University of Southern Queensland

Faculty of Health, Engineering and Sciences

Tracking Machinery to Investigate the Effect of Compaction during Sugar Cane Harvesting

A dissertation submitted by

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ENG 4111 and 4112 Research Project

towards the degree of

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Abstract

The Australian sugar industry is a major part of the agricultural sector within Queensland and New South Wales. Through research it was noticed that there was no easy way for producers to evaluate the traffic pathways through the field. Therefore an investigation was devised to track the machinery during sugar cane harvesting to determine the potential increase in bulk density and therefore the decrease in plant production. A field trial was conducted in the Bundaberg region to assess the validity of such a program constructed to use GPS (global positioning system) data gathered from the load-out bins. Manual observations of the load-out bins during harvesting were also conducted to help validate the program. It was concluded that the program reported the correct answer, but was not running correctly due to limitations. The program was developed to report the number of times the growing bed was crossed and to help identify the potential loss of production in terms of sugar cane yield. From the measurements taken as part of the field trial, an average increase of 0.153tonne/m^3 was witnessed within the traffic lanes. From this data, a yield decrease of 5% was inferred and subsequently a profit reduction of \$0.03 per metre of growing bed crossed.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own effort, excepts where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

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Date

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A special thank you must go to Clyde for allowing me to conduct the testing on his property up in Bundaberg. The contract drivers of the harvester and load-out bins must also be thanked for allowing me to attach the GPS units to the machines while harvesting was being conducted.

A special thanks to Sombat Khawprateep for helping out with the field trials, soil coring and photography during the harvesting operation.

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To the NCEA for allowing me to use the facilities and equipment needed to undertake the soil coring and bulk density data analysis.

Finally, thanks to the University of Southern Queensland for allowing me the opportunity to undertake a thesis and contribute to the knowledge base within my chosen area.

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1.0 Introduction

With the increasing size of machinery used within the modern agricultural industry, soil health has become an ever increasing part of the farming management system. Soil compaction is a function of machine weight and therefore was the main focus point of this project (Hurney 1975).

The larger machines that traffic the soil are causing a higher degree of damage than the previous lighter machines and this is beginning to negatively affect plant production. Root growth and water availability have been noticeably reduced in many studies involving soil compaction (Soane & van Ouwerkerk 1994). Therefore it would prove beneficial to the entire agricultural industry if a program could be created to report to the farmer on where any vehicle has travelled, and then producers could improve the management strategies undertaken.

Due to the daily bin allocation process associated with sugar harvesting, there is an increased pressure on drivers to complete the task as quickly as possible. This causes the load-out and harvester drivers to move through the field in an unorganised manner. This leads to the load-outs entering the field at a point for easy access then manoeuvring under the harvester to be filled by crossing a number of growing beds (Hurney 1975).

The sugar industry would benefit greatly from a program such as this because of the nature of the sugar cane growing cycle. Firstly, sugar cane is a ratoon crop which means that it is harvested every year and the subsequent crop is grown from the shoots left within the soil (Braunack et al. 2006); this allows for the accumulation of soil compaction throughout a number of years. As most producers in Australia use single row harvesters, this means that the traffic lanes within a sugar cane field account for approximately 50% of the layout. Therefore it is essential that any extra trafficked area can be accounted for and aimed to be minimised or mitigated (Barbosa & Magalhães 2015).

1.1 Project Aim

This project aims to investigate machinery position during sugar cane harvest relative to the traffic lanes to determine the risk and degree of soil compaction on the growing bed.

1.2 Project Objectives

To achieve this aim a number of objectives must be met which are:

1. Investigate the configurations and weight of machines that are likely to be used during the completion of harvest
2. Determine the different traffic possibilities that a traffic lane can be subject to in terms of number of load-out bins and field characteristics
3. Measure the soil compaction across the traffic lane before and after harvest, then observe the variability of compaction
4. Investigate the machinery position through the field by attaching a GPS unit and analysing the data to determine how many times the growing beds were crossed during the harvesting process

Project Specification can be found in Appendix A

1.3 Dissertation Outline

1.3.1 Literature Review

This section will contain background literature on soil compaction in sugar cane and the parameters that affect it as a process throughout the field. Compaction management and how the production of sugar cane is effected are other brief topics that are described in this section.

1.3.2 Experimental Methodology

The methodology and order of testing required to satisfy the objectives and aims of the project will be outlined in this section. The experimental design will be detailed and explained here along with the testing exercises.

1.3.3 Results

Results from the experimental method will be reported in this section detailing all the recorded values and begin to draw trends between the data; in the form of graphs and tables.

1.3.4 Discussion

This section will provide reasoning for the trends observed from the results and evaluate the program used to identify the crossing over of the growing beds during harvest. The usefulness and usability will be the main factors evaluated, but accuracy will also be evaluated briefly.

1.3.5 Conclusion

The conclusion will draw all the major findings together and provide a final evaluation of the program and the flow on effects if used correctly. This section will also include the need for further work and the areas that need to be repeated to ensure validity.

2.0 Literature Review

This literature review investigates the fundamental background material concerning soil compaction to gain insight into the relationships between moisture and compaction within the soil during harvesting. The three main sections in focus are: 1) the mechanics of compaction and different parameters that influence the severity, 2) management practices for minimising compaction and, 3) compaction within the sugar cane industry. Understanding this material should provide sufficient information to allow for a better management plan to be formulated and integrated into a sugar cane production system.

2.1 Soil Compaction

2.1.1 General Characteristics

Soil compaction describes the process of a particular volume of soil, when put under a force, deforming and compressing into a smaller volume. All soils consist of a certain percentage of sand, silt, clay and pore spaces and these constituents determine the texture of the soil and help to define a classification. Australia has its own classification standard which was published in 1996, and has since been revised (Isbell 1996). Many different countries have their own classification key due to the abundance of different soils found over the world.

Compaction studies in cultivated soils are especially important in Queensland due to the larger amount of clay soils used for agricultural production. Clay soils are ideal for crop production because of their high water holding capacity. This high water holding capacity is achieved because of the increased amount of smaller pore spaces within the pore network (Haddadchi et al. 2015). As the pore spaces become smaller, the amount of suction needed to release the water increases due to soil physics (Zhang et al. 2016). The soil will have small pores due to clay particles being very small in comparison to sand and silt particles, therefore they fit together easier, lessening the size of the air voids (Gregorich et al. 2011); see **figure 2.1**.

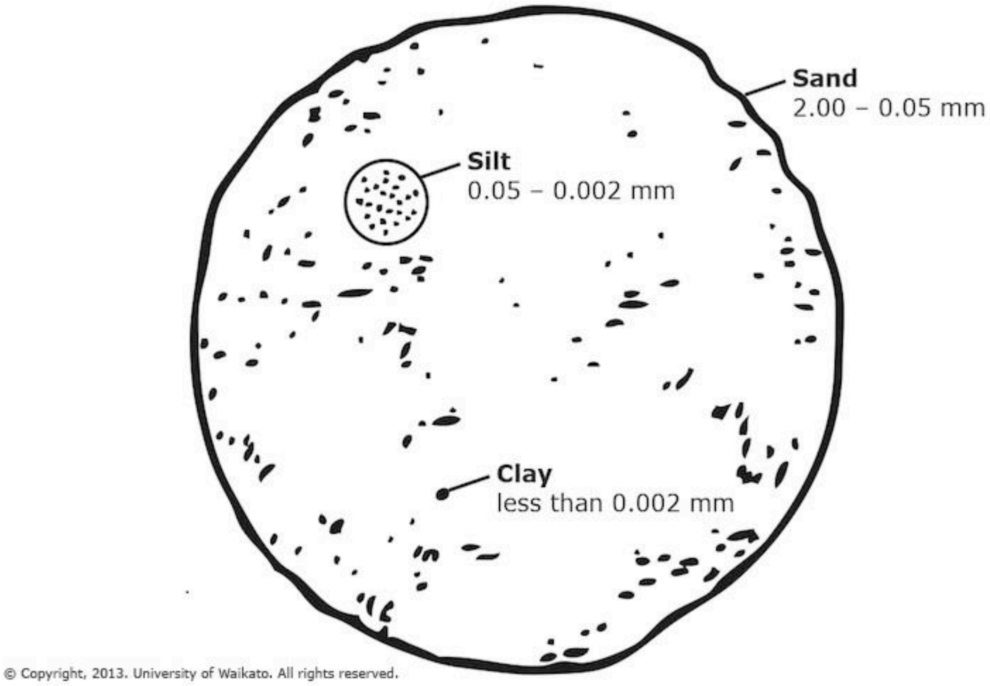


Figure 2.1 Relative sizes of sand, silt and clay (University of Waikato 2013)

As an animal or machine applies its weight to soil, it will cause compaction to a degree corresponding to certain parameters. In some instances the force applied will not be sufficient to cause permanent deformation (no change in density), but as discussed further in this chapter is dependent upon multiple factors. If an area is continually being used for grazing, compaction isn't an issue due to the producer not relying on the area for intensive crop production. During times of drought, cultivation with a feed crop may be used for grazing; in this case the management of the animals is important. If the cultivation receives rainfall then the compaction susceptibility increases and the animals should be removed.

Movement of water through the soil can be described by different methods. Gravity is the fundamental inducer of movement simply by the forces pulling all mass towards the earth's centre; water is forced through the pore network of the soil. Coarse textured soils will have a low water holding capacity due to the larger pore sizes (lack of clay content). The size of the pores will determine how much (force) suction is needed to move the water from the pores (Yu et al. 2011). Due to matric potential, the smaller pores will retain water more easily than larger pores (Prathapar et al. 1992).

2.1.2 Soil Compaction Mechanics

Tyre characteristics such as size, pressure and presence of lugs will influence the wheel-soil contact area which directly correlates to the impact and degree of soil deformation. This is especially important in sugar cane fields as it is approximated that over 50% of the field experiences at least two machine passes (harvester and load-out bin) during a harvest event (Barbosa & Magalhães 2015). Barbosa and Magalhães (2015) reported that tractive tread tyres will exhibit a higher peak pressure when compared to a smooth treaded tyre under the same inflation pressure and approximately same tyre width. However, tyres with minimum void space (white area in **figure 2.2**) will result in the stress propoagtion over the full contact area (Barbosa & Magalhães 2015). **Figure 2.2** below shows the difference in contact area between a tractive treaded tyre and a smooth treaded tyre, under varying loads. Therefore it is more benficial to install smooth treaded tyres where possible to reduce the severity of the compaction, rather than minimise the effected area.

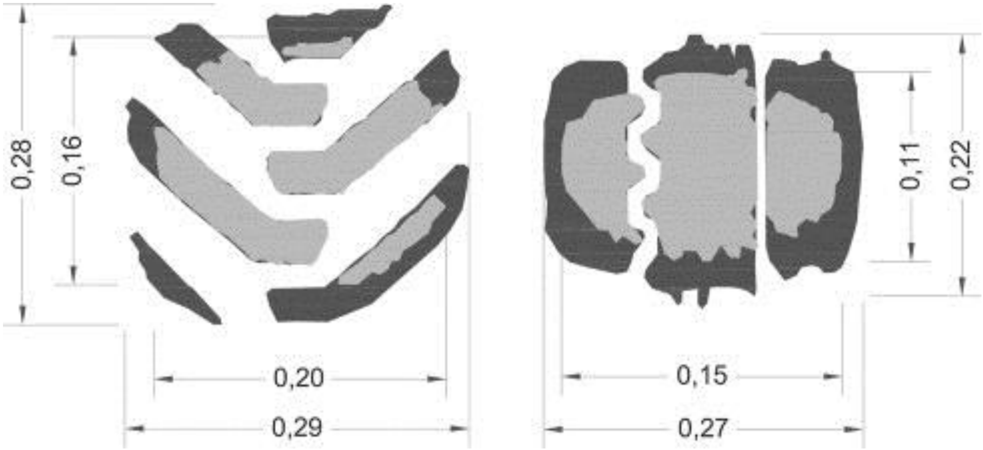


Figure 2.2 Wheel-soil contact area as a function of load (light grey = lesser load, dark grey = larger load) between tractive treaded tyre (left) and smooth treaded tyre (right) (Barbosa & Magalhães 2015)

Describing stresses that are propagated through the soil under the wheel contact area can be accomplished with the help of the equation that Boussinesq (1885) provided (equation 3.1). This equation was formulated under the assumptions that the entire soil medium under investigation was an isotropic, homogenous volume; properties that are continuous across the whole volume (Boussinesq 1885; Horn & Lebert 1994). Equation 2.1 will return the principle stress σ_1 (Pascals) of a point under a vertical point load, P, with a radius from the point load and angle theta from the vertical to the radius explained in **figure 2.3**.

$$\sigma_1 = \frac{3P}{2\pi r^2}\cos\theta \tag{2.1}$$

Where P = load (Newtons)

r = radius to load point (metres)

θ = angle between vertical and radius line of action (radians)

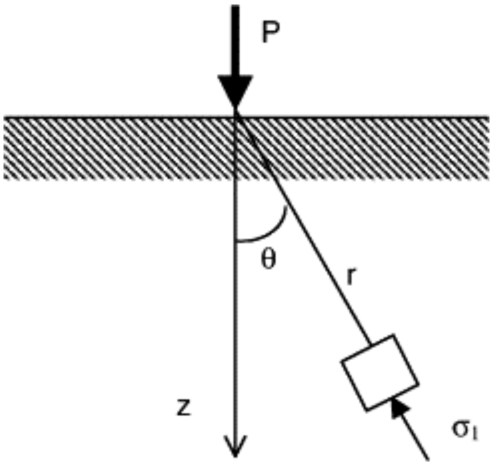


Figure 2.3 Soil element stress under a point load (Defossez & Richard 2002)

This method was valid for approximating the stresses in close proximity to the line of action of the applied load. This led Fröhlich (1934) to further investigate equation 2.1 and found with the addition of a concentration factor, that the wider scope of the stresses could be correctly determined. This concentration factor, xi (ξ), is chosen based on the strength of the soil; ξ=4 is chosen for hard soil, 5 for firm and 6 for soft soils (Fröhlich 1934; Söhne 1953). Söhne (1953) then proposed that the area under investigation should then be split up into n number of loading elements each with a fraction of the total load acting at the centroid of the element. The total vertical stress σ_1 (Pascals) is then calculated via equation 2.2 (Lamandé & Schjønning 2011; Söhne 1953) and demonstrated in **figure 2.4**.

$$\sum_{i=1}^{n}\left(\sigma_1\right)_i = \sum_{i=0}^{n}\frac{\xi P_i}{2\pi r_i^2}\cos^{\xi-2}\theta \tag{2.2}$$

Where ξ = concentration factor

P = load (Newtons)

r = radius from load point (metres)

θ = angle between vertical and radius line of action (radians)

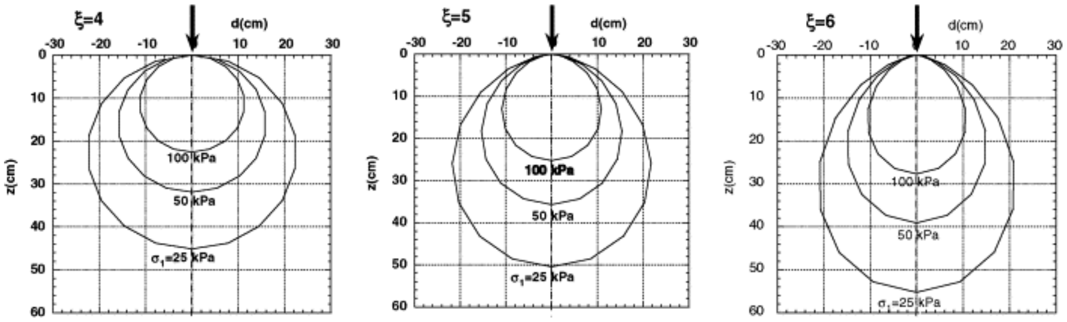


Figure 2.4 Stress distributions within a soil profile under a constant load with concentration factors of 4 (left), 5 (middle) and 6 (right) using equation 2.2 (Defossez & Richard 2002)

It is known that a tyre resting on the soil will not exhibit point load behaviour, rather a load over an area (pressure); an area that takes the shape of an ellipse as seen from **figure 2.2** exaggerated by the smooth treaded tyre (Barbosa & Magalhães 2015; Söhne 1953). Johnson and Burt (1990) then reported that triaxial stresses also needed to be understood due to trafficking causing stress in the vertical, longitudinal and transverse planes. These triaxial stresses are depicted in **figure 2.5**. If the load is static σ_1 is the vertical normal stress (approximated by equation 3.2), σ_2 is the longitudinal and σ_3 is the transverse stress (Johnson & Burt 1990).

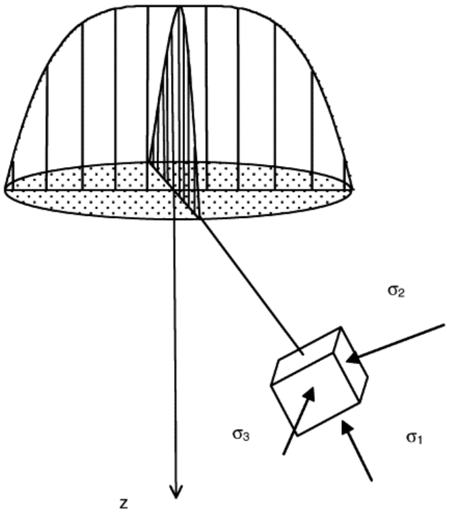


Figure 2.5 Triaxial stresses acting on a soil element under a static load (Defossez & Richard 2002)

To find the longitudinal and transverse stresses, O'Sullivan et al. (1999) investigated the work of Gill and Vanden Berg (1967) who suggested that the mean stress was linked more to compaction rather than the principle stresses. σ_1 was calculated by Söhne (1953) then with the aid of regression constants and a concentration factor chosen based on the soil density, equation 2.3 will give an approximation for σ_2 and σ_3 (Gill & Vanden Berg 1967).

$$\ln\left(\frac{\sigma_1}{\sigma_n}\right) = c_1 z - c_2 A + c_3 \xi \tag{2.3}$$

Where σ_1 is calculated from equation 2.2 (Pascals)

σ_n = principle stresses for n=2 & n=3

c_1, c_2, c_3 = regression constants

A = wheel-soil contact area (metres^2)

ξ = concentration factor

Although shear stresses occur in the soil under a load, the mean normal stress was discovered to be dominant when considering compaction (O'Sullivan et al. 1999). As the stress on the soil increases, the volume of the soil will decrease at a rate due to its elastic nature (and isotropic assumptions). This elastic parameter labelled κ (kappa), describes the swelling index of the soil as seen in **figure 2.6** (Ortigao 1995). If the stress induced on the soil never exceeds a proposed critical pressure P_c, then the soil will be able to elastically deform without permanent damage to the structure (the rebound line will coincide with the compression line in **figure 2.6**). The critical pressure of the soil will change depending on the area under investigation. It will depend typically on soil grain size and moisture content (Bian et al. 2016; Horn & Lebert 1994). Once the stress exceeds the critical pressure of the soil the sample will begin to experience plastic deformation. This phenomenon is described by the virgin compression line and the rate of decrease is labelled λ (lambda). As the stress is released, the rebound line will propagate back towards zero stress at a rate of κ (Defossez & Richard 2002).

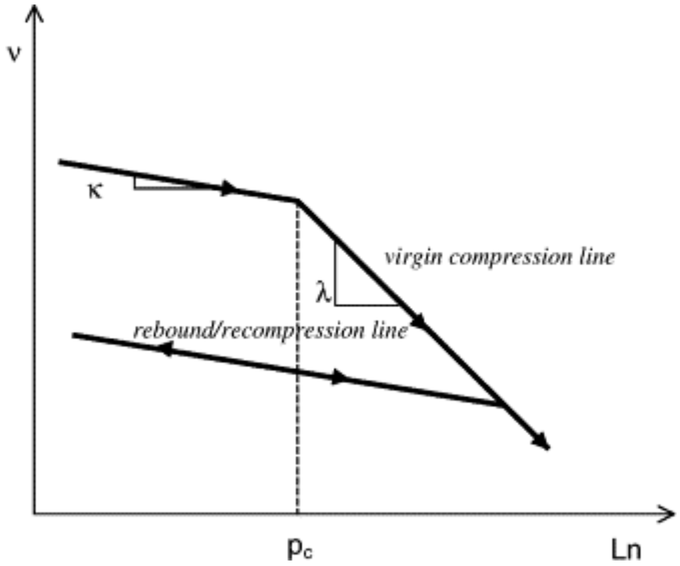


Figure 2.6 Volume as a function of stress in a soil sample (O'Sullivan et al. 1999)

2.1.3 Measuring Soil Compaction

Soil compaction can be measured using volumetric measurements or a range of equipment. A common method to assess compaction is by measuring soil penetration resistance using a soil penetrometer. This device measures the force required to invert a cone of known dimensions into the soil. Force and area are known, and then the pressure resistance can be calculated. Sensors can be attached that determine the depth into the profile that is being measured. Different configurations of this machine include a single unit mounted to a portable trolley which is better for small jobs; or multiple units mounted on a tractor which can map a larger area simultaneously (Fountas et al. 2013). The penetrometer is robust and readily usable; but the result that it provides can be skewed due to a number of soil characteristics. Soil moisture, for instance, needs to be taken into account when conducting this test because wet soil is more susceptible to manipulation by a force. To calibrate the penetrometer results, another test that measures the density of the soil needs to be undertaken so that samples can be compared.

Bulk density is measured by taking a soil sample from the desired area either on the surface or at different depths. This sample is taken with a special steel cylinder that has a known volume and forced into the ground at the desired depth. As it is pushed into the ground the soil is trapped inside, then the extra soil that protrudes out each end is removed ensuring that the amount of dirt inside corresponds to the known volume. Once collected the cylinder needs to be capped to ensure that no moisture escapes. Once at the lab, remove the caps and remove all the dirt from inside the ring into a container and weigh the sample (the weight of the container should be calculated before filling it with dirt). The bulk density is calculated by dividing the total weight of the soil sample by the known volume of the sample that was taken (measured in tonnes per cubic metre) (Chen et al. 2012).

Frame sampling is another way of measuring bulk density and relating to compaction where a square steel frame of 0.5m^2 is hammered into the ground at the desired depth such that the layer of interest is within its bounds. The upper edge of the frame is then used as a reference level and the elevation of the soil surface is then measured (either by hand or electronic methods) 200 times within the square. A layer is then removed and weighed and then elevation measurements are in the same x-y coordinates as the first round which is used to calculate the volume of soil removed giving the bulk density. This process can be repeated at various thicknesses depending on the part of the profile being investigated (Soane & van Ouwerkerk 1994).

Another simple method of calculating bulk density in the field is the rubber balloon method which involves using a balloon or bladder and filling it with water when placed into an area of soil that has been excavated. Pouring a known amount of water into the balloon and ensuring that the entire shape is pressed against the wall of the hole, the volume of dirt extracted can be calculated. The excavated soil is weighed and the bulk density is calculated (Soane & van Ouwerkerk 1994).

With recent upgrades in technology has come the introduction of measuring soil characteristics with minimum soil disruption. One of these methods is x-ray micro tomography where the soil is replicated through the use of images taken by a machine and then analysed. The image taken detects pore volume spaces by distinguishing between air, moisture and soil on a microscopic level through the use of penetrating waves. After testing, it can be observed that this technology is more accurate than the standard cone penetration test, but comes at a much higher price making it unfeasible for field testing. **Figure 2.7** shows an x-ray tomography image of the soil core before and after compaction with the pore spaces shown in c, d, e and f (Menon et al. 2015).

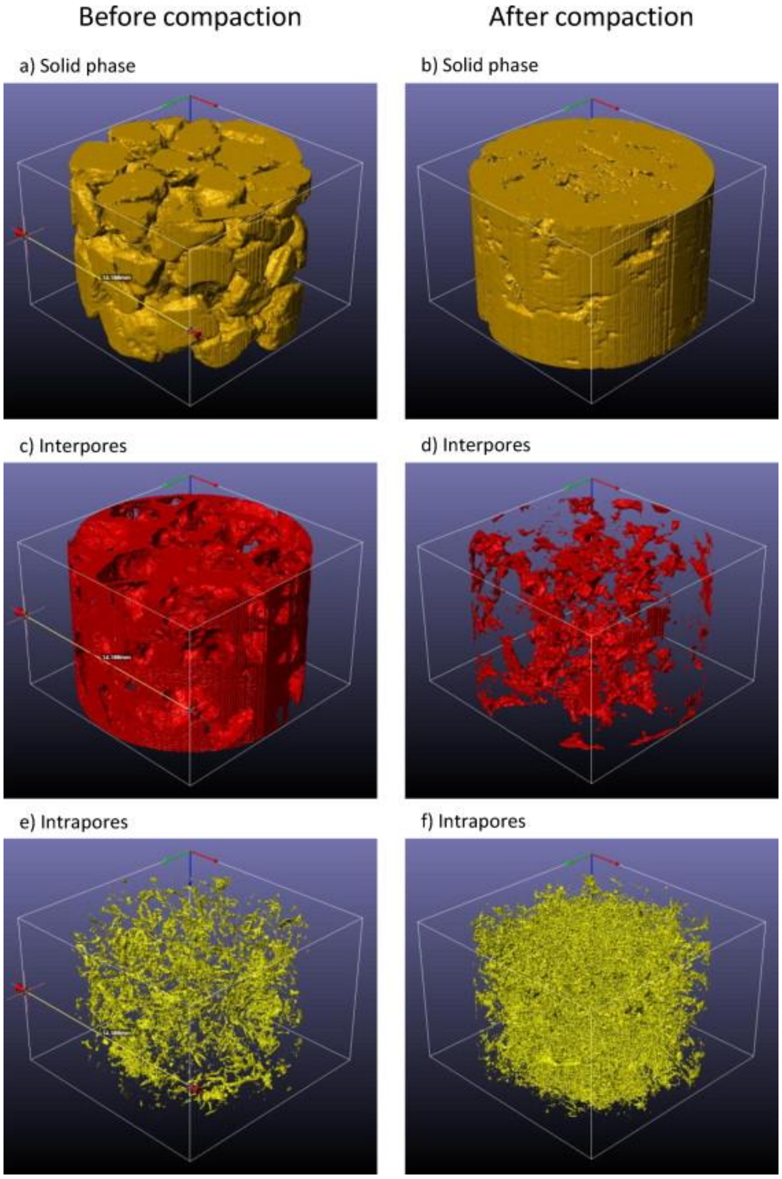


Figure 2.7 X-ray micro tomography image of a soil core (Menon et al. 2015)

Computer models can also be used to make an assessment of the risk of compaction in agricultural production systems. Programs do this based on initial investigation of the soil such as the moisture content and strength of the top and subsoil layers. Then an estimation of the amount and type of traffic that the area is looking to support is input. The model will take the inputs and perform energy flow algorithms which detail the flow paths that energy would mathematically travel to get from one place to another (Rücknagel et al. 2015).

Another method is to lay strain transducers in the ground and apply forces to the gauged areas to investigate the displacement caused by the force. This is another robust test, but errors are still present due to the moisture content and density. Although problems are still present, this test will give indications instantaneously and can be calibrated readily (Shahgholi & Abuali 2015).

2.1.4 Damage Remediation

As seen above, the effects of soil compaction can have an impact on soil characteristics. These effects then have to be undone by disturbing the soil in the root zone to allow for voids to take in air and moisture. The easiest and quickest way to do this is by tilling the ground to the desired depth. This action will break up the topsoil allowing air into the system. This action will also however allow for any moisture in the topsoil to be liberated, which is undesired if the producer is expecting a period of dry after tilling.

Tilling will decrease soil compaction only if undertaken correctly. The depth at which the soil is tilled is dependent upon the tines being used (shape, length and width etc.). The optimum working depth for maximum soil disturbance is called the critical depth. If the tine is used at a depth deeper than critical depth, the soil will begin to be compacted because the tine can no longer force the dirt up and out of the furrow; reducing the area disturbed also. Therefore tilling will only reduce soil compaction if used at critical depth or at a depth that is shallower than critical (Spoor & Godwin 1978).

Another common method is crop rotation; from shallow rooting crops to plants with a deep, more vigorous deep rooting system (**figure 2.8)**. This natural way of remediating soil compaction has set-backs as it will require an entire growing season to achieve results, and this method will also deplete the water availability in the soil. Depending on what crop is produced, it may be able to be grazed or used for hay production; which means that it can reduce the damage of soil compaction while still benefiting the producer, provided it is not carried out at high rates (Calonego & Rosolem 2010).

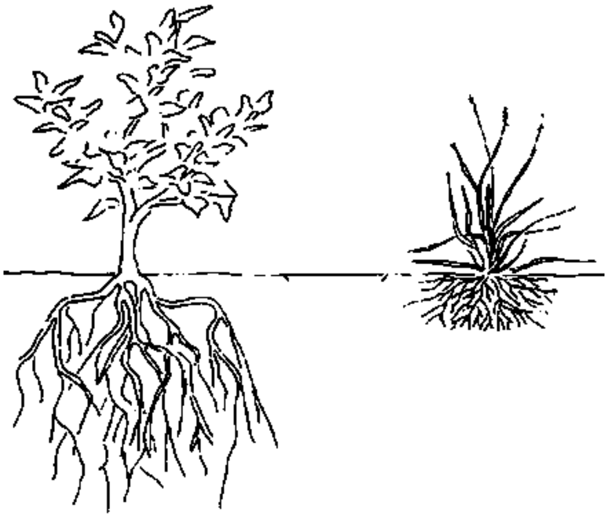


Figure 2.8 (Left) Deep rooting plant (right) and shallow rooting plant (FAO 2008)

2.2 Soil Compaction Management

Farming systems across the world are susceptible to soil compaction which is a leading cause of yield reduction. To reduce the in-field effects of compaction, certain management strategies can be implemented. Ng Cheong et al. (2009) describe management strategies of soil compaction within a sugar farming system. This study found that moisture and traffic management were imperative to the reduction in soil compaction (Antille et al. 2016; Ng Cheong et al. 2009).

2.2.1 Moisture Management

Managing soil moisture during events that require trafficking of the soil can be quite difficult due to the increased pressure on producers to minimise loss of possible profit. The longer that the crop stays in the field, the more the product will degrade. Increased soil moisture has been investigated and found to increase the effects of soil compaction under traffic (Chen et al. 2016). This can be linked to soil cohesion and internal angle of friction within the soils, but have more of an effect in clayey soils; much like the Australian vertosol (Isbell 1996). These parameters describe the shearing resistance of the soil outlined by equation 2.4, which is the Mohr-Coulomb failure criterion used in traditional soil mechanics (Al-Shayea 2001). The internal angle of friction, ϕ (phi), describes the resistance for the soil particles to slide past (fail) each other when subjected to an axial load corresponding to a normal stress of σ_n. Soil cohesion is affected by the amount of clay found in the sample; due to the mineralogical properties of clay (Al-Shayea 2001)

$$\tau = \sigma_n \tan\phi + C \tag{2.4}$$

Where τ = shear stress (Pascals)

σ_n = normal stress (Pascals)

ϕ = internal angle of friction (degrees)

C = soil cohesion (Pascals)

Compaction within a clay soil will be maximised at optimum water content; if the water content is higher or lower than this optimum, the compaction will have a lessened effect. As the moisture content increases (when lower than optimum) the water molecules cause the clay particles to separate slightly and this causes the electrostatic and electromagnetic attractions (van der Walls forces) to decrease (Al-Shayea 2001). Cohesion as a function of moisture content and clay content is shown in **figure 2.9**.

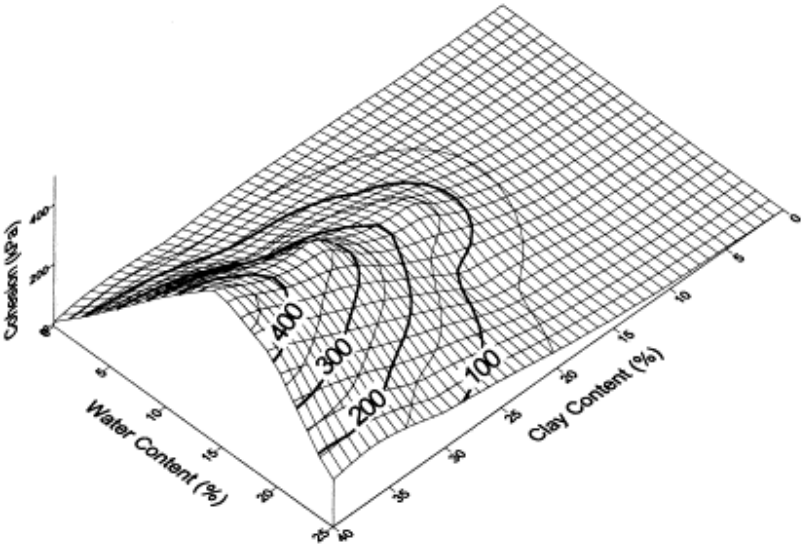


Figure 2.9 Effect of water content and clay content on soil cohesion (Al-Shayea 2001)

The internal angle of friction is hard to manage for any farmer, but is influenced by the moisture and clay content of the soil (Marui & Tiwari 2004). The moisture content can be managed to a degree if the area is under irrigation management; but seasonal rainfall will constantly affect the moisture status of the soil. As **figure 2.10** depicts, the angle of internal friction for clay soils is maximum for samples with small water content, and found to not be affected by clay content at low moisture content. As the soil with increased clay content increases in moisture content, the angle of internal friction becomes less and allows for the shear stress to lower for the same normal stress.

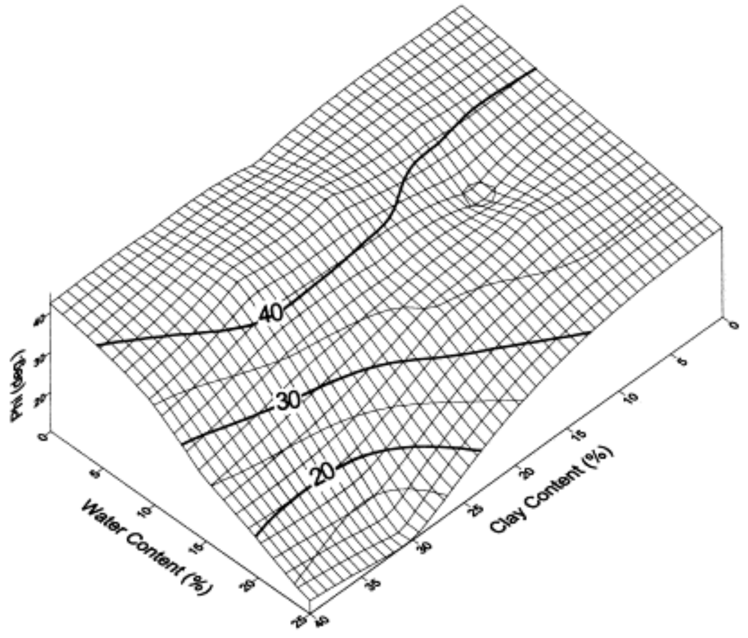


Figure 2.10 Effect of water content and clay content on internal angle of friction (Al-Shayea 2001)

2.2.2 Machinery Management

Random traffic within a field has an increased chance of causing compaction in areas that will dramatically affect the potential production rates of the soil. Repeating passes over the field for different operations without driving in the correct locations increases the density of the entire soil body (McKyes 1985). Progressively driving over the same wheel tracks will cause not only a change in bulk density deeper down the profile, but will also increase the volume of soil affected. **Figure 2.11** describes how the density changes and the corresponding soil volume that is affected under a sprayer tyre after 1, 5, 10 and 15 passes respectively from left to right.

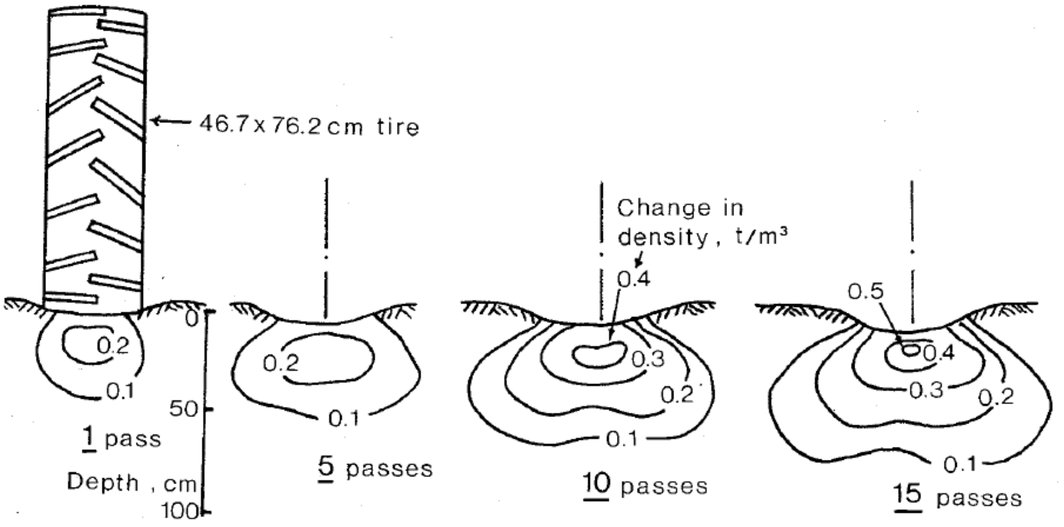


Figure 2.11 Change in density for a clayey soil under a constant load for varying number of repeated passes (McKyes 1985)

Raghavan et al. (1977) found that density change could be directly related to tyre inflation pressure and number of passes. This led to the derivation of equation 2.5 which returns bulk density, γ_d (tonnes/metre^3), knowing the number of repeated passes, average wheel-soil contact pressure and moisture content. As discussed above in the moisture management subsection, soil cohesion will be maximised if soil moisture content is at an optimum (**figure 2.9**). The third term in equation 2.5 accounts for this by adding the logarithm of moisture content below the optimum.

$$\gamma_d = A + B\log(Np) + C\log(w) \tag{2.5}$$

Where A, B, C = soil constants

N = number of repeated passes of tyre

p = average wheel-soil contact pressure (Pascals)

w = moisture content by weight (%), below the soil optimum

After further studies, Raghavan et al. (1977) discovered that wheel slip began to influence the compaction of sandy and clay soils up to a maximum of 35 percent wheel slip. At higher amounts of wheel slip the tyres begin to excavate the topsoil which means that the shear strain characteristics of the soil are of considerable importance. All factors were then included in equation 2.6. This function is limited in validity to moisture content values that are below the optimum humidity for compaction, and wheel slip rates smaller than 25 percent. Examples of soil constants can be found in McKyes (1985), page 111, table 5.1.

$$\gamma_d = \gamma_o + A_1 \log\left\{\frac{Np}{p_o} * (1+S)\right\} + B_1 \log(w) \qquad (2.6)$$

Where γ_o = initial soil density (tonne/metre^3)

A_1, B_1 = soil constants

N = number of repeated passes of tyre

p = average wheel-soil contact pressure (Pascals)

p_o = tyre pressure at which minimum compaction occurs (Pascals)

S = wheel slip (%)

w = moisture content by weight (%), below the soil optimum

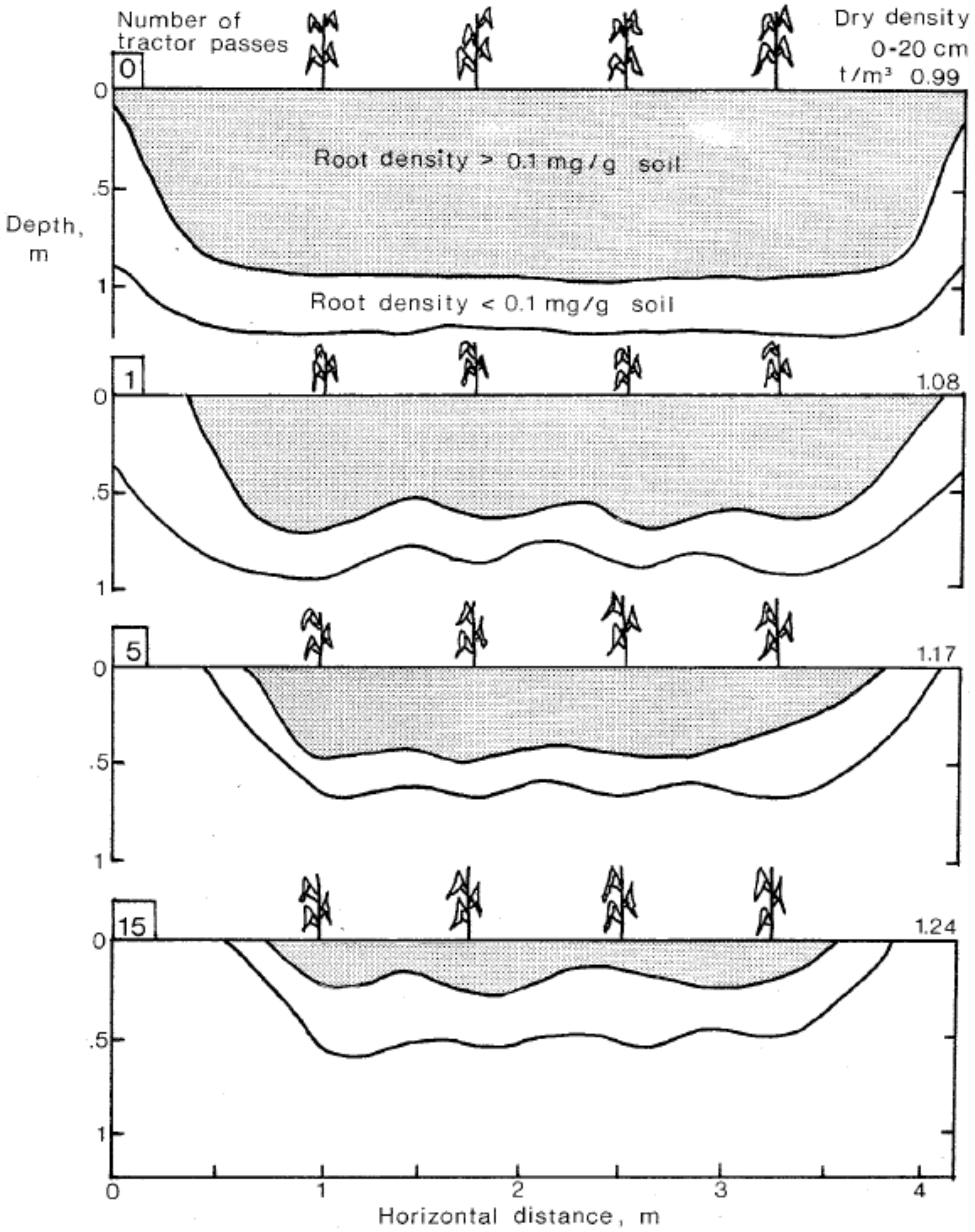


Figure 2.12 Root density distributions for a corn crop after 0, 1, 5 and 15 passes at a constant wheel-soil contact pressure (McKyes 1985)

Figure 2.12 shows how the root density in a field of corn changes under varying amounts of repeated passes. As the soil density increases within the root zone, the plant needs to put more energy into drilling through the stronger soil. Further studies by McKyes (1985) set out to describe yield loss as a function of soil density, and is explained in equation 2.7.

$$Y^* - Y = C\left(\gamma_{dry} - \gamma^*_{dry}\right)^2 \tag{2.7}$$

Where Y^* = maximum obtainable crop yield (tonnes/hectare)

Y = actual crop yield (tonnes/hectare)

C = compaction sensitivity factor

γ_{dry} = actual soil dry density (average of 10-40cm depth) (tonnes/metre^3)

γ^*_{dry} = optimum soil dry density for maximum yield (tonnes/metre^3)

Control traffic farming (CTF) has improved farming systems all across Australia by reducing the amount of random traffic a field experiences. Dedicated traffic lanes were introduced as the machinery used within the agricultural industry became larger and heavier. These newer random traffic machines enabled farmers to be more productive at the cost of soil health (Tullberg et al. 2007).

Permanent traffic lanes not only reduce the effect of compaction within the field, but also increase the tractive efficiency due to the localised compaction under the traffic lane (Taylor 1983). These lanes are formed based on the landscape and desired travel direction by the farmer with the help of guidance systems such as GPS (Global Positioning System). If the trafficking can be kept to the same lanes across every operation that occurs over the land, then a reduction in overlap of operations will also be observed (Gasso et al. 2014). However, implements will need to be a specific width (length from centre to centre of a set of traffic lanes) in order for them to be used effectively. Wheel centres on all machines will also need to be modified to suit the traffic lanes, which can be costly (McPhee et al. 1995).

Once the traffic lanes have been established, the machines that pass over them now need to be as precise as possible. Many tractors now have the ability to be driven via GPS guidance. The basic items needed for operation of a guidance system are the satellites (subscriptions), the receiver (dish) on the tractor and the screen that is used to view all data (area completed, speed and rates). Depending on the guidance system installed, the accuracy of the driving can be more, or less dependable. Systems that offer more accuracy such as real time kinematic (RTK), will have a larger set-up cost due to the need for a base station. The base station is required for this option because the rover (tractor/machine) will transmit and receive signals from the base station as well as directly from the satellite (Perez-Ruiz et al. 2012). These systems can cost between twenty and thirty thousand dollars, including base station; but the savings that are made on spraying and fertiliser can easily outweigh the set-up cost (Kingwell & Fuchsbichler 2011).

Tyre sizes and pressures can also be altered to improve the efficiency of the machine while reducing the effect of compaction. Section 2.1.2 discussed that a smaller peak pressure was desirable. This can be achieved through the implementation of larger diameter tyres which increase the contact area between the tyre and the soil surface. Schjønning et al. (2015) reported that increased tyre pressure will decrease the tyre-soil contact area; while decreasing pressure will increase the contact area. A larger contact area reduces the peak pressure because the same force is acting over a larger area of the soil. Therefore, to reduce the potential for increased soil compaction, tyres that are not being used for power should be smooth treaded, at an optimum tyre pressure and have a large diameter practical to the situation.

2.3 Sugar Cane Production

2.3.1 Bed Preparation

Bed preparation is an intensive program that can be completed many ways depending on the machinery available. Firstly a tractor passes over the final ratoon harvested cane and tills the entire field to unearth the cane still left in the ground to ensure it does not shoot in the next season. This process also equilibrates the compaction across the entire field to a more productive level.

If the field has an increased number of large clods after tilling, then another machine that has an action much like a rotary hoe is used to break down these large clods for ease of workability. Once the soil is free of large clods, another machine tows an implement that forces dirt from in between rows together to form half growing beds. Depending on the tractor, the implement can be used to do a single row, or multiple at a time.

Once the half growing beds are formed, the plant cane is dropped in between a set of beds. Plant cane is cut from a growing crop into billets approximately 30cm in length. Along the stalk of the cane are nodes, and at every node there is an eye that can produce new shoots of cane. The same implement that was used to open the row for the cane to be planted is used to cover the plant cane with dirt to allow growth.

2.3.2 Harvesting

As technology has advanced, the machines used during the harvesting processes of sugar cane have increased dramatically. Firstly the harvester itself is the biggest machine to traverse the lane weighing in at approximately 19 tonne (Deere & Co. 2016c). This machine (3520) was released in 2012 and adopted by many producers because of the advancements with cleaning and cutting efficiencies. Deere & Co. (2016c) have recently (May 2016) released a new model sugar cane harvester (CH570) that weighs an approximate 21.5 tonne with more technological advancements than the previous 3520 (Deere & Co. 2016b). As this machine is very new to the market, most producers will still be using the 3520 or equivalent.

The harvester can store a minimal amount in the on board system and therefore needs to be constantly unloading the cane into a load-out bin that drives alongside the harvester. Configurations of the load-out bins are diverse; the source of power can come from either a tractor or truck and the towed bins can be single, double or triple axle trailers. Tractors and trucks may also have dual drive wheels and in some instances, the trailers may also have dual wheels for weight distribution (Meyer 1998). As discussed in section 2.1.2 and in **figure 2.1**, treaded tyres should only be installed on the drive wheels of these machines and smooth traction tires on the bins to reduce the severity of compaction. Front wheel assist (FWA) tractors are most common for this procedure and weigh up to approximately 12.5 tonne unloaded (Deere & Co. 2016a). Load-out bins vary in size from smaller bins that can weight from 4 to 12 tonne when fully loaded, or larger bins that can be filled to 16 tonne (Braunack et al. 2006).

As the base cutter of the harvester moves along the ground it is idealised that it will not enter the ground and damage the cane root system in the soil. Ma et al. (2014) reports on the efficiency of different base cutter system designs and the related stool damage. As the harvester base cutter is cutting the cane it is being fed into the harvesting system, the damage to the cane left in the ground can be significant enough to disturb its growing ability for the next season. As each ratoon crop grows from the remnant cane in the ground, the sprawl of the new crop can be much greater than the previous; which causes the cane to become more tangled and possibly harder to harvest (Lu et al. 2008).

The sugar industry further impedes on the possible yield due to a localised area being managed so that a single farmer does not have all of his sugar harvested at its prime. This protocol was introduced because the mill can only handle a certain amount of sugar at a time; if every producer harvested at the same time the mill would not be able to process the entire mass. If the sugar is cut and not processed quickly, the sugars will begin to chemically react and break down; the billets have to be processed within 24 hours of harvesting. This means that within the supply area of the mill, each producer is rostered a certain time period to harvest sections of their crop; which may occur close to a rain event (Bundaberg Sugar 2016).

2.3.3 Lane Use during Harvesting

Dual row harvesters are very rare within the Australian sugar industry and therefore the majority of producers use single row harvesters. Single row cane harvesters will need to be driven over every row that has cane growing. Therefore, it is known that any traffic lane set will be used by a minimum of two machines (harvester and load-out bin/tractor). Depending on the length of a harvesting run, yield and the size of the load-out bins there may be need for multiple load-out bins to be used depending on the scenario. Assuming that the machinery can enter and exit from both ends of the traffic lanes, a single lane will experience a minimum of 4 machinery passes during harvest (**figure 2.13**). If the lane can only be entered from one side of the paddock, then machinery will need to reverse over the same part of the lane, multiplying the traffic by two (**figure 2.15**). If one lane is specifically investigated, it can be observed that it will experience double the traffic due to it being used twice for every row of sugar cane harvested. As seen in **figure 2.15** the load-out bin travels along lanes one and two, while the harvester is on lanes three and four. They move in the upwards direction along the lane until the row is fully harvested and will then turn to the right to enter the next lane. The machines will then move downwards in the figure and reach the end of lanes two and three for the load-out bin, and four and five for the harvester; when at the end the machines will both turn left to enter the next lane. This process is repeated until the last row of sugar is harvested. If lane four is investigated, it can be observed that it receives two passes from both the harvester and the load-out bin because both machines only move one lane over every pass (Gui & Wu 2014).

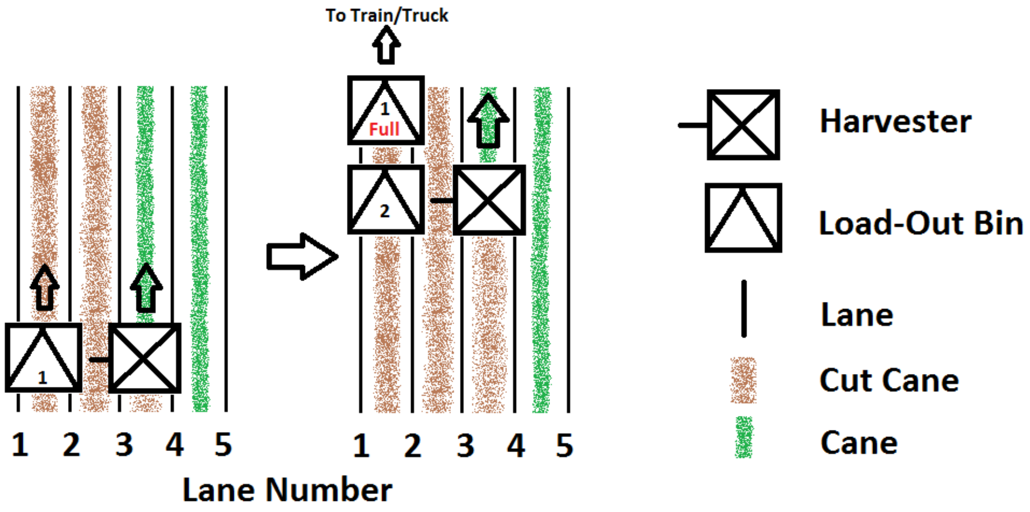


Figure 2.13 Cane harvested from the bed between lanes 1 & 2 exceeds the capacity of a single bin and therefore a second load-out bin is needed. The number inside the load-out bin defines how many bins have been used

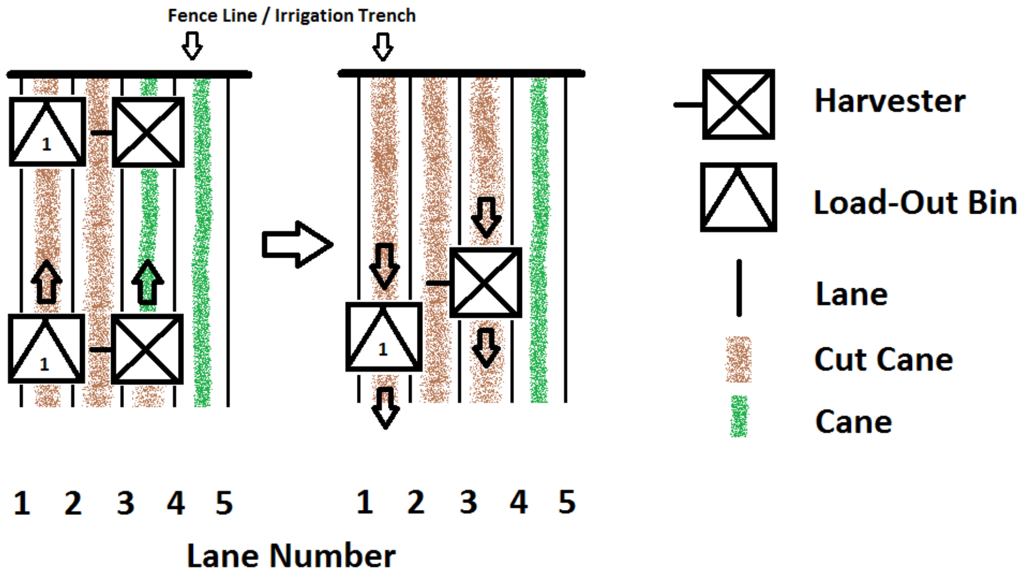


Figure 2.14 Field can only be entered from one end and therefore the machines have to reverse back over the lane to exit field

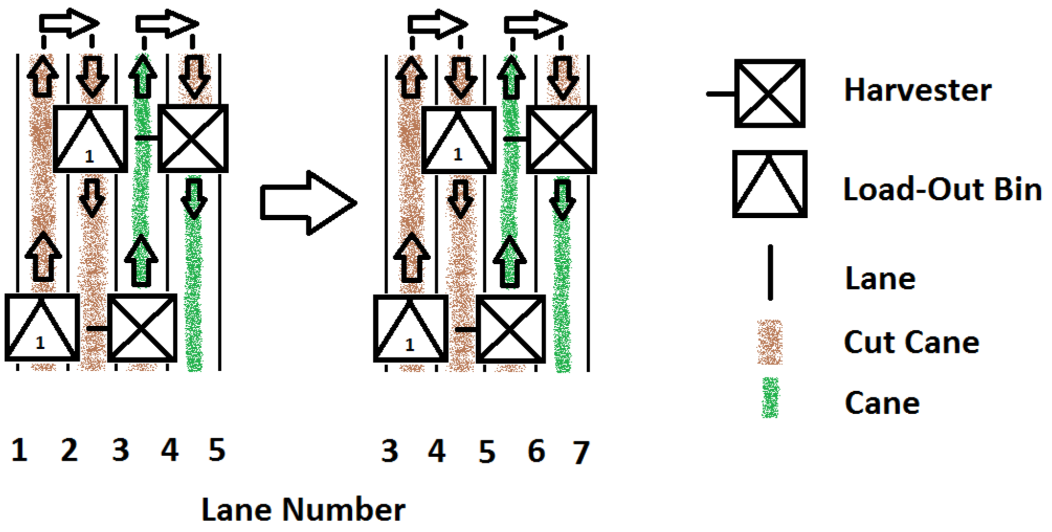


Figure 2.15 Schematic of lane use by harvester and load-out bin needing only 1 pass

With this much traffic, it is important to ensure that all machinery are driving on the traffic lanes. The use of GPS for bed preparation and planting is generally used to allow for minimum error in the placement of the sugar cane, then the harvester can be set up with GPS also and use the same traffic lanes. As the cane is growing, external effects such as wind, rain or hail may cause the stalk to grow irregularly instead of predominately vertical. If this occurs, then the harvester may need to alter its path as it is harvesting.

2.3.4 Effects of Compaction on Crop Production

Soil compaction has many effects on the health of the soil which directly affects the production rates. Studies have previously shown that the effect of soil compaction has altered the production capacity of the ground (Barik et al. 2014). As stated above, compaction of soils will result in smaller pore volumes within the soil. The plants need to provide more suction to make the water available which requires increased energy.

Nutrients that the plant needs for production are present in the soil solution, when the plants take up water, they are also being provided with these nutrients. It is necessary that the plants are supplied with an adequate amount of resources during production. Some nutrients can only be accessed by the plant if they are in close proximity to the roots of the plant; other nutrients are free to move with the soil solution. Soil compaction will both reduce the size of pores, making it harder to access water and nutrients, but also decrease the hydraulic conductivity which reduces the rate that water enters the soil (Di Sante et al. 2015).

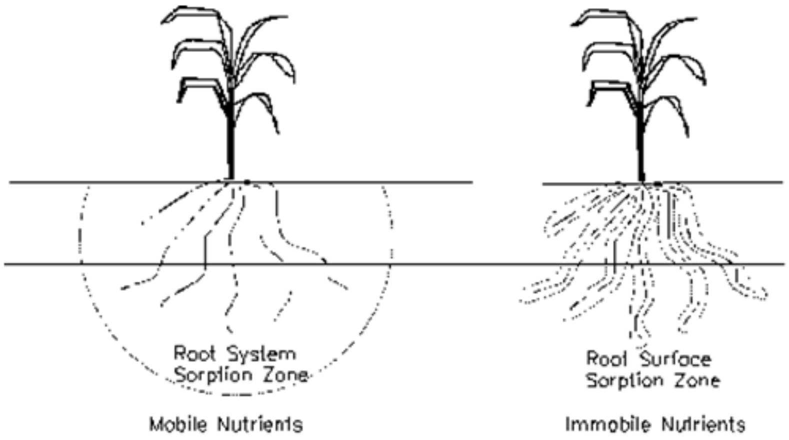


Figure 2.16 (left) Mobile nutrient uptake potential area (right) immobile nutrient uptake potential area (Raun et al. 1995)

Compaction will also affect the infiltration rates of rainfall into agricultural soils due to the shrinkage of the soil pores (Gui & Wu 2014). **Figure 2.17** shows a soil sample with aggregates sieved and confined to 2-5 mm to investigate the difference in water infiltration before and after compaction, while fully saturated. White areas indicate soil aggregates while the colours ranging from blue to red indicate the velocity of water. Red corresponds to a velocity approximating to 0.4 ms^{-1} while the blue areas indicate a velocity much lower approximating to 0.005 ms^{-1}. The speed of infiltration is expected to be quite high in a sample such as this due to the aggregate size being relatively large (**figure 2.1**) and this is reinforced by Valdes et al. (2014) who reported the infiltrations rate of clay to be in the range between $10^{-5} – 10^{-8}$ ms^{-1}. Therefore, in clay soils it is imperative that the highest infiltration rate is achieved to allow the plants the maximum amount of available moisture. **Figure 2.17** shows that after compaction the rate is similar in some areas, but the relative area that transmits water is much smaller (Menon et al. 2015).

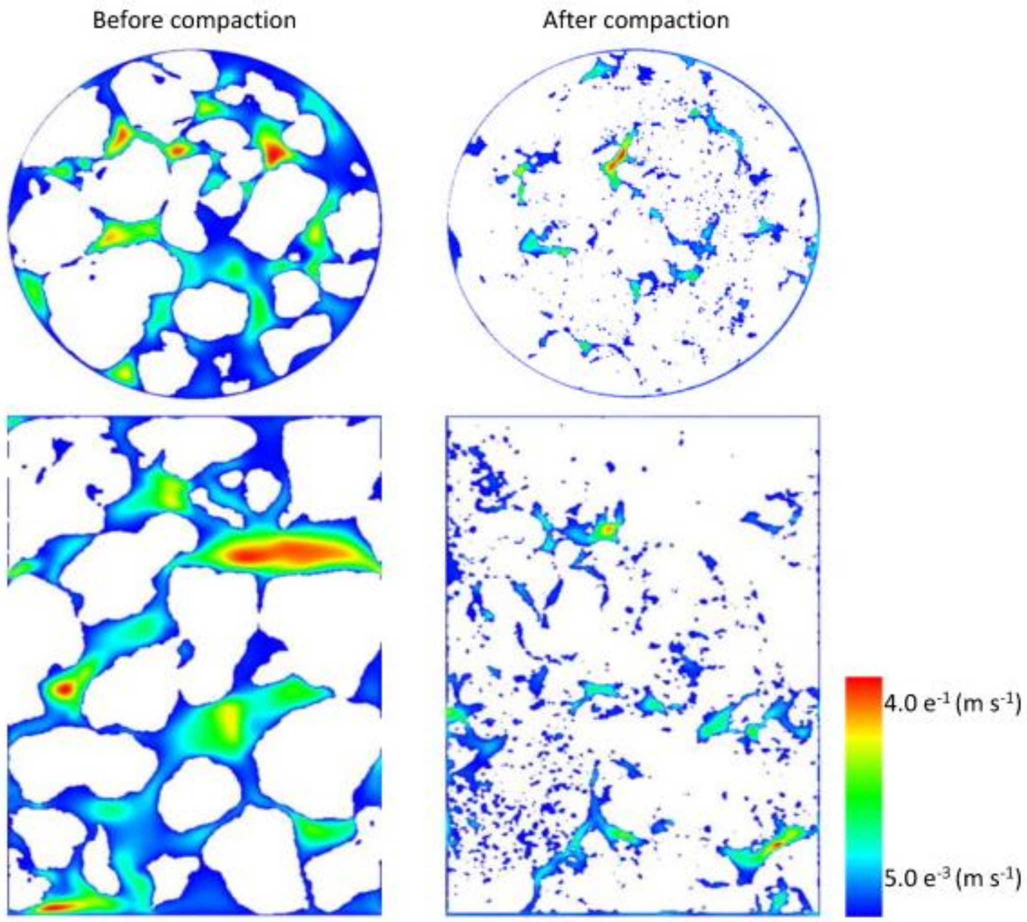


Figure 2.17 Cross sectional view of water velocity through a soil sample before and after arbitrary compaction (Menon et al. 2015)

Limited root growth is an adverse effect of compaction in many agricultural production systems (Batey & McKenzie 2006). As soil is compacted the particles are forced closer together while the soil pores are reduced in size. This will affect the root growth of any plant as extra energy is needed to break through the harder soil. In this case, the roots will find it easier to propagate laterally rather than down the profile which ultimately reduces the maximum potential nutrient and water uptake area of the plant (Nunes et al. 2015). **Figure 2.18** describes root length under different soil strengths for a maize crop, which have similar rooting systems to sugar cane plants.

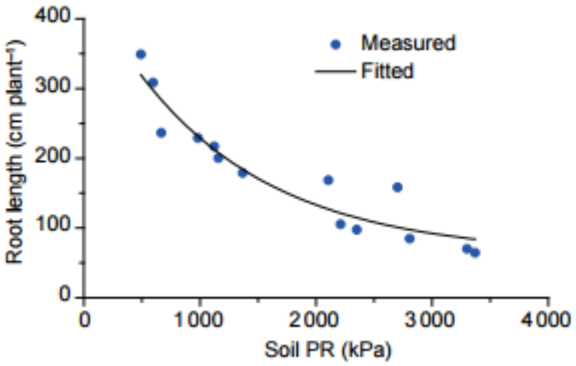


Figure 2.18 Root length of maize under soils with varying soil penetration resistances (Lin et al. 2016)

As the soil becomes more compacted, the root-soil contact area increases which decreases the oxygen diffusion rate. As the soil pores become smaller, they are more likely to be filled with water, which effects how much of the pore network can distribute oxygen throughout the system. If oxygen cannot be taken up or diffused back into the soil, then the production rate of the crop will be affected (Soane & van Ouwerkerk 1994).

3.0 Design and Methodology

The following methodology details the steps taken to complete the field trials as well as the data gathering and analysis.

3.1 Field Trial

This section will contain an outline of the steps taken to complete the necessary testing when out in the field. Although timing of testing was dependant on factors that could not be predicted or controlled, the procedures remained constant.

3.1.1 Site Selection

The trial site was located near Bundaberg, QLD, (24°46'55.2"S 152°14'46.9"E) shown in **figure 3.1**. This site was chosen based on its attributes: I) conditions were typical for many areas of sugar cane being grown in Queensland; and II) the site was being harvested during the time of the dissertation and therefore all work could be completed.

Figure 3.1 Location of Bundaberg trial site

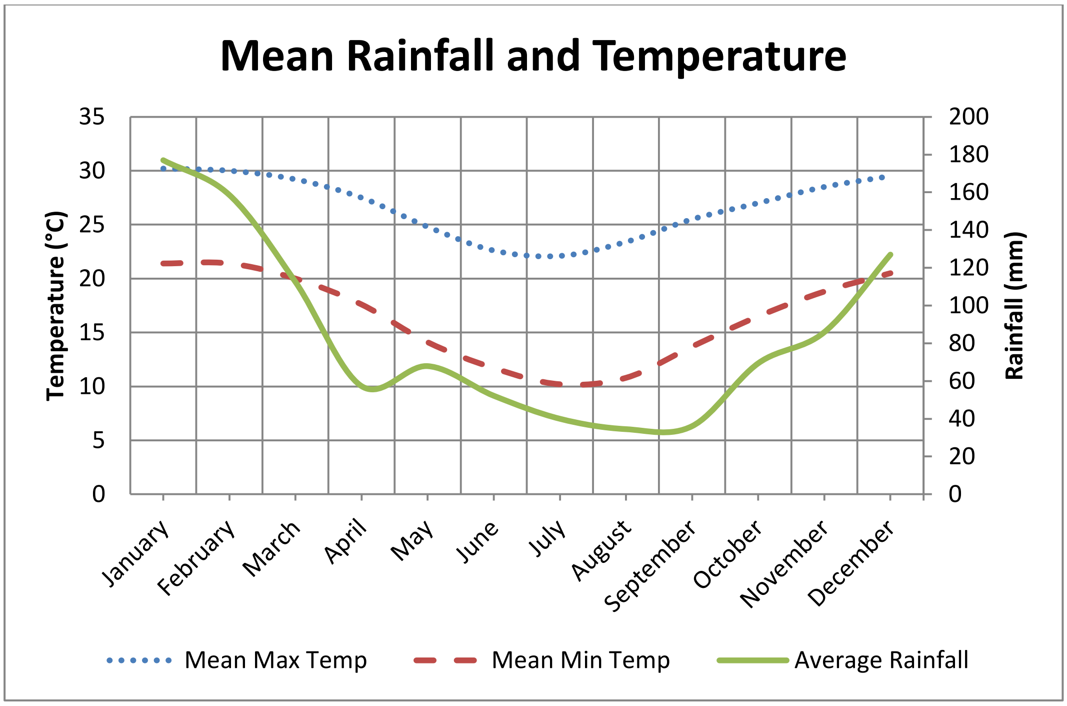


Figure 3.2 Mean rainfall and temperatures for Bundaberg (BOM 2016)

3.1.2 Original Experimental Design

Soil compaction was measured using a cone penetrometer at an interval of 20 centimetres (Braunack et al. 2006) perpendicular to the direction of the traffic lane. The testing run spanned across three growing beds and two traffic lanes to ensure that the effect of compaction in the traffic lanes was adequately measured. This process was completed three times along the harvesting run under the same conditions to help attain a comparable average. The penetrometer measured down to a depth of 600 millimetres ensuring that a sufficient portion of the soil profile was measured, other investigations have also used this depth (Braunack & McGarry 2006). This operation was conducted before and after harvesting to model the increase in compaction from the machines that are involved with harvesting. **Figure 3.3** shows the layout for the penetrometer and soil cores that were to be collected for the different situations (1, 2 and 3 load out bins plus the harvester, and a control with zero traffic).

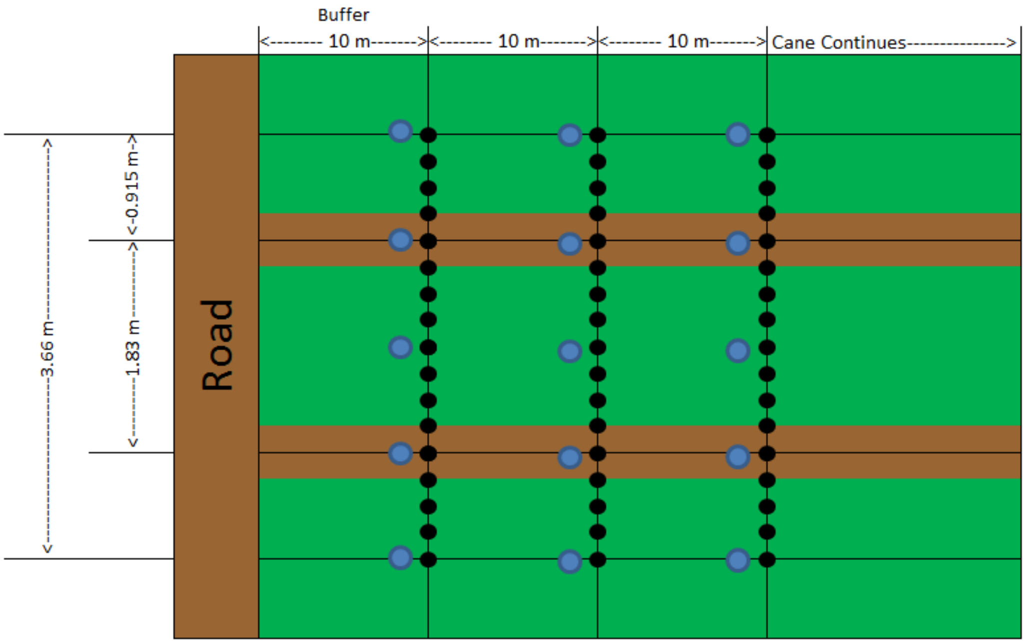


Figure 3.3 Original design where the small black dots represent the penetrometer sample points and the larger blue dots represent the soil coring sample points. This would be repeated for 1, 2 and 3 load out bins plus the harvester. The green area represents the plant cane and brown strips represent the traffic lane.

The variability of the configurations that the lane can experience was tested by observing a number of fields under different conditions. Firstly the scenario of the traffic lane only is used by the harvester and one load-out bin, which is the more common occurrence. Another possible use of lanes is the harvester once and two or more load-out bins due to the first load-out bin being full before the complete harvest of the row.

Bulk density and moisture measurements were taken as close as possible to the areas that the cone penetrometer was used to calibrate the compaction data (see **figure 3.3**). For bulk density, a steel cylinder of known volume was inserted into the ground at the same depth of 600 millimetres down the soil profile and split up into sections 100 millimetres in length. The dry weight of the soil was then found by drying the moisture out of the sample for 72 hours at 105 degrees. The weight of the solids divided by the known volume gives the bulk density. Moisture content was found by measuring the weight of the sample before and after drying; the difference in weight (without the weight of the bag) is the weight of water that was in the sample. The weight of water divided by the total wet weight of the sample is the moisture content (by weight) as a percentage.

The accuracy of the driving of the load-out bin was determined by placing flexible poles into the centre of two traffic lanes. These poles represented the straight path that the machines should be driving along. A mark was made on the front (bulbar or front bumper) in the centre of the machine that was driving down the row and the flexible poles came in contact with the front of the machine. Observations were made on where the pole came in contact with the machine relative to the centre mark and recorded on a datasheet. The poles were set up in a row with a constant distance separating them of 1 metre for a length of 20 metres. This process was conducted multiple times during the harvest on random traffic lanes. This was not completed due to the GPS data being of more relevance and more accurate.

The cone penetrometer was not taken to conduct testing due to the timeliness involved with the harvesting process. The location of the testing area was not decided until the property owner was allocated a volume of cane for the time period. This made the testing methods and procedures difficult to schedule because of the time dependency of both the harvesting and the testing itself. The cone penetrometer data is needed alongside the bulk density data to ensure the validity, which is explained further in section 5.0, and therefore the bulk density data is only referred to as a general outcome and not explicitly valid for this project.

Adding to the difficulty for testing was that there was not a block of plant cane within close proximity to the area that was being harvested during the time allocation. Testing on the block of plant cane would have allowed for the results to be the most meaningful because the soil is much looser and susceptible to compaction.

3.1.3 Adjusted Experimental Design

Observations were made on how many times a traffic lane receives traffic during the harvesting operation. As seen in **figures 2.13, 2.14 & 2.15** above in chapter 2 there are multiple ways that a lane can be used during this process; because of this, some lanes experience more/less and heavier/lighter machinery. This was completed by simply observing the operations and making note of what machines enter/leave the traffic lane during the harvesting of the cane. The weights of each machine are known and a total weight for that lane will be deduced.

The signature of the machines crossing the growing beds during harvesting was determined from the GPS data and then corresponded to the total amount of times that the soil in the growing bed was disturbed or compacted. The growing beds are prepared using a planter with high precision guidance and therefore assumed they have an accurate and relatively straight heading. The data from the load out bins was then analysed by manipulation in matlab to determine when the load out bins crossed over the growing bed. This data was taken while the load out bins were harvesting to ensure that there was no bias towards the drivers aiming to drive in the middle of the growing beds, and to simulate the characteristics of normal harvesting.

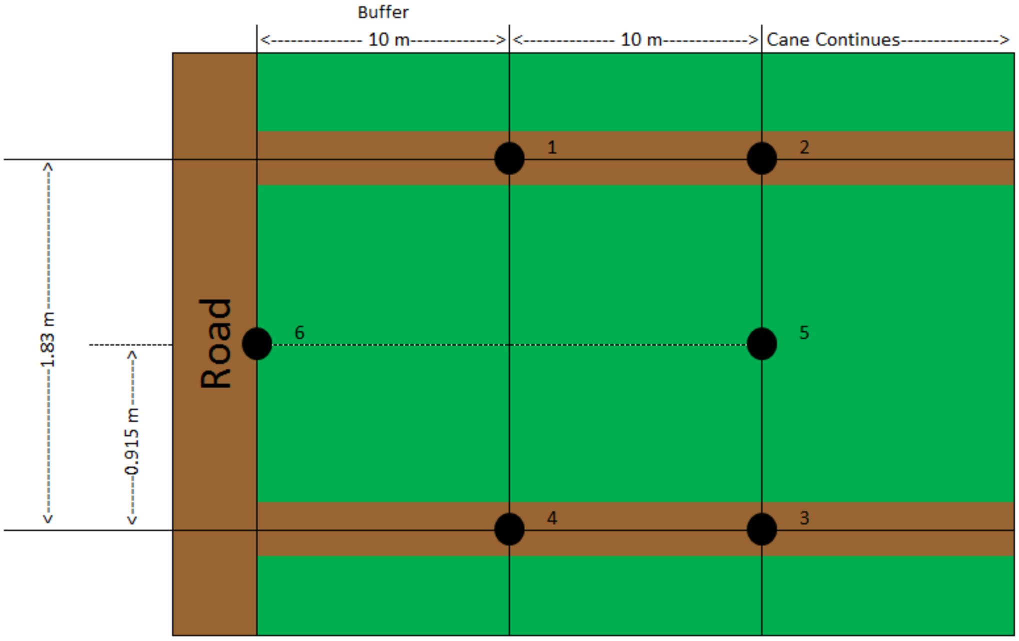


Figure 3.4 Adjusted soil coring layout; the black dots represent the area from where the soil core was taken.

Due to the unavailability of the soil penetrometer, the soil compaction was measured by taking four soil cores within the traffic lane and one on the growing bed before and after harvest. The first two were taken 10 metres in from the headland of the block to ensure a significant buffer from the turning of vehicles. The next sets of cores were taken 20 metres in from the headland in order to attain replicates of the same soil conditions. The growing bed core was taken from 20 metres in from the headland to give an estimate of the uncompacted soil density; inferring the relation between traffic and compaction. A soil core was then taken on the headland (core #6 in **figure 3.4**) where traffic was known to be very high. As the harvester turns around at the end of the traffic lane, it drives over the end 5-10 metres at a high frequency due to the minimal room for manoeuvring. Therefore this measurement would give an idea on the extreme value for compaction within the field. **Figure 3.4** shows the layout of the collected soil cores and **figure 3.5** shows the block that the cores were taken from. A different block was used for the coring because while the observations were being made, there wasn't sufficient time to complete the soil coring while the harvester was in operation.

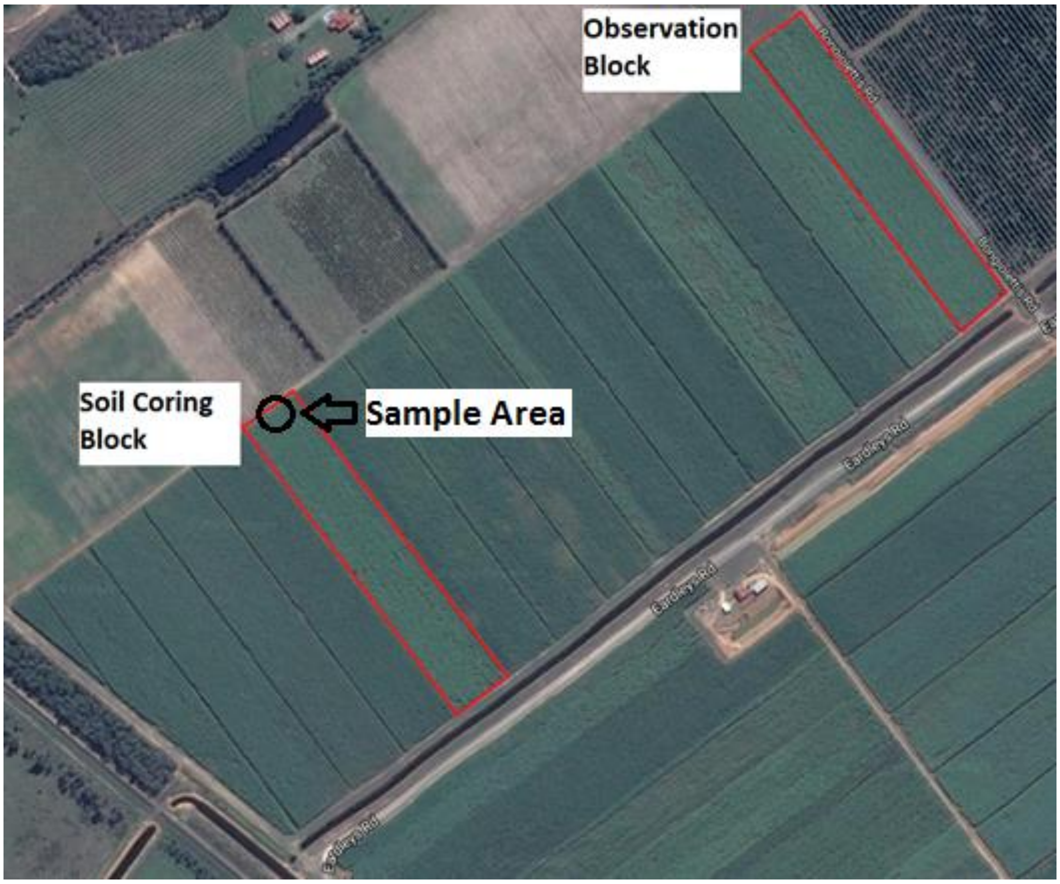


Figure 3.5 The two blocks that data was taken from, approximately 710 metres away from each other. The soil coring block was a third ratoon crop, while the observation block was second ratoon; refer to **figure 3.4** for details on sampling area (Google Maps 2016)

The harvester and load out bins used during harvesting was of standard size for many sugar cane growing areas in Australia. **Table 3.1** below outlines the machine weights and tyre characteristics that were used on this particular property. The tyre section widths and weights were used once the field observations were completed to calculate an approximate value for the load on each traffic lane of the field.

Table 3.1 Machine and tyre characteristics

		Load-Out 1	**Load-Out 2**	**Harvester**
Front Wheels (mm)	*Section Width*	587	587	335
	Total Diameter	1585	1585	993
	Centre-to-Centre	1913	1913	1965
Rear Wheels (mm)	*Section Width*	622	622	620
	Total Diameter	1805	1805	1628
	Centre-to-Centre	1878	1878	1880
Weight (tonne)	*Empty*	6	6	11
	Full	12	15	---

3.2 Data Analysis

3.2.1 Observation Data

Observation data was analysed with excel as its functions are able to handle the required calculations for the situations. Cells were arranged that the block was split up into the amount of traffic lanes observed, and divided into equal quarter lengths. The lengths were divided only into four parts due to the error involved with trying to observe where the machine is from the end of the field. Therefore the field was split up into approximately 100 metre sections and the analysis of the observations was carried out.

As each quarter of the traffic lane was investigated, the corresponding cell was coloured a different colour based on the degree of machinery that passed (see **figure 4.1** in section 4.0). Then the weights of the machines are known and can be used to determine the relationship between length and weight for each of the traffic lanes. The observations were taken on field simultaneously with the load-outs with the GPS to help give reference when analysing the GPS data in matlab.

3.2.2 Guidance Data Points

The GPS units that were fastened to the load-out bins resulted in a number of data points containing easting and northing values. These easting and northing values were then manipulated with the use of matlab (version 2014a) (MathWorks 2014) to trim unwanted data and evaluate the changes in direction while travelling along the traffic lane to determine how many times the growing bed was crossed over. The program was able to assess the total amount of data, trim the unwanted points and analyse the situation to determine possible growing bed crosses autonomously.

3.2.3 Bulk Density Data

The bulk density measurements will be collected and analysed briefly due to the inadequate number of samples to make a valid discussion. The results that yielded from this procedure however, helped back up why the tracking data is important to gather and analyse. Once the cores were taken they were wrapped up in oven bags and weighed wet. Once the weights were recorded the samples were dried at 105 degrees for 72 hours and the dry weights were then recorded. The dry weight divided by the volume of the sample yields the bulk density. Simple data analysis features in excel were used to manipulate the bulk density data to provide graphs and the change in bulk density over the harvest event.

4.0 Results

This section incorporates the results that were gathered during the project for the soil compaction component and the machinery tracking with the GPS units as well as the observations that were made.

4.1 Machinery Tracking Observations

4.1.1 Number of load-out passes per section of Traffic Lane

Figure 4.1 shows a variability map of the gross amount of machines that each 100 metre section of the traffic lane received during the testing period (sections are labelled in **figure 4.1**). The observed values are seen to vary from two machines per section to an extreme of seven machinery passes. Firstly, a trend can be seen that the top half (sections 1 and 2) of the field has experienced significantly more machinery passes than the bottom half. **Table 4.1** gives an overview on the total amount of passes per section of traffic lane.

Table 4.1 Total amount of load-out passes per traffic lane section over the entire field

Number of Passes	**Amount per field section**
0	12
2	54
3	44
4	31
5	16
6	5
7	2

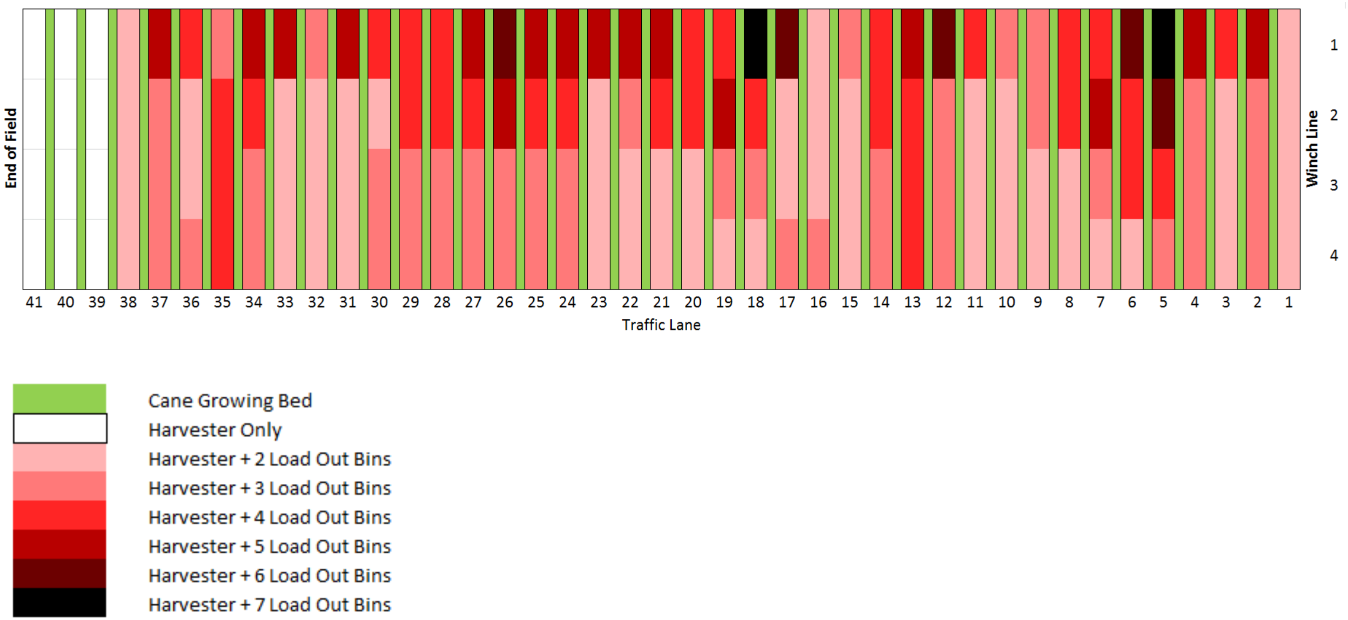


Figure 4.1 Traffic lanes and corresponding observed amount of traffic experienced during harvesting with section numbers to the right of the winch line

The areas that show only harvester passes were not part of the effective observation area, but are included to show that if harvesting is conducted the same way for every ratoon crop, then a small number of the traffic lanes on the end of the field will experience only the harvester as traffic. These areas experienced no load-out bin traffic because the as the harvester is unloading the cane, the load-out bin sits two traffic lanes (or two growing beds are in between the machines) to the left or right depending on the direction of travel.

Sections 1 and 2 tend to have a larger number of machinery passes because that end of the field was closer to the road leading to the sugar cane railway line. The load-out would enter the field from the top of **figure 4.1** and be filling up within the first 100 metres which caused them to back out of the field on the same set of traffic lanes increasing the amount of passes. Other instances saw the increase in passes throughout sections 1 and 2 by the load-outs entering the field and catching up to the load-out being filled in order to be ready so the harvester doesn't have to slow down or stop. This involved the load-outs entering a set of traffic lanes offset from the set being harvested currently to avoid collecting trash being extracted by the harvester. Once the current load-out is full the next one pulls over across multiple growing beds and sets up under the harvester to be filled.

Therefore **table 4.2** shows the average amount of machinery passes for each of the 100 metre sections across the entire field. Also from the observations, it can be deducted whether the load-out bin was full, filling or empty in each of the different sections of the field. Empty and full weights are given in **table 3.1** above in section 3.0, and filling weight was assumed to be the mid-point (average) between these two values. **Figure 4.2** shows the equivalent weight that each traffic lane sustained during harvesting.

Table 4.2 Average amount of load-out bin passes in each 100 metre section of the field

Field Section (as in figure 4.1)	Average Load-Out Passes/traffic lane
1	4.42
2	3.24
3	2.63
4	2.55

4.1.2 Total Load-Out bin weight per section of traffic lane

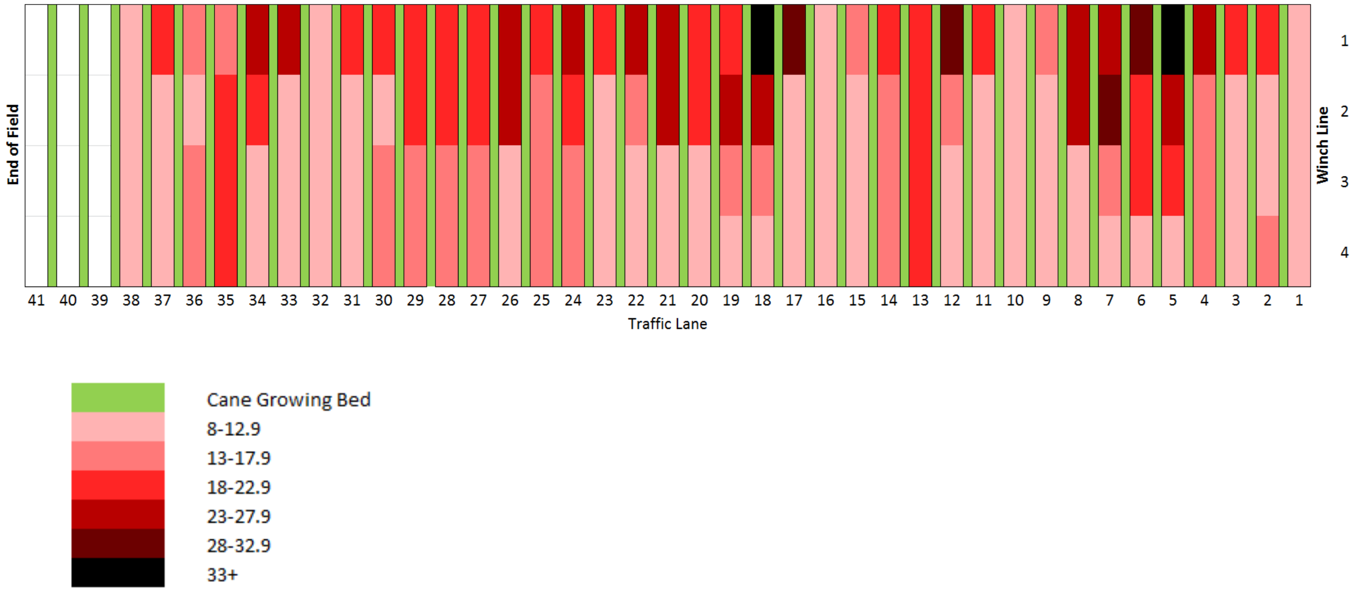


Figure 4.2 Traffic lanes and corresponding load-out bin weight ranges during harvest across the entire observed field (amounts given in tonnes)

Table 4.3 below shows the weights for the full, empty and filling load-out bins that were used to determine **figure 4.2** above. The total weight was calculated and then halved because this analysis is investigating one single traffic lane; when the load-out bin travels over the lane, only half of the weight is on a single lane (assuming the load-out bin is symmetric along the long axis). The accuracy of this data is not high due to the human error involved with taking such observations; it is limited by the distance and the observer's depth perception.

Table 4.3 Load-Out bin weights for different scenarios

	Load-Out Bin 1	**Load-Out Bin 2**
Full weight (tonne)	6	7.5
Filling weight (tonne)	4.5	5.25
Empty weight (tonne)	3	3

The same trend as seen in **figure 4.1** can be seen in **figure 4.2** as sections 1 and 2 have a higher average loading then sections 3 and 4; this is directly related to the amount of traffic that the area receives. From this result, the average load/section can be calculated as well as the occurrence of the different loading situations to determine the distribution of the weight across the field. **Table 4.4** outlines the different loading ranges and the corresponding amount observed within the field for each section of each traffic lane. This data was calculated excluding the weight of the harvester; this data is the weight added by the load-out bins only. **Table 4.5** shows the calculated averages of loading that each section was subject to.

Table 4.4 Occurrence of different load ranges for all sections and traffic lanes

Load Range (tonne)	**Frequency throughout the field**
8-12.9	70
13-17.9	31

18-22.9	30
23-27.9	15
28-32.9	4
33+	2

From this data it is observed that 46% of the field is loaded with 8-12.9 tonnes, 20.4% is subject to a load of 13-17.9 tonnes and 19.7% is loaded with 18-22.9 tonnes. The remaining 13.9% of the field is made up of loads between 23 and the peak load of 34.5 tonnes which corresponds to the area near the headland (section 1). It should be noted that this data pertains to the traffic experienced by the traffic lane; the loads that the growing bed experienced (while the machine crossed over) will differ from these values and are reported further in this chapter.

Table 4.5 Average load per traffic lanes for the different sections over the entire field

Field Section	**Average load/traffic lane (tonne)**
1	21.2
2	16.1
3	13.0
4	12.1

Traffic lanes situated in section 1 receive an average of 21.2 tonnes while those in section 4 receive nearly half at 12.1 tonnes. This trend has followed through from the tracking variability in **figure 4.1** due to the increased amount of traffic experienced in this area.

4.2 Guidance data from Load-Out Bins

The GPS units used to sample the data for this section was fastened to the roof of each load-out bin in order for them to receive adequate signal. The units were aimed to be started at the same time that the harvester started harvesting the observation block (**figure 3.5** in chapter 3.0). The machines were briefly stationary (for a tea break) while harvesting the previous block and it was decided that they would begin sampling then. It was later discovered that the GPS units had an automatic time-out feature that didn't allow the full observation block to be sampled. 24 traffic lane runs from the observation block were collected; but numerous more from the previous block were available. It was then decided that the samples from the observation block would be used to calibrate the program used to analyse the GPS data because the observations made in section 4.1 above can be used to ensure the correct data is being used. Once calibrated, the program would then be used on all available traffic lane runs to ensure a useful amount of data was being analysed.

4.2.1 Data cleaning and manipulation

The raw data from the GPS units contained points that could be removed before the construction of the program initiated. The group of points that show the load-out bins travelling to the road where the railway line was situated parallel to the road were first to be removed. But this process was manual because the program could not determine the bounds of the testing area automatically. **Figure 4.3** shows the raw data collected from load-out bin 2 and the cleaning of the raw data where the data collected on the road to the railway line is deleted in **figure 4.4**.

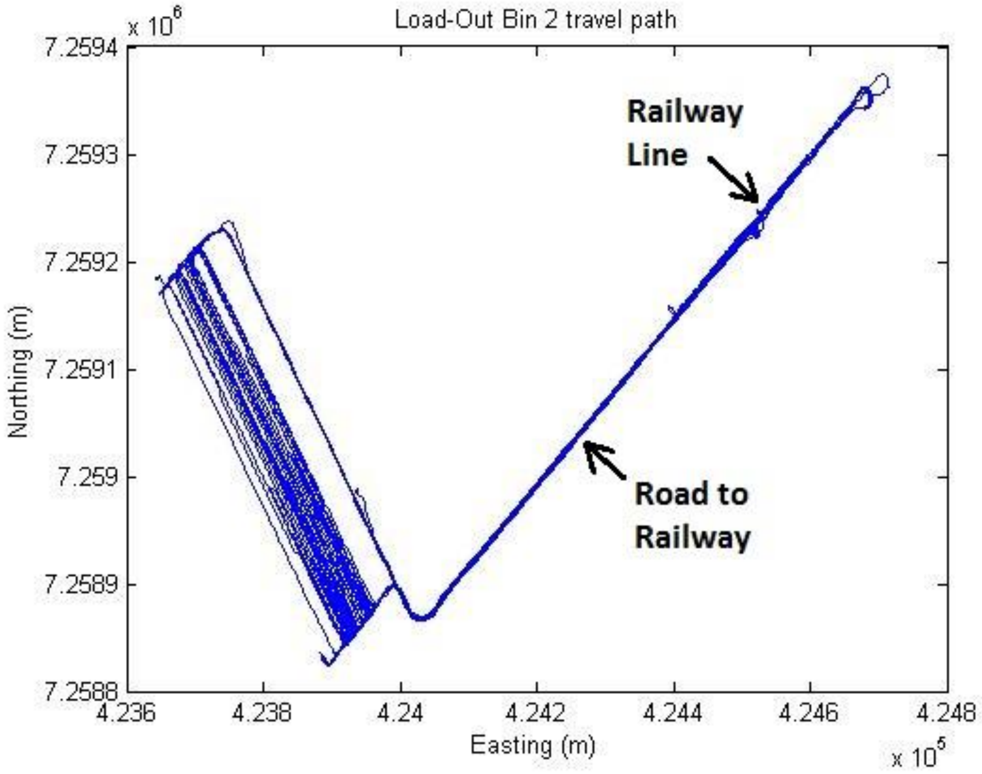


Figure 4.3 Raw GPS data collected from Load-Out bin 2

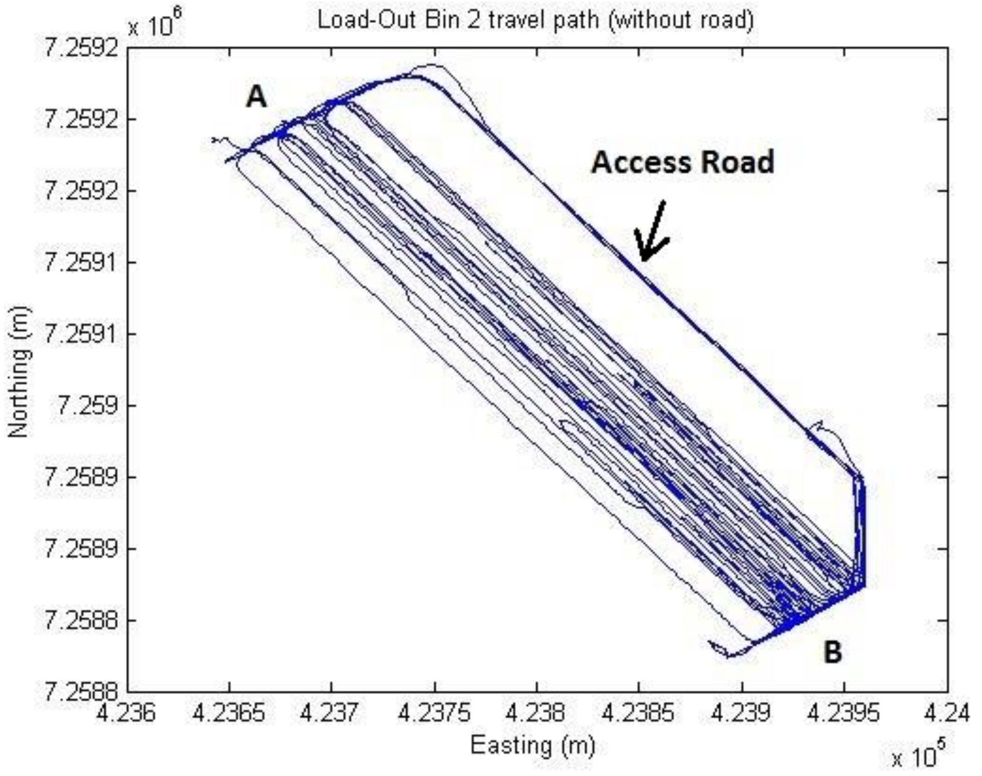


Figure 4.4 Corrected data for load-out bin 2 with the points travelling to the railway line deleted

Once the road to the railway was deleted, all other cleaning up was completed manually due to the difficulty in removing the traffic lane runs by themselves. Therefore the program was manufactured so that it could provide the trail the load-out bin left while it was travelling (to ensure that the correct run was being separated) and remove the run up the traffic lane from the rest of the data. The traffic runs are the parallel lines in the area between point A and B (on **figure 4.4**) except the thicker line to the north east of the majority of parallel lines labelled access road. This was completed for entire number of traffic lanes and then further investigated individually.

4.2.2 Analysis of Traffic Lane Sets

Figure 4.5 below shows a zoomed image (for ease of differentiation) of the recorded traffic lane runs from A to B and the constant changing of direction investigated. The traffic lane runs at the bottom of the group are grouped more tightly due to the presence of a winch row between different blocks of sugar cane. The load-out bins will use this row to move from one end of the field to the other to minimise compaction on the soil used for growing; this is only feasible when the winch row is within three to four traffic lanes away from the harvester.

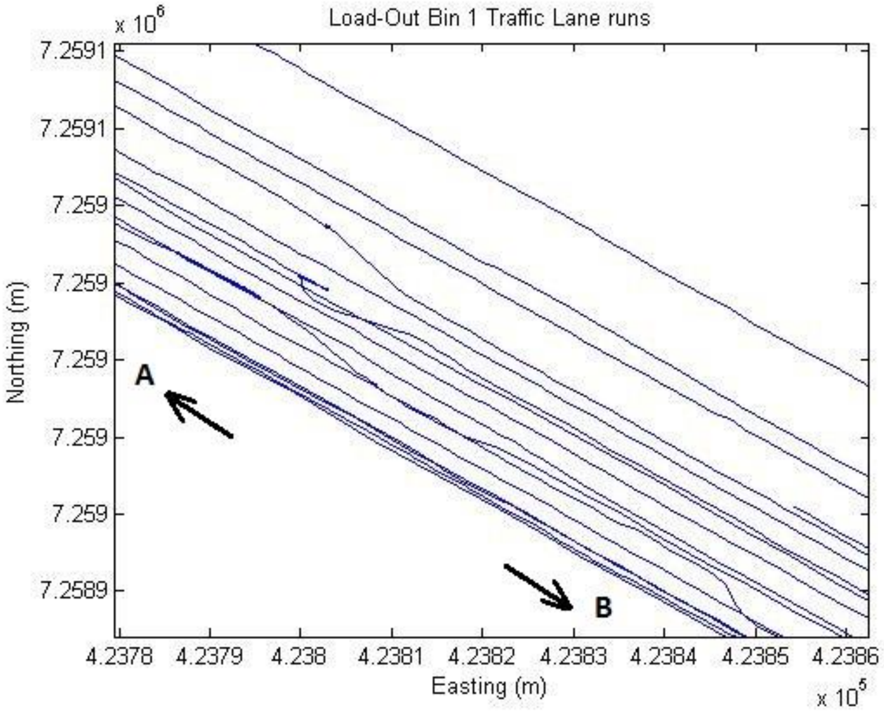


Figure 4.5 Zoomed image showing the traffic lane runs made by load-out bin 1

It was decided a value of 40 degrees would be used to determine if load-out bin 1 had changed course enough to be assumed that it had crossed the growing bed. Why this was chosen is explained further in chapter 5. Observations recorded that there was a pass over of the growing bed between lane 6 & 7 by load-out bin 1 and 2. This was then checked by applying the program to those specific traffic lanes and the result from that is outlined below (growing bed in between traffic lane 6 & 7 corresponds to rows 13 to 17 of the program) in **table 4.6**. After observing this and checking with the other reference lanes, it was decided that the program was functioning as intended. The below results are in the form of number of direction changes larger than 40 degrees between points in the distance between each end of the field from a given entered traffic lane set. The traffic lane number here does not correspond to the traffic lanes discussed in the above observation section. As stated above, the data from the GPS units does not correlate to the observation data and therefore should not be confused.

Table 4.6 Direction changes for each set of traffic lanes entered by load-out bin 1

Traffic Lane Set Entered	Number of Direction Changes	Observed Direction Changes
1	8	Not Observed
2	0	Not Observed
3	0	Not Observed
4	0	Not Observed
5	0	Not Observed
6	4	Not Observed
7	46	Not Observed
8	5	Not Observed
9	0	0
10	0	0

11	4	4
12	0	0
13	3	3
14	70	0
15	0	0
16	0	0
17	1	0

It can be observed that there are some discrepancies that resulted from the program being unable to handle certain situations (traffic lane set 1, 7, 8, 11 and 14 in **table 4.6**). These scenarios involved the harvester manoeuvring in a discontinued path due to obstructions within the field, or simply by stopping and allowing the GPS to ‘roam’. Roaming occurs when the GPS unit is stationary and data is still being collected. Given the accuracy of the GPS units used, the data points wavered slightly from the actual position of the GPS unit in the field. This caused the data to assume the machine was moving slightly around the actual point that the GPS was located; which caused the load-out bin data to appear to be moving. More information regarding these discrepancies is explained in the discussion within chapter 5.0.

As seen, lanes 14 and 17 from the program did not calculate to be the same value as the observed amount seen for those specific lanes and this is because of the scenario explained above where the machine was stationary while the GPS was gathering data. All other data from the program agrees with the observed values. The program was run for load-out bin 1 and then checked by applying to load-out bin 2. The results for load-out bin 2 are outlined in **table 4.7**.

Table 4.7 Direction changes for each set of traffic lanes entered by load-out bin 2

Traffic Lane Set Entered	Number of Direction Changes	Observed Direction Changes
1	6	Not Observed
2	0	Not Observed
3	3	Not Observed
4	34	Not Observed
5	0	Not Observed
6	0	Not Observed
7	0	0
8	5	4
9	0	0
10	2	2
11	0	0
12	2	2
13	1	1
14	1	2
15	1	0
16	0	0
17	0	0
18	1	1

19	0	0
20	0	0

Load-out bin 2 was operated by a different driver which exhibited different driving techniques on and off the field. Therefore after close observation preliminary observations from the program outputs it was decided that the turning angle should change to 25 degrees. The model was then run and the results from **table 4.7** further increase the validity of the program due to most of the observed values equating to the calculated values. Small discrepancies are still present in calculated rows 8, 14 and 15 which are due to some simple errors. Rows 1 and 4 are also the outcome of minor errors within the data which will be discussed further in chapter 5.0. As the driver is turning more slightly than the driver of load-out bin 1, the program calculates a single turning manoeuvre to be more than the actual; this scenario is also explained further in chapter 5.0.

Once the program was considered complete and working in order, the results were calculated for the total amount of growing bed passes that each machine made during the time the GPS units were gathering data. The results are below in **table 4.8**.

Table 4.8 Total growing bed pass-overs for the load-out bins

	Load-Out Bin 1	**Load-Out Bin 2**
Total Growing Bed Passes	16	18

These results have been attained by further manual investigation of the traffic lanes that are displaying inaccurate values for the number of traffic lane passes (in **table 4.6** & **4.7**).

4.2.3 Total affected area by passing over growing bed

Now that the number of growing bed passes has been calculated, the size of the tyres can be input to give an approximation into the total amount of area affected within the sampled area. This was completed for the entire sampling area that each load-out bin collected data for. Firstly, for ease of calculation, it was decided that when the load-out bins travelled across the growing bed, they did so at the same angle used to complete the program (load-out 1 – 40 degrees & load-out 2 – 25 degrees). This isn't a true assumption for every case, but the values calculated for this scenario will give a good approximation of affected area. For every time the load-out bin was modelled to cross over the growing bed, it is known that each wheel passes over. The rear wheels have a larger section width and therefore the dimensions of the rear wheels were chosen to complete the analysis; this ensures the worst case scenario for discussion purposes. It was decided that the area under investigation would be between where the two rear wheels of the load-out bin would generally traffic up and down the lanes. **Figure 4.6** shows the area under investigation.

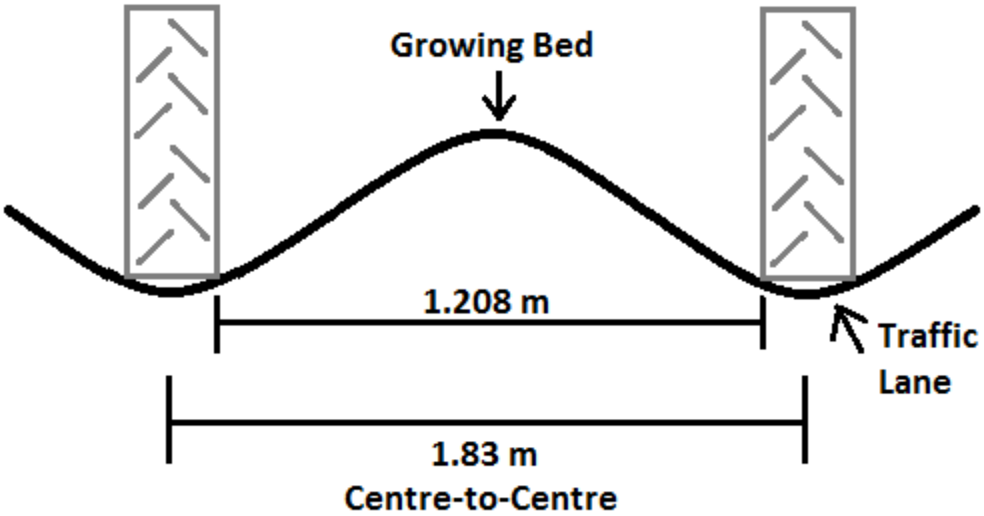


Figure 4.6 The area of the growing bed in between the inside of the rear wheels of the load-out bin is the area under investigation

Therefore for every time that a load-out bin 1 passed over the growing bed it effected 4.68m^2 & load-out bin 2 effected 7.11m^2 (these values incorporate all four wheel tracks). Using the results of the total amount of growing bed passes in **table 4.8** the resulting total effected area for each of the load-out bins and the field in total (20 rows sampled) is outlined in **table 4.9**.

Table 4.9 Total effected area by both load-out bins within the sampled area by passing over the growing bed

	Effected Area (m^2)	Percentage of Sampled Field (%)
Load-Out Bin 1	74.81	0.77
Load-Out Bin 2	128.0	1.32
Total	202.82	2.09

These values may not seem significant, but as we investigate the total amount of traffic that the field receives by normal trafficking, approximately 50% is traffic lane (due to the single row harvester). It must be kept in mind that this investigation only included a single harvest event for the sugar cane block. If the traffic was measured over the multiple ratoon crops, the total amount of effected area would increase. After the final harvest is completed, the growing bed could be subject to an effected area of up to 5-10%. Depending on the drivers, yield and harvesting run length, these values will vary among different farming blocks.

4.3 Soil Compaction Data

4.3.1 Gravimetric Moisture Content data

The gravimetric soil water content was measured from the soil cores taken before the harvest event to give an indication of how wet the soil was. As explained in chapter 2.0 soils with higher moisture content will compact to a higher degree than soil with lower moisture content. Therefore **table 4.10** reports the initial soil moisture contents for the different soil cores at the measured depths.

Table 4.10 Gravimetric soil moisture content (%) of each soil cores before harvest

	Core Number (from figure 3.4)					
Depth (mm)	*1*	*2*	*3*	*4*	*5*	*6*
0-100	16.4	14.4	15.6	15.9	13.9	12.7
100-200	13.2	14.0	14.1	14.1	12.7	13.2
200-300	12.2	22.6	13.1	13.7	12.5	12.7
300-400	12.4	14.5	14.1	12.4	16.2	12.7
400-500	14.5	21.9	20.6	15.4	23.4	13.2
500-600	19.0	24.9	22.0	22.4	25.9	16.3
600-700	18.9	22.9	22.0	23.4	23.8	20.8

From **figure 3.4** it can be observed that cores 1, 2, 3 and 4 should show similar qualities as they each lay within the traffic lane inside the buffer zone of the field. Even with the small amount of data collected, a trend can be seen between these 4 soil cores with most values being within 10-20% of each other with some obvious outliers corresponding to the moisture content for cores 1 and 2 at depths of 600-700mm and 200-300mm respectively. Soil core 5 which was taken from the growing bed, giving ideal circumstances (which cannot be confirmed due to the lack of history of the block), would expect to exhibit higher moisture contents at increased depths due to the decrease in soil compaction. The shallower depths of soil core 5 are lower than the traffic lane soil cores in this instance most likely because of the sugar cane using the soil moisture for growth (the growing bed soil moisture is easier to access than the traffic lane soil moisture). Soil core 6 which was taken from the outer edge of the crop would expect to have lower moisture contents at each depth due to the crop use as well as increased traffic resulting in increased soil compaction at all depths. This is observed as it is lowest or equal lowest for the depths of 0-100mm, 400-500mm, 500-600mm and 600-700mm, and within 0.5 of a percent of the lowest value for all other depths.

4.3.2 Bulk Density data

The increase/decrease in bulk density for each of the soil cores within the traffic lanes were calculated and reported in **table 4.11** below.

Table 4.11 Increase in bulk density (tonne/m^3) due to harvest for soil cores 1, 2, 3, 4 and 5 at different depths

	Core Number (from figure 3.4)				
Depth (mm)	*1*	*2*	*3*	*4*	*5*
0-100	0.5037	-0.0848	0.0734	0.1569	-0.2616
100-200	0.0737	0.2124	0.028	0.218	-0.3112
200-300	0.2804	0.2981	0.1563	0.2116	-0.0369
300-400	0.0538	0.3464	-0.0777	0.0114	0.0074
400-500	-0.0504	0.0738	-0.0606	-0.0054	0.1682
500-600	-0.1199	0.0646	0.1773	0.0839	-0.0769
600-700	-0.2318	0.1643	-0.087	0.0863	-0.1305

The negative values present in **table 4.11** represent a bulk density decrease due to harvesting, which is very unlikely and more likely due to error in not taking enough samples. Samples could not be taken from exactly the same spot after harvest and this also introduces some error in the calculations due to certain soil characteristics (discontinuities in soil type and texture etc.). Although it is observed that the negative values are small (disregarding soil core 1 at 600-700mm depth) which indicates that with more replicates, the testing would have been much more accurate and the negative values would be expected to filter out. Soil core 5 data was taken before and after to assess the bulk density of soil that was not influenced by traffic during the harvest event. Soil core 6 wasn't taken after harvest, it was intended to give a potential indication of the highest bulk density within the field and provide a comparison value.

5.0 Discussion

This section of the dissertation will investigate the outcomes outlined in the results and begin to draw conclusions as to why certain results were attained.

5.1 Machinery Tracking Observations

The first obvious trend within the observed machinery data was that the top two sections of the field experienced up to 3 times as much traffic as the lower two sections in **figure 4.1**. It was discussed that this occurred due to the road that led to the railway line being situated closer to the top side of the field; meaning the machines could unload and get back to the field quicker if they used this road. The increased traffic in the top two sections directly relates to the total weight that the section experienced during the harvesting. The machines that fill up within the top two sections would reverse back over the same traffic lane and this caused the top two sections to experience double the traffic relative to the bottom two sections on the same traffic lane.

This data is not of the best resolution due to the field being split up into 4 sections of approximately 100 metres in length. A more detailed variation map would provide better data when considering which areas of the field are experiencing larger amounts of traffic. In the investigation above (**figure 4.1** & **4.2**) a large amount of the section isn't subject to the labelled traffic passes / weight that are shown. In some instances the machine only travelled 20 metres into the section, but when the investigation was completed the entire 100 metre section would be shown to have been subject to the machine passes.

This process can be made more automated by improving the program that was produced in matlab to determine lengths of travel as well as traffic lane passes. The next section will discuss the program and will further investigate this possibility.

5.2 Evaluation of Lane Use Program

5.2.1 Data gathering

The matlab program was created to automatically calculate how many times each of the load-out bins changed direction within the field, which inferred a crossing of the growing bed. The GPS data was gathered from the load-out bins during the harvesting event on the observation block (**figure 3.5**); but the GPS units experienced trouble when gathering this data. The GPS units were attached to the roof of each machine before they started harvesting the observation block to ensure that the entire observation block was investigated. This meant that the units needed to be gathering data for a large period of time, up to 5 hours. When the GPS units were taken off the machines to receive the data, it was noticed that an error had occurred and the machines stopped gathering data approximately half way through the observation block (due to the units losing signal with the satellites and then timing out of the session). The units gathered some data from the previously harvested block and it was decided that this data be used in conjunction with the data from the observation block; as long as the observation block data was used to calibrate the program (because it could be checked against the observation data).

5.2.2 Post Processing

When the data was downloaded from the GPS unit, it underwent post-processing with the help of a University of Southern Queensland surveying and spatial science colleague. The post-processing was completed by running the data through a program that can increase the accuracy of each of the points based on the location from where the data was taken and the time at which it was taken. The estimated accuracies of the processed data points ranges are below in **table 5.1**. This ensured that the data used in the program was accurate enough for the program that was being created to investigate the machinery position within the field.

Table 5.1 Accuracy range and percentage of data

Range (cm)	Percentage (%)
0-5	-
5-15	82.62
15-30	6.95
30-50	2.67
50-100	2.57
100-200	5.12
200-500	0.08

5.2.3 Program Limitations

After the program was completed, it was discovered that there were some limitations; but due to time constraints these limitations were not able to be overcome. The first limitation noticed was the manner in which the crossing of the growing bed was calculated. The program determined the amount of times the direction of the machine changed to return the amount of times the growing bed was crossed. This was validated using the manual observation data collected to ensure that the result was correct. But this outcome was coincidental in that after reasonable examination, the direction changes couldn't give an accurate representation of growing bed crosses. **Figure 5.1** shows a scenario with multiple direction changes and a different amount of growing bed changes.

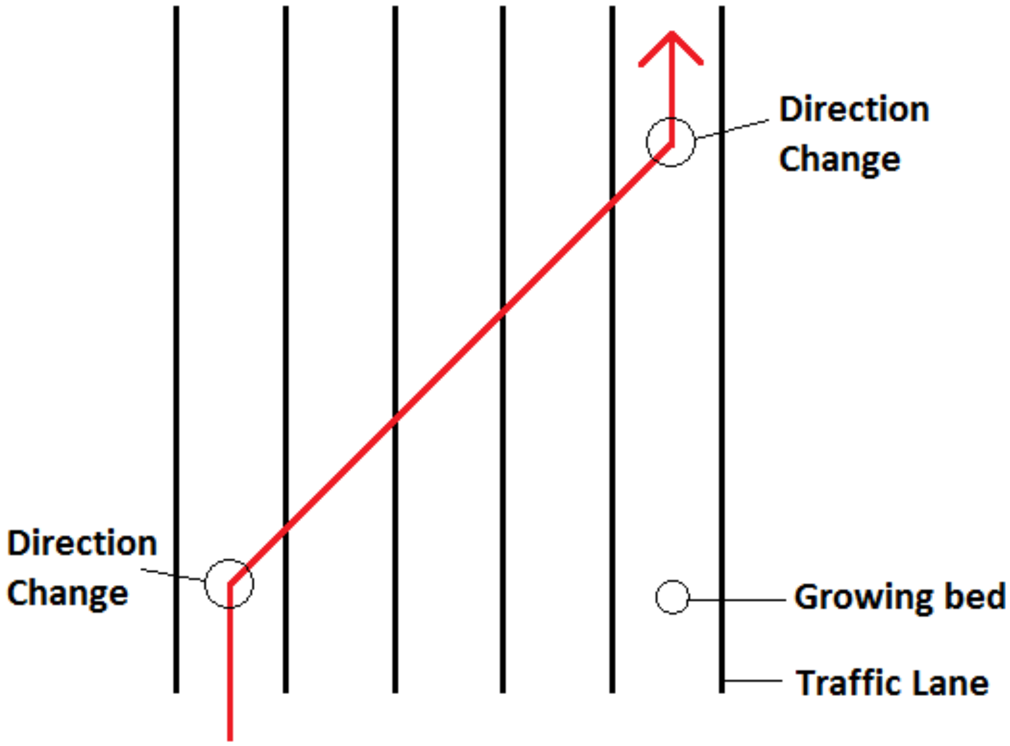


Figure 5.1 Scenario showing 2 direction changes and 4 growing bed crossings; red line shows the load-out path

Therefore it was decided that this method was not entirely suitable to determine the amount of times each of the load-out bins crossed the growing bed. In some instances the program resulted in the correct answer according to the observation results, but this was merely a coincidence.

Another limitation that was observed was that the program couldn’t adapt to the changing speed of the load-out bins. When the load-outs crossed over the growing bed quickly, the change in direction is larger because it happens more sudden. The slower crossings of the load-outs will have a much smaller change in direction between data points. **Figure 5.2** & **figure 5.3** shows the difference between a slow turning vehicle and a fast turning vehicle and the difference in the angle between the two scenarios. Future work could involve incorporating a dynamic average location to help alleviate these limitations.

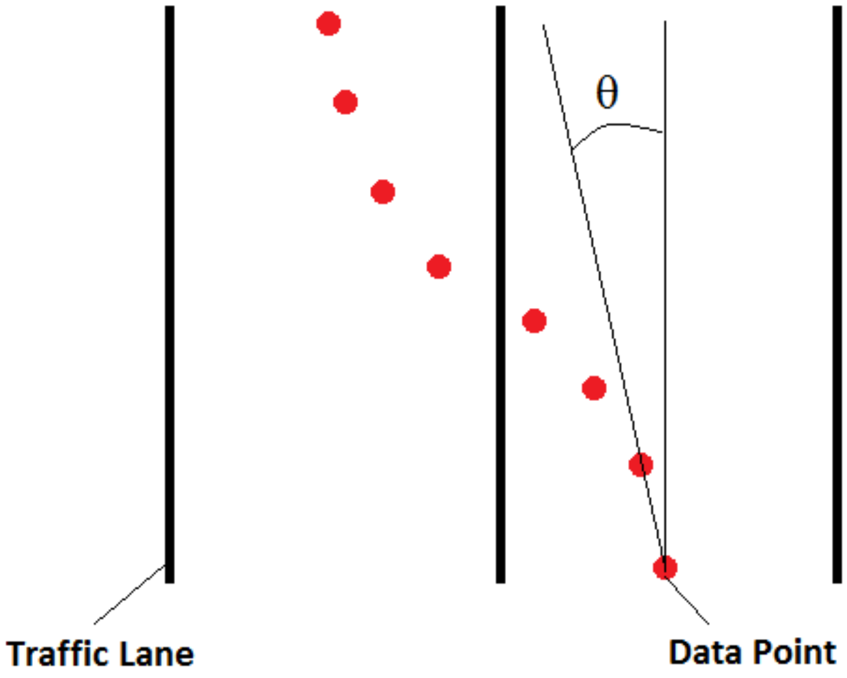


Figure 5.2 Data points showing the path of a load-out bin travelling slow across the growing bed

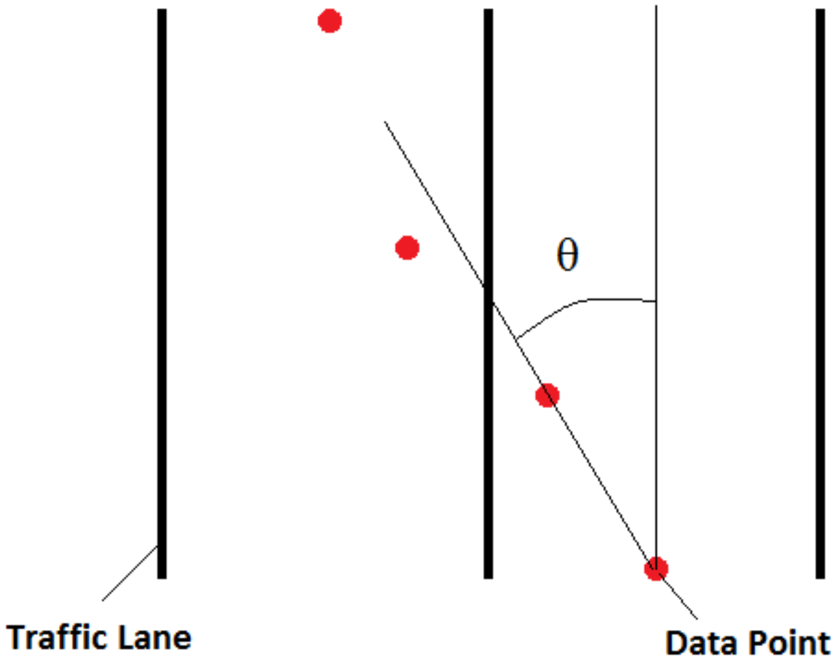


Figure 5.3 Data points showing the path of a load-out bin travelling fast across the growing bed

As seen in **figure 5.2** & **5.3** as the machine passes more quickly over the growing bed the data points are more spread apart which means that after travelling a certain path, the angle between the points grows larger. When the machine passes more slowly over the growing bed in the same manner, the angle is decreased and this may cause problems when the program is running. If the turning angle is set to a certain amount and the machine passes more quickly over the growing beds and the angle is greater than this value, then the crossing of the growing bed will be left out from the calculations.

The two load-out bins were driven by different people and therefore the driving style of the different drivers wasn't the same and the program had to account for this. It was found that one of the drivers turned sharper than the other and therefore the program had to be completed and designed differently for each of the load-out bins.

As the load-out bins travelled down certain traffic lanes, the pathway was blocked or obstructions caused the harvester to deviate from travelling straight and constantly through the field. Stopping in the field cause the GPS units to roam and record data that was not the same, but very close to the actual location of the load-out bin (due to GPS accuracy). As seen in **figure 5.4** this caused the program to think that there were many direction changes, but it simply meant the machine wasn't moving.

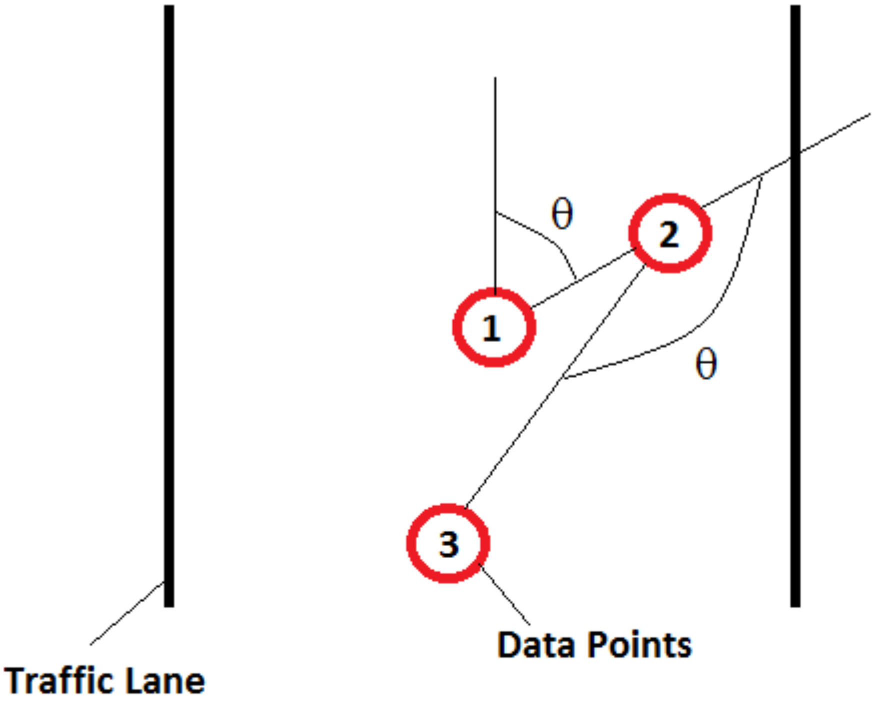


Figure 5.4 Stationary machine causing data points to roam around the machine location and the large change in direction angles θ

Therefore the stationary machine causes the program to calculate an over-exaggeration of direction changes. Another driving characteristic that caused the inappropriate calculation of the number of growing bed crosses was the reversing of the machines within the field. These circumstances caused problems in the same way that the stopping of machines did.

To improve these limitations it would be advised that the lane crossings be distinguished by investigating when the GPS trail data from the load-outs crosses a reference line that describes the growing bed. A reference line for each of the growing beds (1.83 metres apart) can be described and then it could be determined when the load-outs crossed the growing bed and how many growing beds; or a lateral movement perpendicular to the growing beds. This would require a far more detailed analysis and a much more intricate program coding to calculate.

5.3 Soil Bulk Density

To prepare **figure 4.2** different weights were used for different scenarios involving the load-out bins. If the load-out was empty, half full or full; the corresponding weight was used to determine the variability within the field. Full and empty weights were easily calculable and the half full weight was the average of these two values. This is a fair assumption due to the resolution of the variability map already being relatively inaccurate.

The soil bulk density samples taken during this dissertation were minimal and should not be used as true evidence of the situation. But the samples that were taken did exhibit the characteristics that were expected. To further increase the validity of the bulk density data, many more samples need to be taken before and after harvesting on a fallow area in the field. The fallow field will allow for all of the measurements to be compared to an initial level of compaction at the start of the growing stage. To ascertain a better average increase in bulk density, more soil core samples need to be taken. To further increase the accuracy, the testing method could be improved; using bulk density rings inserted at the depths in focus rather than using the soil corer and approximations on lengths of soil cores. The use of the soil cone penetrometer is also advised for further accuracy.

The core from the growing bed was taken to indicate a productive state of the soil used for the growing of the sugar cane. This was not a control to compare the traffic lanes with because a control for this testing would be a field that has been planted with plant cane.

The core on the growing bed was taken before and after harvesting, but this was to give an average for the area. Further studies would involve not only trafficking over the traffic lanes but also the growing beds to show the increase in bulk density due to the load-out bins crossing.

A core was taken from the headland of the crop to indicate a theoretical maximum based on the machinery used during the harvesting process. But as the sugar cane is a ratoon crop, this headland area may have received undisturbed compaction for up to four years. The headland receives extra traffic due to the machines involved with the harvest turning around and general traffic at the end of the field.

5.3.1 Production Loss due to Soil Compaction

The increase in bulk density causes stunted growth to the sugar crop due to the limitations involved with root growth and water availability. From previous studies it has been known to directly affect the yield of the sugar cane at harvesting (Braunack 1999). It was discovered that sugar cane in the Queensland region was at optimum growth when the soil bulk density was 90% of the maximum soil bulk density (**figure 5.5**) for that particular soil. Braunack (1999) then underwent some economic analysis and discovered that loss due to traffic compaction averaged throughout Queensland ranged between $145 to $431 per hectare at a yield loss of 5% and 15% respectively. This data was taken 16 years ago and the new prices of sugar cane have surely deviated, but this was the latest data that could be found regarding this information; the machines have grown in size and weight and the sugar cane itself has most likely seen an increase in sell price. From **figure 5.5** it can be observed that compaction levels above and below the optimum cause lowered levels of yield. The smaller degree of compactness may cause the yield to drop due to plant stability during weather events that cause the destruction/deformation of the plants. Higher levels of compactness will cause decreased root growth and therefore limit the amount of growing that the cane can sustain (Magarey et al. 1999).

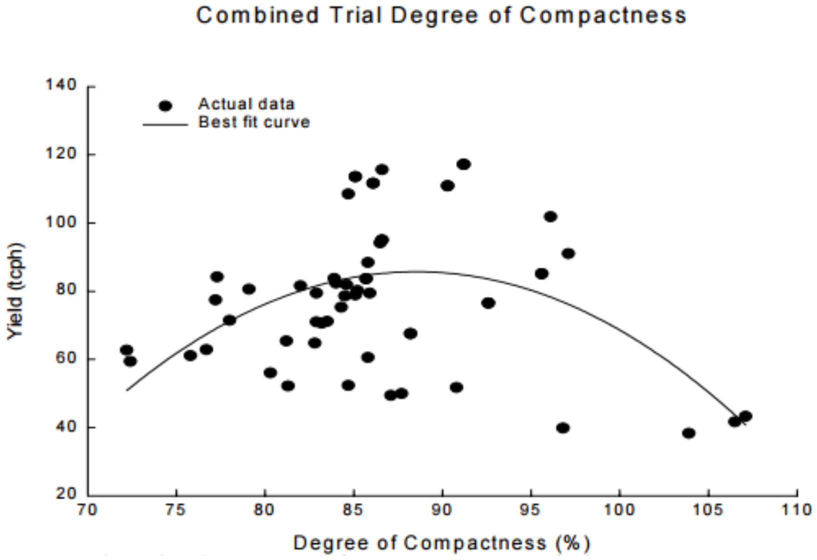
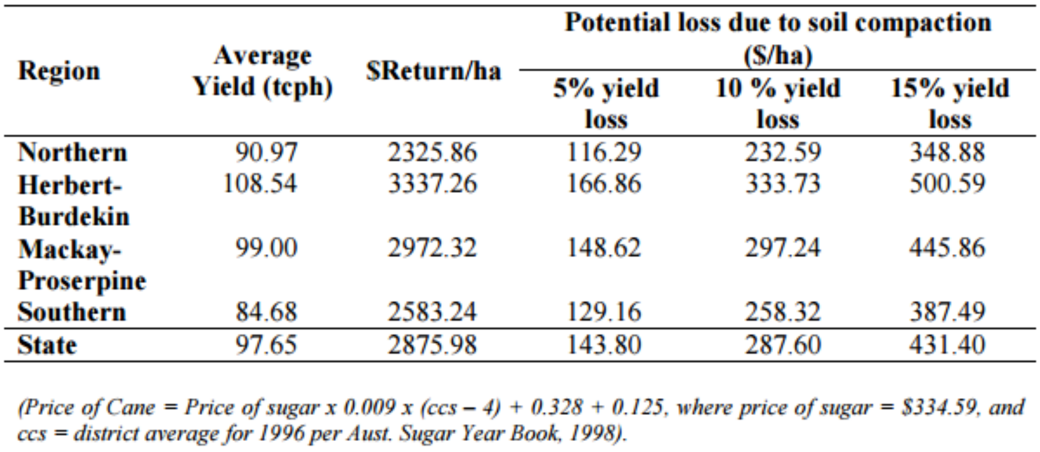


Figure 5.5 Sugar Cane yield as a function of degree of compactness (relative to the maximum bulk density of the soil) (yield measured in tonnes of cane per hectare) (Braunack 1999)

This dissertation focused on the increase in bulk density and therefore the degree of compactness that is occurring above the optimum. **Table 5.2** below shows the profit loss due to soil compaction in dollars per hectare for different regions across Australia; this data is old as new data surrounding this was hard to obtain as it's not freely available. More recent costings were not freely available and therefore this data will be used for the analysis with recent economic characteristics in mind.

Table 5.2 Potential loss to sugar cane growers due to varying yield losses caused by soil compaction ($/ha) (Braunack 1999)



Region	Average Yield (tcph)	$Return/ha	Potential loss due to soil compaction ($/ha)		
			5% yield loss	10 % yield loss	15% yield loss
Northern	90.97	2325.86	116.29	232.59	348.88
Herbert-Burdekin	108.54	3337.26	166.86	333.73	500.59
Mackay-Proserpine	99.00	2972.32	148.62	297.24	445.86
Southern	84.68	2583.24	129.16	258.32	387.49
State	97.65	2875.98	143.80	287.60	431.40

(Price of Cane = Price of sugar x 0.009 x (ccs – 4) + 0.328 + 0.125, where price of sugar = $334.59, and ccs = district average for 1996 per Aust. Sugar Year Book, 1998).

Table 5.2 outlines the potential loss due to soil compaction at different rates of yield loss. Even at 5% yield loss the potential loss in dollars per hectare can reach up to \$166/ha, and this figure differs depending on the region under investigation and the current prices of sugar. The field involved with this dissertation was expected to yield approximately 80-100 tonne/ha which relates closely with the Northern region above in **table 5.2**. The most damaging scenario is considered (15% yield loss) for the following analysis.

From the results in section 4.2 above it was calculated that 202.82 m^2 of growing bed was effected by traffic and has therefore been subject to soil compaction. This result corresponds to the 15 rows sampled from the load-out bins. As seen from **figure 3.5** in the methodology section above, each block is made up of approximately 40 growing bed rows and there are 14 blocks of this size in the area that the trails were conducted. If the area was investigated as a whole, then the total area subject to the soil compaction would be 7581.4 m^2 (0.75814 ha). This equates to a loss of \$264.50 at a yield loss of 15% for the total area in **figure 3.5** for the single year that this analysis was completed. It must be remembered that this was a single year of harvest as part of a four year cycle and therefore the total effected area could increase to approximately 5 hectares from the load-out bins alone. This increases the cost of driving over the growing bed to \$581.45 for the four year period with the old pricing of sugar cane and compaction damage.

Using this old data a cost per metre of crossing of growing bed can be determined as below:

$$\text{Area inolved with 1m of tyre traffic=1} * 0.622 = 0.622m^2$$

$$0.622m^2 = 0.0000622ha$$

$$0.0000622 * 348.88 = \$0.0217 / m / load - out$$

This value increases to \$0.0311/m/load-out when investigating a 15% decrease in yield within the Herbert-Burdekin region. This means that for every metre of growing bed the load-out bin traffics over, the loss of profit is equal to \$0.03. This value accumulates over the four years that the cane is being grown and harvested.

As indicated earlier, this information is out of date and the machinery used to conduct this previous experiment was not as large as those seen in the industry currently. Further work in this area would be to gather more recent data and prices on sugar cane.

6.0 Conclusions

This project was conducted to investigate the effect of soil compaction during sugar cane harvesting. It was also undertaken to determine if a program could be devised to calculate the amount of times the growing beds were crossed. After researching the approximate prices for sugar cane within Australia, an analysis was completed and the loss of profit per metre of crossed growing bed was calculated (based on the wheel characteristics from the property used for testing in this dissertation). This project found that the proposed program was able to be devised but not without its limitations. It was concluded that the results from the program were validated from the observation results, but this was a coincidence. The program counted the number of direction changes, but this was found to yield results that did not properly calculate the number of growing bed changes. With small changes in the process of calculation, the program could be modified to report the correct answer.

Results from the soil coring were as expected from the literature where the traffic lanes saw an increase in bulk density after the harvester and load-out bins passed. The top 40cm of the soil within the traffic lane resulted in an average increase of 0.153tonnes/m^3 after being subject to 3 load-out bin passes. The increased gravimetric moisture content within this upper 40cm layer was also concluded to have aided in the increase in bulk density.

Further work that could be conducted from this dissertations conclusion could firstly be the further investigation of the bulk density increases in different sections of the field. This project only measured the increase in bulk density within the traffic lane, not the growing bed itself; this would further validate the need for a program to calculate the number of growing bed crosses.

The program used to calculate the growing bed passes can be further worked on by improving the method in which it conducts the analysis. If this process could be improved, it would be highly beneficial to the agricultural industry; not only within sugar harvesting but many other cereal and premium cropping systems. Further to this, the filling rate could be worked in along with the position and scenario within the field (filling or empty) and determine a value for weight per metre of field in each of the traffic lanes.

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Appendix

A Project Specification

ENG4111/4112 Research Project

Project Specification

For:	David West
Title:	Tracking Machinery to Investigate the Effect of Compaction during Sugar Cane Harvesting
Major:	Agricultural
Supervisor:	Dr Troy Jensen
Enrolment:	ENG4111 – ONC S1, 2016 ENG4112 – ONC S2, 2016
Project Aim:	This project aims to investigate machinery position during sugar cane harvest relative to the traffic lanes to determine the potentially affected area by soil compaction within the growing bed and therefore the potential loss of profit.

Programme: Issue B, 16th September 2016

1. Continue Research on soil compaction and the effect on the soil structure of the soil and also research the processes involved with sugar cane from planting to harvesting.

2. Research the weight of each machine that potentially passes over the soil and consider the different wheel configurations and hence, the force exerted by each wheel.

3. Research and explain how the compaction effect is measured and how the machinery will be tracked in the field.

4. Conduct initial testing on the traffic lanes before harvesting and log all data on a computer.

5. Conduct testing on the traffic lanes after harvesting and log data to begin to compare the differences.

6. Determine positions of the traffic lanes with the use of a computer program and the path taken by the machinery to investigate how much of the time the machinery crossed over the growing bed.

7. Analyse the data and draw conclusions involving soil compaction within the growing bed and potential productivity loss.

B Matlab Code

B.1 Load-Out Bin program

```
% APPENDIX B.1
% ENG4111/4112
% Engineering Research Project part 1 & 2
% Author: DAVID WEST
% Student Number: 0061046391
% Supervisor: Dr. Troy Jensen
% -----------------------------------------------------------------
% This program computes the amount of times the growing bed is
crossed by
% the load-out bins given the appropriate data is input (easting
and
% northing data points). The usability of this program is not of a
% satisfactory level and is hard interpret, therefore it is known
that a
% refined version should be created if further work is to be
conducted.
% There are many assumptions and cases that it cannot handle
including:
%   - the scenario when the load-out changes direction and
maintains that
%   direction for a period where it crosses mutiple lanes, this
program
%   will compute the change in direction as a single lane cross
instead of
%   multiple.
%   - other scenarios are outlined in the discussion of the
related
%   dissertation.
% -----------------------------------------------------------------

clear all
close all
clc

%% Load out 1
%------------------------------------------------------------------
% import raw data
LOB_1_data_raw=xlsread('DWEST_LOAD_OUT_1.SVY.xlsx');

LOB_1_easting_raw=LOB_1_data_raw(:,2);
LOB_1_northing_raw=LOB_1_data_raw(:,3);

LOB_1_dE_raw=zeros(10,1);
LOB_1_dN_raw=zeros(10,1);

% dE = E2-E1
% dN = N2-N1
for i=1:length(LOB_1_easting_raw)-1
    LOB_1_dE_raw(i)=LOB_1_easting_raw(i+1)-LOB_1_easting_raw(i);
end

for i=1:length(LOB_1_northing_raw)-1
    LOB_1_dN_raw(i)=LOB_1_northing_raw(i+1)-LOB_1_northing_raw(i);
end
```

```
% azimuth=atan(dE/dN)
LOB_1_azimuth_raw=atan(LOB_1_dE_raw./LOB_1_dN_raw);

% distance=sqrt(dE^2 + dN^2)
LOB_1_distance_raw=sqrt((LOB_1_dE_raw.^2)+(LOB_1_dN_raw.^2));

%-------------------------------------------------------------------
% determing unwanted data
% when machine not moving (distance = 0)

j=0;
LOB_1_distance_not_move_cor=[0;0];
LOB_1_azimuth_not_move_cor=[0;0];
LOB_1_easting_not_move_cor=[0;0];
LOB_1_northing_not_move_cor=[0;0];

for i=1:length(LOB_1_distance_raw)
    if LOB_1_distance_raw(i)>0
        j=j+1;
        LOB_1_distance_not_move_cor(j)=LOB_1_distance_raw(i);
        LOB_1_azimuth_not_move_cor(j)=LOB_1_azimuth_raw(i);
        LOB_1_easting_not_move_cor(j)=LOB_1_easting_raw(i);
        LOB_1_northing_not_move_cor(j)=LOB_1_northing_raw(i);
    end
end

% delete data east of 4.241e+5

j=0;
LOB_1_easting_road_cor=[0;0];
LOB_1_northing_road_cor=[0;0];
LOB_1_azimuth_road_cor=[0;0];

for i=1:length(LOB_1_easting_not_move_cor)
    if LOB_1_easting_not_move_cor(i)<4.2396e+5
        j=j+1;
        LOB_1_easting_road_cor(j)=LOB_1_easting_not_move_cor(i);
        LOB_1_northing_road_cor(j)=LOB_1_northing_not_move_cor(i);
        LOB_1_azimuth_road_cor(j)=LOB_1_azimuth_not_move_cor(i);
    end
end

% for i=5667:5890
%     figure(1)
%     plot(LOB_1_easting_road_cor(i),LOB_1_northing_road_cor(i))
%     hold on
% end

LOB_1_row_01=503:767;     % s empty f full
LOB_1_row_02=823:952;     % s full f empty
LOB_1_row_03=1015:1056;   % empty all the way
LOB_1_row_04=1058:1239;   % full all the way
LOB_1_row_05=1324:1528;   % s full f empty
LOB_1_row_06=1649:1850;   % s empty f full
LOB_1_row_07=1887:2228;   % s full f empty obstruction near middle
LOB_1_row_08=2247:2413;   % s empty f full obstruction near middle
LOB_1_row_09=2445:2655;   % s full f empty
LOB_1_row_10=2682:2790;   % s empty f full
```

```
LOB_1_row_11=2832:3077;  % filling up all the way, obstruction in
middle
LOB_1_row_12=3152:3395;  % filling up all the way
LOB_1_row_13=4858:4937;  % empty all the way
LOB_1_row_14=5353:5645;  % filling up all the way, stop in the
middle
LOB_1_row_15=5682:5890;  % filling up all the way
LOB_1_row_16=5955:6112;  % s empty f full
LOB_1_row_17=6330:6458;  % s full f empty

LOB_1_azimuth_row_01=LOB_1_azimuth_road_cor(LOB_1_row_01);
LOB_1_azimuth_row_02=LOB_1_azimuth_road_cor(LOB_1_row_02);
LOB_1_azimuth_row_03=LOB_1_azimuth_road_cor(LOB_1_row_03);
LOB_1_azimuth_row_04=LOB_1_azimuth_road_cor(LOB_1_row_04);
LOB_1_azimuth_row_05=LOB_1_azimuth_road_cor(LOB_1_row_05);
LOB_1_azimuth_row_06=LOB_1_azimuth_road_cor(LOB_1_row_06);
LOB_1_azimuth_row_07=LOB_1_azimuth_road_cor(LOB_1_row_07);
LOB_1_azimuth_row_08=LOB_1_azimuth_road_cor(LOB_1_row_08);
LOB_1_azimuth_row_09=LOB_1_azimuth_road_cor(LOB_1_row_09);
LOB_1_azimuth_row_10=LOB_1_azimuth_road_cor(LOB_1_row_10);
LOB_1_azimuth_row_11=LOB_1_azimuth_road_cor(LOB_1_row_11);
LOB_1_azimuth_row_12=LOB_1_azimuth_road_cor(LOB_1_row_12);
LOB_1_azimuth_row_13=LOB_1_azimuth_road_cor(LOB_1_row_13);
LOB_1_azimuth_row_14=LOB_1_azimuth_road_cor(LOB_1_row_14);
LOB_1_azimuth_row_15=LOB_1_azimuth_road_cor(LOB_1_row_15);
LOB_1_azimuth_row_16=LOB_1_azimuth_road_cor(LOB_1_row_16);
LOB_1_azimuth_row_17=LOB_1_azimuth_road_cor(LOB_1_row_17);

%% Load out 2
%-----------------------------------------------------------------

LOB_2_data_raw=xlsread('NEW_LOADOUT_BIN_DWEST.SVY.xlsx');

LOB_2_easting_raw=LOB_2_data_raw(:,2);
LOB_2_northing_raw=LOB_2_data_raw(:,3);

LOB_2_dE_raw=zeros(10,1);
LOB_2_dN_raw=zeros(10,1);

% dE = E2-E1
% dN = N2-N1

for i=1:length(LOB_2_easting_raw)-1
    LOB_2_dE_raw(i)=LOB_2_easting_raw(i+1)-LOB_2_easting_raw(i);
end

for i=1:length(LOB_2_northing_raw)-1
    LOB_2_dN_raw(i)=LOB_2_northing_raw(i+1)-LOB_2_northing_raw(i);
end

% azimuth=atan(dE/dN)

LOB_2_azimuth_raw=atan(LOB_2_dE_raw./LOB_2_dN_raw);

% distance=sqrt(dE^2 + dN^2)
LOB_2_distance_raw=sqrt((LOB_2_dE_raw.^2)+(LOB_2_dN_raw.^2));

%-----------------------------------------------------------------
% determing unwanted data
```

```
% when machine not moving (distance = 0)

j=0;
LOB_2_distance_not_move_cor=[0;0];
LOB_2_azimuth_not_move_cor=[0;0];
LOB_2_easting_not_move_cor=[0;0];
LOB_2_northing_not_move_cor=[0;0];

for i=1:length(LOB_2_distance_raw)
    if LOB_2_distance_raw(i)>0
        j=j+1;
        LOB_2_distance_not_move_cor(j)=LOB_2_distance_raw(i);
        LOB_2_azimuth_not_move_cor(j)=LOB_2_azimuth_raw(i);
        LOB_2_easting_not_move_cor(j)=LOB_2_easting_raw(i);
        LOB_2_northing_not_move_cor(j)=LOB_2_northing_raw(i);
    end
end

% delete data east of 4.2396e+5

j=0;
LOB_2_easting_road_cor=[0;0];
LOB_2_northing_road_cor=[0;0];
LOB_2_azimuth_road_cor=[0;0];

for i=1:length(LOB_2_easting_not_move_cor)
    if LOB_2_easting_not_move_cor(i)<4.2396e+5
        j=j+1;
        LOB_2_easting_road_cor(j)=LOB_2_easting_not_move_cor(i);
        LOB_2_northing_road_cor(j)=LOB_2_northing_not_move_cor(i);
        LOB_2_azimuth_road_cor(j)=LOB_2_azimuth_not_move_cor(i);
    end
end


% for i=8350:8565
%     figure(1)
%     plot(LOB_2_easting_road_cor(i),LOB_2_northing_road_cor(i))
%     hold on
% end

LOB_2_row_01=320:550;      % empty all the way
LOB_2_row_02=585:829;      % filling all the way
LOB_2_row_03=1210:1330;    % short run filling up
LOB_2_row_04=1460:1685;    % s filling f empty
LOB_2_row_05=1902:2135;    % s filling f empty
LOB_2_row_06=2299:2550;    % filling all the way
LOB_2_row_07=2600:2661;    % empty all the way
LOB_2_row_08=4400:4605;    % s empty f filling
LOB_2_row_09=4650:4770;    % s filling f full
LOB_2_row_10=4841:4890;    % empty all the way
LOB_2_row_11=4910:5100;    % filling all the way
LOB_2_row_12=5609:5840;    % filling all the way
LOB_2_row_13=5925:6141;    % filling all the way
LOB_2_row_14=6180:6324;    % s filling f full
LOB_2_row_15=6345:6470;    % s empty f filling
LOB_2_row_16=6520:6750;    % filling all the way
LOB_2_row_17=6830:7060;    % filling all the way
LOB_2_row_18=7292:7530;    % s empty f filling
LOB_2_row_19=7987:8160;    % filling all the way
```

```
LOB_2_row_20=8350:8565;    % filling all the way

LOB_2_azimuth_row_01=LOB_2_azimuth_road_cor(LOB_2_row_01);
LOB_2_azimuth_row_02=LOB_2_azimuth_road_cor(LOB_2_row_02);
LOB_2_azimuth_row_03=LOB_2_azimuth_road_cor(LOB_2_row_03);
LOB_2_azimuth_row_04=LOB_2_azimuth_road_cor(LOB_2_row_04);
LOB_2_azimuth_row_05=LOB_2_azimuth_road_cor(LOB_2_row_05);
LOB_2_azimuth_row_06=LOB_2_azimuth_road_cor(LOB_2_row_06);
LOB_2_azimuth_row_07=LOB_2_azimuth_road_cor(LOB_2_row_07);
LOB_2_azimuth_row_08=LOB_2_azimuth_road_cor(LOB_2_row_08);
LOB_2_azimuth_row_09=LOB_2_azimuth_road_cor(LOB_2_row_09);
LOB_2_azimuth_row_10=LOB_2_azimuth_road_cor(LOB_2_row_10);
LOB_2_azimuth_row_11=LOB_2_azimuth_road_cor(LOB_2_row_11);
LOB_2_azimuth_row_12=LOB_2_azimuth_road_cor(LOB_2_row_12);
LOB_2_azimuth_row_13=LOB_2_azimuth_road_cor(LOB_2_row_13);
LOB_2_azimuth_row_14=LOB_2_azimuth_road_cor(LOB_2_row_14);
LOB_2_azimuth_row_15=LOB_2_azimuth_road_cor(LOB_2_row_15);
LOB_2_azimuth_row_16=LOB_2_azimuth_road_cor(LOB_2_row_16);
LOB_2_azimuth_row_17=LOB_2_azimuth_road_cor(LOB_2_row_17);
LOB_2_azimuth_row_18=LOB_2_azimuth_road_cor(LOB_2_row_18);
LOB_2_azimuth_row_19=LOB_2_azimuth_road_cor(LOB_2_row_19);
LOB_2_azimuth_row_20=LOB_2_azimuth_road_cor(LOB_2_row_20);

%% Determine changes in azimuth
% Load out 1

LOB_1_azimuth_deg_01=LOB_1_azimuth_row_01*360/pi;
LOB_1_azimuth_deg_02=LOB_1_azimuth_row_02*360/pi;
LOB_1_azimuth_deg_03=LOB_1_azimuth_row_03*360/pi;
LOB_1_azimuth_deg_04=LOB_1_azimuth_row_04*360/pi;
LOB_1_azimuth_deg_05=LOB_1_azimuth_row_05*360/pi;
LOB_1_azimuth_deg_06=LOB_1_azimuth_row_06*360/pi;
LOB_1_azimuth_deg_07=LOB_1_azimuth_row_07*360/pi;
LOB_1_azimuth_deg_08=LOB_1_azimuth_row_08*360/pi;
LOB_1_azimuth_deg_09=LOB_1_azimuth_row_09*360/pi;
LOB_1_azimuth_deg_10=LOB_1_azimuth_row_10*360/pi;
LOB_1_azimuth_deg_11=LOB_1_azimuth_row_11*360/pi;
LOB_1_azimuth_deg_12=LOB_1_azimuth_row_12*360/pi;
LOB_1_azimuth_deg_13=LOB_1_azimuth_row_13*360/pi;
LOB_1_azimuth_deg_14=LOB_1_azimuth_row_14*360/pi;
LOB_1_azimuth_deg_15=LOB_1_azimuth_row_15*360/pi;
LOB_1_azimuth_deg_16=LOB_1_azimuth_row_16*360/pi;
LOB_1_azimuth_deg_17=LOB_1_azimuth_row_17*360/pi;

turning_deg_1=40;

LOB_1_j_row_01=0;

for i=2:length(LOB_1_azimuth_deg_01)
    if LOB_1_azimuth_deg_01(i)<LOB_1_azimuth_deg_01(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_01(i)>LOB_1_azimuth_deg_01(i-
1)+turning_deg_1
        LOB_1_j_row_01=LOB_1_j_row_01+1;
    end
end

LOB_1_j_row_02=0;

for i=2:length(LOB_1_azimuth_deg_02)
```

```
    if LOB_1_azimuth_deg_02(i)<LOB_1_azimuth_deg_02(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_02(i)>LOB_1_azimuth_deg_02(i-
1)+turning_deg_1
        LOB_1_j_row_02=LOB_1_j_row_02+1;
    end
end

LOB_1_j_row_03=0;

for i=2:length(LOB_1_azimuth_deg_03)
    if LOB_1_azimuth_deg_03(i)<LOB_1_azimuth_deg_03(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_03(i)>LOB_1_azimuth_deg_03(i-
1)+turning_deg_1
        LOB_1_j_row_03=LOB_1_j_row_03+1;
    end
end

LOB_1_j_row_04=0;

for i=2:length(LOB_1_azimuth_deg_04)
    if LOB_1_azimuth_deg_04(i)<LOB_1_azimuth_deg_04(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_04(i)>LOB_1_azimuth_deg_04(i-
1)+turning_deg_1
        LOB_1_j_row_04=LOB_1_j_row_04+1;
    end
end

LOB_1_j_row_05=0;

for i=2:length(LOB_1_azimuth_deg_05)
    if LOB_1_azimuth_deg_05(i)<LOB_1_azimuth_deg_05(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_05(i)>LOB_1_azimuth_deg_05(i-
1)+turning_deg_1
        LOB_1_j_row_05=LOB_1_j_row_05+1;
    end
end

LOB_1_j_row_06=0;

for i=2:length(LOB_1_azimuth_deg_06)
    if LOB_1_azimuth_deg_06(i)<LOB_1_azimuth_deg_06(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_06(i)>LOB_1_azimuth_deg_06(i-
1)+turning_deg_1
        LOB_1_j_row_06=LOB_1_j_row_06+1;
    end
end

LOB_1_j_row_07=0;   % middle obstruction

for i=2:length(LOB_1_azimuth_deg_07)
    if LOB_1_azimuth_deg_07(i)<LOB_1_azimuth_deg_07(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_07(i)>LOB_1_azimuth_deg_07(i-
1)+turning_deg_1
```

```
        LOB_1_j_row_07=LOB_1_j_row_07+1;
    end
end

LOB_1_j_row_08=0;   % middle obstruction

for i=2:length(LOB_1_azimuth_deg_08)
    if LOB_1_azimuth_deg_08(i)<LOB_1_azimuth_deg_08(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_08(i)>LOB_1_azimuth_deg_08(i-
1)+turning_deg_1
        LOB_1_j_row_08=LOB_1_j_row_08+1;
    end
end

LOB_1_j_row_09=0;

for i=2:length(LOB_1_azimuth_deg_09)
    if LOB_1_azimuth_deg_09(i)<LOB_1_azimuth_deg_09(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_09(i)>LOB_1_azimuth_deg_09(i-
1)+turning_deg_1
        LOB_1_j_row_09=LOB_1_j_row_09+1;
    end
end

LOB_1_j_row_10=0;

for i=2:length(LOB_1_azimuth_deg_10)
    if LOB_1_azimuth_deg_10(i)<LOB_1_azimuth_deg_10(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_10(i)>LOB_1_azimuth_deg_10(i-
1)+turning_deg_1
        LOB_1_j_row_10=LOB_1_j_row_10+1;
    end
end

LOB_1_j_row_11=0;

for i=2:length(LOB_1_azimuth_deg_11)
    if LOB_1_azimuth_deg_11(i)<LOB_1_azimuth_deg_11(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_11(i)>LOB_1_azimuth_deg_11(i-
1)+turning_deg_1
        LOB_1_j_row_11=LOB_1_j_row_11+1;
    end
end

LOB_1_j_row_12=0;

for i=2:length(LOB_1_azimuth_deg_12)
    if LOB_1_azimuth_deg_12(i)<LOB_1_azimuth_deg_12(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_12(i)>LOB_1_azimuth_deg_12(i-
1)+turning_deg_1
        LOB_1_j_row_12=LOB_1_j_row_12+1;
    end
end
```

```
LOB_1_j_row_13=0;

for i=2:length(LOB_1_azimuth_deg_13)
    if LOB_1_azimuth_deg_13(i)<LOB_1_azimuth_deg_13(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_13(i)>LOB_1_azimuth_deg_13(i-
1)+turning_deg_1
        LOB_1_j_row_13=LOB_1_j_row_13+1;
    end
end

LOB_1_j_row_14=0;

for i=2:length(LOB_1_azimuth_deg_14)
    if LOB_1_azimuth_deg_14(i)<LOB_1_azimuth_deg_14(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_14(i)>LOB_1_azimuth_deg_14(i-
1)+turning_deg_1
        LOB_1_j_row_14=LOB_1_j_row_14+1;
    end
end

LOB_1_j_row_15=0;

for i=2:length(LOB_1_azimuth_deg_15)
    if LOB_1_azimuth_deg_15(i)<LOB_1_azimuth_deg_15(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_15(i)>LOB_1_azimuth_deg_15(i-
1)+turning_deg_1
        LOB_1_j_row_15=LOB_1_j_row_15+1;
    end
end

LOB_1_j_row_16=0;

for i=2:length(LOB_1_azimuth_deg_16)
    if LOB_1_azimuth_deg_16(i)<LOB_1_azimuth_deg_16(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_16(i)>LOB_1_azimuth_deg_16(i-
1)+turning_deg_1
        LOB_1_j_row_16=LOB_1_j_row_16+1;
    end
end

LOB_1_j_row_17=0;

for i=2:length(LOB_1_azimuth_deg_17)
    if LOB_1_azimuth_deg_17(i)<LOB_1_azimuth_deg_17(i-1)-
turning_deg_1 ||...
            LOB_1_azimuth_deg_17(i)>LOB_1_azimuth_deg_17(i-
1)+turning_deg_1
        LOB_1_j_row_17=LOB_1_j_row_17+1;
    end
end

% Load out 2 -----------------------------------------------------
LOB_2_azimuth_deg_01=LOB_2_azimuth_row_01*360/pi;
LOB_2_azimuth_deg_02=LOB_2_azimuth_row_02*360/pi;
LOB_2_azimuth_deg_03=LOB_2_azimuth_row_03*360/pi;
```

```
LOB_2_azimuth_deg_04=LOB_2_azimuth_row_04*360/pi;
LOB_2_azimuth_deg_05=LOB_2_azimuth_row_05*360/pi;
LOB_2_azimuth_deg_06=LOB_2_azimuth_row_06*360/pi;
LOB_2_azimuth_deg_07=LOB_2_azimuth_row_07*360/pi;
LOB_2_azimuth_deg_08=LOB_2_azimuth_row_08*360/pi;
LOB_2_azimuth_deg_09=LOB_2_azimuth_row_09*360/pi;
LOB_2_azimuth_deg_10=LOB_2_azimuth_row_10*360/pi;
LOB_2_azimuth_deg_11=LOB_2_azimuth_row_11*360/pi;
LOB_2_azimuth_deg_12=LOB_2_azimuth_row_12*360/pi;
LOB_2_azimuth_deg_13=LOB_2_azimuth_row_13*360/pi;
LOB_2_azimuth_deg_14=LOB_2_azimuth_row_14*360/pi;
LOB_2_azimuth_deg_15=LOB_2_azimuth_row_15*360/pi;
LOB_2_azimuth_deg_16=LOB_2_azimuth_row_16*360/pi;
LOB_2_azimuth_deg_17=LOB_2_azimuth_row_17*360/pi;
LOB_2_azimuth_deg_18=LOB_2_azimuth_row_18*360/pi;
LOB_2_azimuth_deg_19=LOB_2_azimuth_row_19*360/pi;
LOB_2_azimuth_deg_20=LOB_2_azimuth_row_20*360/pi;

turning_deg_2=20;

LOB_2_j_row_01=0;

for i=2:length(LOB_2_azimuth_deg_01)
    if LOB_2_azimuth_deg_01(i)<LOB_2_azimuth_deg_01(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_01(i)>LOB_2_azimuth_deg_01(i-
1)+turning_deg_2
        LOB_2_j_row_01=LOB_2_j_row_01+1;
    end
end

LOB_2_j_row_02=0;

for i=2:length(LOB_2_azimuth_deg_02)
    if LOB_2_azimuth_deg_02(i)<LOB_2_azimuth_deg_02(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_02(i)>LOB_2_azimuth_deg_02(i-
1)+turning_deg_2
        LOB_2_j_row_02=LOB_2_j_row_02+1;
    end
end

LOB_2_j_row_03=0;

for i=2:length(LOB_2_azimuth_deg_03)
    if LOB_2_azimuth_deg_03(i)<LOB_2_azimuth_deg_03(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_03(i)>LOB_2_azimuth_deg_03(i-
1)+turning_deg_2
        LOB_2_j_row_03=LOB_2_j_row_03+1;
    end
end

LOB_2_j_row_04=0;

for i=2:length(LOB_2_azimuth_deg_04)
    if LOB_2_azimuth_deg_04(i)<LOB_2_azimuth_deg_04(i-1)-
turning_deg_2 ||...
```

```
            LOB_2_azimuth_deg_04(i)>LOB_2_azimuth_deg_04(i-
1)+turning_deg_2
        LOB_2_j_row_04=LOB_2_j_row_04+1;
    end
end

LOB_2_j_row_05=0;

for i=2:length(LOB_2_azimuth_deg_05)
    if LOB_2_azimuth_deg_05(i)<LOB_2_azimuth_deg_05(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_05(i)>LOB_2_azimuth_deg_05(i-
1)+turning_deg_2
        LOB_2_j_row_05=LOB_2_j_row_05+1;
    end
end

LOB_2_j_row_06=0;

for i=2:length(LOB_2_azimuth_deg_06)
    if LOB_2_azimuth_deg_06(i)<LOB_2_azimuth_deg_06(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_06(i)>LOB_2_azimuth_deg_06(i-
1)+turning_deg_2
        LOB_2_j_row_06=LOB_2_j_row_06+1;
    end
end

LOB_2_j_row_07=0;

for i=2:length(LOB_2_azimuth_deg_07)
    if LOB_2_azimuth_deg_07(i)<LOB_2_azimuth_deg_07(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_07(i)>LOB_2_azimuth_deg_07(i-
1)+turning_deg_2
        LOB_2_j_row_07=LOB_2_j_row_07+1;
    end
end

LOB_2_j_row_08=0;

for i=2:length(LOB_2_azimuth_deg_08)
    if LOB_2_azimuth_deg_08(i)<LOB_2_azimuth_deg_08(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_08(i)>LOB_2_azimuth_deg_08(i-
1)+turning_deg_2
        LOB_2_j_row_08=LOB_2_j_row_08+1;
    end
end

LOB_2_j_row_09=0;

for i=2:length(LOB_2_azimuth_deg_09)
    if LOB_2_azimuth_deg_09(i)<LOB_2_azimuth_deg_09(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_09(i)>LOB_2_azimuth_deg_09(i-
1)+turning_deg_2
        LOB_2_j_row_09=LOB_2_j_row_09+1;
    end
```

```
end

LOB_2_j_row_10=0;

for i=2:length(LOB_2_azimuth_deg_10)
    if LOB_2_azimuth_deg_10(i)<LOB_2_azimuth_deg_10(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_10(i)>LOB_2_azimuth_deg_10(i-
1)+turning_deg_2
        LOB_2_j_row_10=LOB_2_j_row_10+1;
    end
end

LOB_2_j_row_11=0;

for i=2:length(LOB_2_azimuth_deg_11)
    if LOB_2_azimuth_deg_11(i)<LOB_2_azimuth_deg_11(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_11(i)>LOB_2_azimuth_deg_11(i-
1)+turning_deg_2
        LOB_2_j_row_11=LOB_2_j_row_11+1;
    end
end

LOB_2_j_row_12=0;

for i=2:length(LOB_2_azimuth_deg_12)
    if LOB_2_azimuth_deg_12(i)<LOB_2_azimuth_deg_12(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_12(i)>LOB_2_azimuth_deg_12(i-
1)+turning_deg_2
        LOB_2_j_row_12=LOB_2_j_row_12+1;
    end
end

LOB_2_j_row_13=0;

for i=2:length(LOB_2_azimuth_deg_13)
    if LOB_2_azimuth_deg_13(i)<LOB_2_azimuth_deg_13(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_13(i)>LOB_2_azimuth_deg_13(i-
1)+turning_deg_2
        LOB_2_j_row_13=LOB_2_j_row_13+1;
    end
end

LOB_2_j_row_14=0;

for i=2:length(LOB_2_azimuth_deg_14)
    if LOB_2_azimuth_deg_14(i)<LOB_2_azimuth_deg_14(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_14(i)>LOB_2_azimuth_deg_14(i-
1)+turning_deg_2
        LOB_2_j_row_14=LOB_2_j_row_14+1;
    end
end

LOB_2_j_row_15=0;
```

```
for i=2:length(LOB_2_azimuth_deg_15)
    if LOB_2_azimuth_deg_15(i)<LOB_2_azimuth_deg_15(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_15(i)>LOB_2_azimuth_deg_15(i-
1)+turning_deg_2
        LOB_2_j_row_15=LOB_2_j_row_15+1;
    end
end

LOB_2_j_row_16=0;

for i=2:length(LOB_2_azimuth_deg_16)
    if LOB_2_azimuth_deg_16(i)<LOB_2_azimuth_deg_16(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_16(i)>LOB_2_azimuth_deg_16(i-
1)+turning_deg_2
        LOB_2_j_row_16=LOB_2_j_row_16+1;
    end
end

LOB_2_j_row_17=0;

for i=2:length(LOB_2_azimuth_deg_17)
    if LOB_2_azimuth_deg_17(i)<LOB_2_azimuth_deg_17(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_17(i)>LOB_2_azimuth_deg_17(i-
1)+turning_deg_2
        LOB_2_j_row_17=LOB_2_j_row_17+1;
    end
end

LOB_2_j_row_18=0;

for i=2:length(LOB_2_azimuth_deg_18)
    if LOB_2_azimuth_deg_18(i)<LOB_2_azimuth_deg_18(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_18(i)>LOB_2_azimuth_deg_18(i-
1)+turning_deg_2
        LOB_2_j_row_18=LOB_2_j_row_18+1;
    end
end

LOB_2_j_row_19=0;

for i=2:length(LOB_2_azimuth_deg_19)
    if LOB_2_azimuth_deg_19(i)<LOB_2_azimuth_deg_19(i-1)-
turning_deg_2 ||...
            LOB_2_azimuth_deg_19(i)>LOB_2_azimuth_deg_19(i-
1)+turning_deg_2
        LOB_2_j_row_19=LOB_2_j_row_19+1;
    end
end

LOB_2_j_row_20=0;

for i=2:length(LOB_2_azimuth_deg_20)
    if LOB_2_azimuth_deg_20(i)<LOB_2_azimuth_deg_20(i-1)-
turning_deg_2 ||...
```

```
            LOB_2_azimuth_deg_20(i)>LOB_2_azimuth_deg_20(i-
1)+turning_deg_2
        LOB_2_j_row_20=LOB_2_j_row_20+1;
    end
end

plot (LOB_2_easting_road_cor(LOB_2_row_01),...
    LOB_2_northing_road_cor(LOB_2_row_01),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_02),...
    LOB_2_northing_road_cor(LOB_2_row_02),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_03),...
    LOB_2_northing_road_cor(LOB_2_row_03),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_04),...
    LOB_2_northing_road_cor(LOB_2_row_04),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_05),...
    LOB_2_northing_road_cor(LOB_2_row_05),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_06),...
    LOB_2_northing_road_cor(LOB_2_row_06),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_07),...
    LOB_2_northing_road_cor(LOB_2_row_07),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_08),...
    LOB_2_northing_road_cor(LOB_2_row_08),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_09),...
    LOB_2_northing_road_cor(LOB_2_row_09),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_10),...
    LOB_2_northing_road_cor(LOB_2_row_10),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_11),...
    LOB_2_northing_road_cor(LOB_2_row_11),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_12),...
    LOB_2_northing_road_cor(LOB_2_row_12),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_13),...
    LOB_2_northing_road_cor(LOB_2_row_13),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_14),...
    LOB_2_northing_road_cor(LOB_2_row_14),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_15),...
    LOB_2_northing_road_cor(LOB_2_row_15),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_16),...
    LOB_2_northing_road_cor(LOB_2_row_16),'b','MarkerSize',1),
hold on
plot (LOB_2_easting_road_cor(LOB_2_row_17),...
    LOB_2_northing_road_cor(LOB_2_row_17),'b','MarkerSize',1)
title 'Load-Out Bin 1 Traffic Lane runs'
xlabel 'Easting (m)'
ylabel 'Northing (m)'

Total_j_row_01=LOB_1_j_row_01+LOB_2_j_row_01;
```

```
Total_j_row_02=LOB_1_j_row_02+LOB_2_j_row_02;
Total_j_row_03=LOB_1_j_row_03+LOB_2_j_row_03;
Total_j_row_04=LOB_1_j_row_04+LOB_2_j_row_04;
Total_j_row_05=LOB_1_j_row_05+LOB_2_j_row_05;
Total_j_row_06=LOB_1_j_row_06+LOB_2_j_row_06;
Total_j_row_07=LOB_1_j_row_07+LOB_2_j_row_07;
Total_j_row_08=LOB_1_j_row_08+LOB_2_j_row_08;
Total_j_row_09=LOB_1_j_row_09+LOB_2_j_row_09;
Total_j_row_10=LOB_1_j_row_10+LOB_2_j_row_10;
Total_j_row_11=LOB_1_j_row_11+LOB_2_j_row_11;
Total_j_row_12=LOB_1_j_row_12+LOB_2_j_row_12;
Total_j_row_13=LOB_1_j_row_13+LOB_2_j_row_13;
Total_j_row_14=LOB_1_j_row_14+LOB_2_j_row_14;
Total_j_row_15=LOB_1_j_row_15+LOB_2_j_row_15;
Total_j_row_16=LOB_1_j_row_16+LOB_2_j_row_16;
Total_j_row_17=LOB_1_j_row_17+LOB_2_j_row_17;
Total_j_row_18=LOB_2_j_row_18;
Total_j_row_19=LOB_2_j_row_19;
Total_j_row_20=LOB_2_j_row_20;

%% Affected area

front_wheels=0.587;
rear_wheels=0.622;
distance_across_bed=1.83-0.622;
total_j_LOB_1=16;
total_j_LOB_2=18;
total_area_20=19*1.83*400;
effected_area=2*rear_wheels*distance_across_bed;

effected_area_LOB_1=total_j_LOB_1*effected_area;
effected_area_LOB_2=total_j_LOB_2*effected_area;
```

B.2 Soil bulk density program

```
% % APPENDIX B.2
% ENG4111/4112
% Engineering Research Project part 1 & 2
% Author: DAVID WEST
% Student Number: 0061046391
% Supervisor: Dr. Troy Jensen
% -----------------------------------------------------------------

close all
clear all
clc

% -----------------------------------------------------------------
data=xlsread('Matlab_Soil_Weights.xlsx');

depth=[-5;-15;-25;-35;-45;-55;-65];
before_core=data(:,1);
before_wet_weight=data(:,2);
before_dry_weight=data(:,3);
before_water_weight=data(:,4);
before_moisture_content=data(:,5);
before_bulk_density=data(:,6);

before_den_core_1=before_bulk_density(1:7);
before_den_core_2=before_bulk_density(8:14);
before_den_core_3=before_bulk_density(15:21);
before_den_core_4=before_bulk_density(22:28);
before_den_core_5=before_bulk_density(29:35);
before_den_core_6=before_bulk_density(36:42);

after_core=data(1:35,7);
after_wet_weight=data(1:35,8);
after_dry_weight=data(1:35,9);
after_water_weight=data(1:35,10);
after_moisture_content=data(1:35,11);
after_bulk_density=data(1:35,12);

after_den_core_1=after_bulk_density(1:7);
after_den_core_2=after_bulk_density(8:14);
after_den_core_3=after_bulk_density(15:21);
after_den_core_4=after_bulk_density(22:28);
after_den_core_5=after_bulk_density(29:35);

figure (1)
subplot (2,2,1)
plot
(before_den_core_1,depth,after_den_core_1,depth,before_den_core_6,
depth)
title 'Soil Core 1 Bulk Density'
xlabel 'Bulk Density (g/cm^3)'
ylabel 'Depth (m)'

subplot (2,2,2)
plot
(before_den_core_2,depth,after_den_core_2,depth,before_den_core_6,
depth)
```

```
subplot (2,2,3)
plot
(before_den_core_3,depth,after_den_core_3,depth,before_den_core_6,
depth)

subplot (2,2,4)
plot
(before_den_core_4,depth,after_den_core_4,depth,before_den_core_6,
depth)

figure (2)
plot
(before_den_core_5,depth,after_den_core_5,depth,before_den_core_6,
depth)
%-------------------------------------------------------------------
```