash Flows (I = 7%)	-51296	52434	42750	37031	29146	27239
8	Accumulative Net Income	-51296	1138	43888	80919	110065	137304
9	**Percentage of Investment Returned**	**43%**	**101%**	**149%**	**190%**	**223%**	**253%**

Lead distance = 100 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	47673	47673	47673	47673	47673	47673
4	Change in Taxable Income	47673	2923	20823	29773	47673	47673
5	Change in Tax (40%)	19069	1169	8329	11909	19069	19069
6	Change in Net Cash Flow	-60896	46504	39344	35764	28604	28604
7	PV of Δ Net cash Flows (I = 7%)	-60896	43461	34364	29194	21822	20394
8	Accumulative Net Income	-60896	-17435	16930	46124	67945	88339
9	**Percentage of Investment Returned**	**32%**	**81%**	**119%**	**152%**	**176%**	**199%**

Appendix C. Capital Budgets for Four Ton Payload Increase

Lead distance = 20 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	67595	67595	67595	67595	67595	67595
4	Change in Taxable Income	67595	22845	40745	49695	67595	67595
5	Change in Tax (40%)	27038	9138	16298	19878	27038	27038
6	Change in Net Cash Flow	-48943	58457	51297	47717	40557	40557
7	PV of Δ Net cash Flows (I = 7%)	-48943	54633	44805	38951	30941	28917
8	Accumulative Net Income	-48943	5690	50494	89446	120387	149303
9	**Percentage of Investment Returned**	**45%**	**106%**	**156%**	**200%**	**235%**	**267%**

Lead distance = 40 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	75642	75642	75642	75642	75642	75642
4	Change in Taxable Income	75642	30892	48792	57742	75642	75642
5	Change in Tax (40%)	30257	12357	19517	23097	30257	30257
6	Change in Net Cash Flow	-44115	63285	56125	52545	45385	45385
7	PV of Δ Net cash Flows (I = 7%)	-44115	59145	49022	42893	34624	32359
8	Accumulative Net Income	-44115	15030	64052	106945	141569	173928
9	**Percentage of Investment Returned**	**51%**	**117%**	**172%**	**219%**	**258%**	**294%**

Lead distance = 80 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	82402	82402	82402	82402	82402	82402
4	Change in Taxable Income	82402	37652	55552	64502	82402	82402
5	Change in Tax (40%)	32961	15061	22221	25801	32961	32961
6	Change in Net Cash Flow	-40059	67341	60181	56601	49441	49441
7	PV of Δ Net cash Flows (I = 7%)	-40059	62936	52565	46203	37718	35251
8	Accumulative Net Income	-40059	22877	75441	121645	159363	194614
9	**Percentage of Investment Returned**	**55%**	**126%**	**184%**	**236%**	**278%**	**317%**

Lead distance = 100 km

Step	Year	0	1	2	3	4	5
1	Investment(-ve)	-89500					
2	Depreciation of Capital		-44750	-26850	-17900		
3	Transport cost saving	61694	61694	61694	61694	61694	61694
4	Change in Taxable Income	61694	16944	34844	43794	61694	61694
5	Change in Tax (40%)	24678	6778	13938	17518	24678	24678
6	Change in Net Cash Flow	-52484	54916	47756	44176	37016	37016
7	PV of Δ Net cash Flows (I = 7%)	-52484	51324	41712	36061	28240	26392
8	Accumulative Net Income	-52484	-1160	40552	76614	104853	131245
9	**Percentage of Investment Returned**	**41%**	**99%**	**145%**	**186%**	**217%**	**247%**