THE INFLUENCE OF ROAD CONDITION ON THE SHELF LIFE OF TOMATOES

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DISSERTATION SUMMARY

THE INFLUENCE OF ROAD CONDITION ON THE SHELF LIFE OF TOMATOES

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Department: Civil Engineering

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ABSTRACT

Title: The influence of road condition on the shelf life of tomatoes

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In the modern era consumer awareness on quality aspects has been a growing concern for the fresh produce market due to the fact that consumer perspective defines the bottom line of all agricultural businesses. External damage to produce does not only render fruit less attractive but damaged locations serve as entry points for pathogens resulting is food safety issues.

Because tomatoes have a limited shelf life, it is vital to control the factors that lead to earlier deterioration of the quality of the product. Shipping, handling and distribution can cause numerous forms of cuts and bruises on harvested tomatoes which compromise their quality and appearance. Furthermore the economic value to the retailer and grower is reduced (Chonhenchob et al., 2009).

Post-harvest science focus mainly on the quality of fresh produce. One of the areas of interest is the shipment of tomatoes using road transport. Trucks are one of the best methods for transporting perishable products because of shorter transport times and the ability to reach more inland destinations than any other mode of transport (Jarimopas et al., 2005; Chonhenchob et al., 2009). Although the flexibility of road transport is an advantage, previous studies have indicated that fruit and vegetables suffer mechanical damage due to in-transit vibrations which is caused by the road condition (Jarimopas et al., 2005).

The condition of roads in South Africa is dependent on the management plan execution by the managing agent. The National Road Network, maintained by SANRAL is predominantly in a good condition (Ittmann, 2013). In contrast, condition assessment data for provincial roads indicate that roads are deteriorating at an alarming pace, not to mention that the majority of road networks under municipal authorities have no data at all (SAICE, 2011).

To date there is no model that relates tomato damage and loss in shelf life to the road condition, fruit maturity and position in the container. For this experiment the in-transit conditions were monitored on trucks travelling from three farms in Limpopo, owned by the ZZ2 group, to the fresh produce market in Pietermaritzburg. These trucks drive on a variety

of roads including gravel or rural roads where higher roughness values are probable along with more produce damage.

The experimental setup consisted of two phases. The first phase was the in-transit monitoring of the conditions to which tomatoes are exposed when shipped from grower to the farmers market. The second phase was the laboratory simulation of in-transit conditions to create a model for the prediction of shelf-life under controlled conditions.

Equipment for the field experiment included a profilometer to determine road conditions, accelerometers to determine in-transit vibrations, pressure sensors to determine in-transit pressures. Equipment for the laboratory experiment included a vibration table to simulate different road conditions, pressure sensors to measure pressures that can be related to in-transit pressures and a colour meter to measure colour changes in damaged and control tomatoes.

From the in-transit pressure analysis it was concluded that the amount of pressure cycles that a tomato experience increase as the roughness of the road increase and the force distribution that is applied to the tomatoes becomes wider to include forces larger in magnitude. Good correlations existed between in-transit and laboratory pressures.

Colour measurements had no strong trends that could be related to damage and an experimental model based on consumer perspective was developed. The experimental model was designed based on a marketability matrix that models the decision of the consumer on whether to purchase a tomato or not. Ultimately it is a subjective matter and each consumer would react differently towards the colour and firmness of the tomato in question.

The model indicated that for roads with high roughness values (International Roughness Index (IRI) > 8 m/km), which mostly consist of farm roads that are poorly maintained, all tomatoes in the first and second layers would acquire significant damage irrespective of the maturity of the fruit. On well-maintained roads with roughness values less than 3.5 m/km red tomatoes in the top layers tend to damage more with an increase in time as compared to tomatoes in the lower layers. Green and pink tomatoes are more resistant to damage in the top layers than the red tomatoes.

From the damage models it is apparent that as the roughness of the road increases the damage to tomatoes increase as well. Tomato maturity and the position of the tomatoes in a container also influence the amount of damage to the fruit.

With this information in hand, logistic planners can make informed decisions during route planning in weighing transportation costs to the cost of losses to produce during transportation. Similar models can be developed to include other fruits and vegetables.

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- Aurecon SA (pty) ltd
- And my friends and family

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LIST OF SYMBOLS AND ABREVIATIONS

FFT	-	Fast Fourier Transform
GDP	-	Gross Domestic Product
GPS	-	Global Positioning System
HDM4	-	Highway Development and Management Tools version 4
IMG	-	Immature Green
IRI	-	International Roughness Index
LP	-	Light Pink
MEMS	-	Micro-Electro Machined Semiconductor
OECD	-	Organisation for Economic Co-operation and Development
PMG	-	Partially Mature Green
PRMG	-	Provincial Road Maintenance Grant
PSD	-	Power Spectral Density
RAL	-	Roads Agency Limpopo
RMSVA	-	Root Mean Square Vertical Acceleration
SANRAL	-	South African National Roads Agency Limited
TMG	-	Typical Mature Green
TRB	-	Transportation Research Board
USA	-	United States of America
USB	-	Universal Serial Bus
V-PI	-	Vehicle – Pavement Interaction
NCHRP	-	National Cooperative Highway Research Program

1 INTRODUCTION

1.1 BACKGROUND

One of the main purposes of most commercial businesses is to maximise income. Agricultural businesses are no different in this regard. Because tomatoes have a limited shelf life, it is vital to control the factors that lead to earlier deterioration of the quality of the product. Shipping, handling and distribution can cause numerous forms of cuts and bruises on harvested tomatoes which compromise their quality and appearance. Furthermore the economic value to the retailer and grower is reduced (Chonhenchob et al., 2009).

Trucks are one of the best methods for transporting perishable products because of shorter transport times (direct transport from origin to destination) and the ability to reach more inland destinations than any other mode of transport (Jarimopas et al., 2005; Chonhenchob et al., 2009). Although the flexibility of road transport is an advantage, previous studies have indicated that fruit and vegetables suffer mechanical damage due to in-transit vibrations (Jarimopas et al., 2005). The potential damages can be limited through improved packaging and vehicle technology but this increases capital expenditures (Steyn et al., 2011).

Other post-harvest factors that influence shelf life include temperature changes during transit, the ripeness of the tomatoes being transported and the methods of packaging (Schoorl & Holt, 1982; Steyn & Coetzer, 2014). Former studies conducted on tomatoes considered the stiffness of the fruit in relation to the ripening colour. Stresses were applied to the sides and the top of the tomatoes. Colour changes in the tomatoes were observed where these stresses were applied (Steyn & Coetzer, 2014). It was recommended by Steyn & Coetzer (2014) that simulations of the in-transit vibrations should be carried out to consider the continual effect of pressures applied by the tomatoes on each other.

Previous research regarding vehicle pavement interaction and tomato damage indicated that there is a relationship between the measured vibrations on a truck and the amount of damage observed on tomatoes (Hinsch et al., 1993; Steyn & Coetzer, 2014). With deteriorating road conditions the vibrations increase and in response so does the damage to tomatoes (Chonhenchob et al., 2009; Steyn & Coetzer, 2014). Certain positions on the truck and within the pallet stack inflicted more damage than other positions. The indication is that produce in the top rear position of the vehicle experienced twice the amount of acceleration than produce in the bottom position (Hinsch et al., 1993). In some cases improved packaging can reduce the effect of in-transit vibrations.

Tomatoes at different ripening stages are affected differently by pressures experienced during shipment. This is due to the difference in the stiffness of a green, pink and red tomato (Steyn & Coetzer, 2014). Currently there is no research that relates damage during shipment to the ideal time to transport produce during their ripening stages.

1.2 OBJECTIVE OF THE STUDY

The objective of this study is to find a correlation between the shelf life and transport operating conditions for tomatoes taking into consideration the ripeness of the fruit. Operating conditions includes the different road conditions and the choice of packaging (half bins/small boxes).

To date there is no model that relates damage incurred during transit to the shelf-life of tomatoes. A gap therefore exists to formulate a model relating the shelf-life, damage, in-transit vibrations and road condition. Furthermore this model should also consider the ripening phases of the tomatoes. To achieve this the following will be investigated:

- In-transit stresses on tomatoes;
- Road and operating conditions;
- Laboratory simulations to relate damage to road conditions, and
- The effect of tomato maturity on the stiffness of tomatoes (red, pink and green).

1.3 SCOPE OF THE STUDY

The scope of this study was to investigate the in-transit stresses that tomatoes of different ripeness experience due to different road conditions and to simulate these conditions in the laboratory.

The experimental setup consisted of two phases. The first phase was the in-transit monitoring of the conditions to which tomatoes are exposed when shipped from grower to the farmers market. The second phase was the laboratory simulation of in-transit conditions to create a model for the prediction of shelf-life as influenced by road conditions.

The first phase of the project consisted of the road roughness measurement with a laser profilometer, the measurement of vertical accelerations that the vehicle and transported cargo are exposed to, and the measurement of the in-transit pressures applied to the tomatoes.

The second phase of the project involved an experimental setup in the laboratory. A vibration table was used to simulate the in-transit conditions while monitoring pressures were applied to the tomatoes. Different situations were assessed including the effect of the number of layers of tomatoes as well as tomato maturity. The laboratory analysis was conducted to control specific parameters identified during the field investigation and to monitor the effect that variations in these parameters have on product quality.

1.4 METHODOLOGY

The research methodology is as follows:

- Measurement of the in-transit stresses that tomatoes of different ripeness experience;
- Measurement of road condition;
- Measurement of the vibrations on a standard vehicle to relate vibrations to road condition;
- Laboratory simulations of vibrations measured when using half bins and small boxes;
- Establishment of a relationship between in-transit stresses, damage on tomatoes and road condition;
- Relate damage incurred to expected shelf life;
- Develop a model that link operating conditions with in-transit damage of tomatoes at different ripening stages, and
- Expand model to relate operating conditions to shelf life.

1.5 ORGANISATION OF THE REPORT

The research project consists of the following chapters:

- Chapter 1: Introduction
- Chapter 2: Literature Review
- Chapter 3: Methodology
- Chapter 4: Data Collection and Processing
- Chapter 5: Data Analysis
- Chapter 6: Conclusions and Recommendations
- Chapter 7: References
- Chapter 8: Appendixes

1.6 REFERENCES

Chonhenchob, V; Sittipod, S; Swasdee, D; Rachtanapun, P; Singh, S P; Sing, J., 2009. Effect of truck vibrations during transport on damage to fresh produce shipment in Thailand. *Journal of Applied Packaging Research,* 3(1), pp. 27-38.

Hinsch, R. T., Slaughter, D. C., Craig, W. L. & Thompson, J. F., 1993. Vibration of fresh fruits and vegetables durung refrierated truck transport. *American Society of Agricultural Engineers,* 36(4), pp. 1039-1042.

Jarimopas, B., Singh, S. P. & Saengnil, W., 2005. Measurement and analysis of truck transport vibration levels and damage to packaged tangerines during transit. *Packaging technology and science,* 18(4), p. 179.

Schoorl, D. & Holt, J. E., 1982. Road-vehicle-load interactions for transport of fruit and vegetables. *Agricultural Systems,* Volume 8, pp. 143-155.

Steyn, WJvdM., Bean, W., King, D. & Komba, J., 2011. *Evaluation of Selected Effects of Pavement Riding Quality in Logistics Costs in South Africa.* Transportation Research Board Volume 2227, pp. 138-145. Washington, Transportation Research Board.

Steyn, WJvdM. & Coetzer, S., 2014. *ZZ2 Evaluation and Produce Damage - Final Report,* Pretoria: University of Pretoria.

2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides background on the importance and economic value of the agricultural and transport sectors while considering the influence of road condition on the damage susceptibility of tomatoes. The focus of this study is on the effect that road condition has on tomato quality, but for a complete overview, other elements and their influence were also investigated in the literature.

The relationship between economic growth and infrastructure investment became a well-studied topic since it was first published by Aschauer in the late 1980s and early 1990s (Aschauer, 1989). As these studies progressed the 'chicken or egg' question was asked regarding economic development and transport infrastructure. Gramlich (1994) argued that it is unclear whether economic growth is an output from transport infrastructure development, or if transport infrastructure expansion results from economic development.

South Africa has an extensive road network that falls under the top 10 networks, lengthwise, in the world (Nation Master, 2016). Proclaimed roads account for 618 081 km of which more than 500 000 are non-urban. Just over 450 000 km of the proclaimed network has a gravel surfacing (Kannemeyer, 2014). The condition of South Africa's road network varies considerably and is dependent on the managing body responsible. The shift of rail-friendly freight onto the road network caused accelerated deterioration and rural and secondary pavements are prematurely reaching the end of optimum functionality. Underinvestment in expansions and maintenance is adding to early pavement deterioration (Ittmann, 2013).

The transport and agriculture sectors contributed 9.0 per cent and 2.2 per cent respectively to the Gross Domestic Product (GDP) in 2013. In South Africa transportation costs as a percentage of logistics totalled to 61.2 per cent in 2013 as opposed to the global average of 39 per cent. The agriculture sector has decreased from 7.1 per cent of the GDP in 1970 to 2.2 per cent in 2013. This is a well-known appearance as a country moves from an agricultural based economy towards a manufacturing economy. Agricultural growth is however an important component in poverty reduction (Directorate Statistics and Economic Development, 2013).

The main purpose of most commercial businesses is to maximise income. Agricultural businesses are no different in this regard. Because tomatoes have a limited shelf life, it is vital to control the factors that lead to earlier deterioration of the quality of the product. Shipping, handling and distribution can cause numerous forms of cuts and bruises on harvested tomatoes which compromise their quality and appearance. Furthermore the economic value to the retailer and grower is reduced (Chonhenchob et al., 2009).

Trucks are one of the best methods for transporting perishable products because of shorter transport times (direct transport from origin to destination) and the ability to reach more inland destinations than any other mode of transport (Jarimopas et al., 2005; Chonhenchob et al., 2009). Although the flexibility of road transport is an advantage, previous studies have indicated that fruit and vegetables suffer mechanical damage due to in-transit vibrations (Jarimopas et al., 2005). The potential damages can be limited through improved packaging and vehicle technology but this increases capital expenditures (Steyn et al, 2010).

Other post-harvest factors that influence shelf life include temperature changes during transit, the ripeness of the tomatoes being transported and the methods of packaging (Schoorl and Holt, 1982; Steyn and Coetzer, 2014). Former studies conducted on tomatoes considered the stiffness of the fruit in relation to the ripening colour. Stresses were applied to the sides and the top of the tomatoes. Colour changes in the tomatoes were observed where these stresses were applied (Steyn and Coetzer, 2014). It was recommended that simulations of the in-transit vibrations should be carried out to consider the continual effect of pressures applied by the tomatoes on each other (Steyn and Coetzer, 2014).

The successful operation of a country's economy is determined by a number of factors including an efficient logistics and transport system. Logistic costs increase with poor road conditions and transpire into increased end-product costs to the consumer. Higher commodity prices decrease the global competitiveness of a country.

2.2 SOUTH AFRICAN ECONOMY

South Africa ranks as the third largest economy behind Nigeria and Egypt on the African continent. On world scale ratings Nigeria ranks 23rd and South Africa ranks 32th (International Monetary Fund, 2016). SA is one of the world's largest producers and exporters of platinum and gold. Numerous other sectors in the South African economy can be defined as world class and rival similar sectors in other parts of the world.

Unfortunately, a large percentage of South Africans are poor. Crime and unemployment rates are high and the standard of public education is low, contributing to an unending spiral of poverty. The lack of basic services and infrastructure in rural communities is considered worrying (The Heritage Foundation, 2016).

Even though the general outlook on the economic state of South Africa is negative, the potential areas of growth should not be overlooked. South Africa has one of the largest road networks in the world ranking tenth behind first world economies such as the United States, China and Australia (Kannemeyer, 2014; Nation Master, 2016). The country ranks fourteenth globally when the length of railway networks are compared (The World Factbook, 2016). Table 2-1 shows the top world economies based on GDP along with their road and rail network lengths as well as the Nominal GDP per length of road. Five of the top economies in the world also fall under the top 10 countries for the extent of their road and rail networks. Figure 2-1 compares the top world economies with ten economies that are performing poorly. From the graph it would seem that Bahrain is competing with the top economies but the length of the road network is only 4 122 km with a GDP of $30.079 billion. When considering the South African case proclaimed roads totals over 600 000 km and the GDP is $ 266.213 billion.

Table 2-1: Comparison of the Nominal GDP of the top 10 performing countries in the world and the extent of their transport network (Nation Master, 2016; The World Factbook, 2016).

Country	Nominal GDP (billion $)	Length of Rail Network (km)	Length of Road Network (km)	Nominal GDP per Length of Road Network ($/km)
USA	17 968	293 564	6 586 610	2 727 959
China	11 385	191 270	4 106 387	2 772 510
Japan	4 116	27 155	1 210 251	3 400 947
Germany	3 371	43 468	645 000	5 226 357
United Kingdom	2 865	30 859	394 428	7 263 683
France	2 423	29 640	1 028 466	2 355 936
India	2 183	68 525	4 689 842	465 474
Italy	1 819	20 182	487 700	3 729 752
Brazil	1 800	28 538	1 580 964	1 138 546
Canada	1 573	77 932	1 042 300	1 509 162
South Africa	226	20 986	618 081	430 709

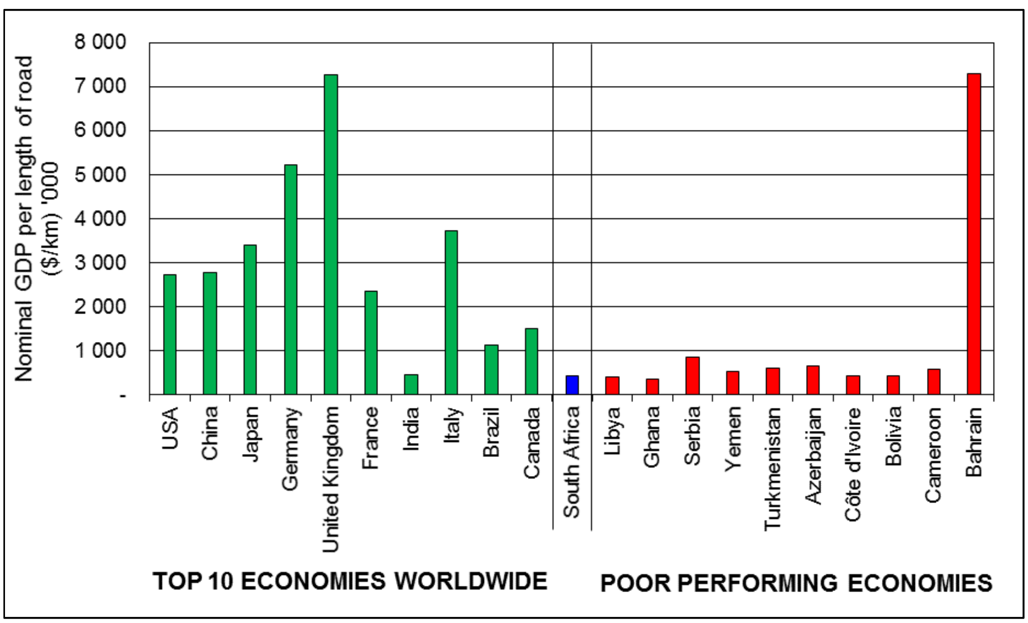


Figure 2-1: Nominal GDP per length of road for the top ten economies in the world versus ten poor performing economies (Nation Master, 2016; The World Factbook, 2016).

Although a country needs more than an extensive transportation network for its economy to bloom, the World Bank (1994) stated that public capital, especially infrastructure expenditure can be seen as the "wheels" of economic development. Public infrastructure can be a tool through which government can successfully stimulate and grow a country's economy. Transport facilities can improve time and space utility of goods and services by increasing market mobility and improving access.

The economic sectors of South Africa as a percentage of the GDP for 2013 is presented in Figure 2-2. Transport, storage and communication, all functions of supply chain and logistics activities, contributed 9.0 per cent of the GDP (Media Club South Africa, 2016). This contribution can partially be accredited to the extensive transport network.

Over the past four decades, agriculture as a percentage of the GDP has decreased from 9.1 per cent in 1960 to 2.2 per cent in 2013. Although a significant change, the country is starting to mature in terms of the secondary and tertiary sectors (Media Club South Africa, 2016).

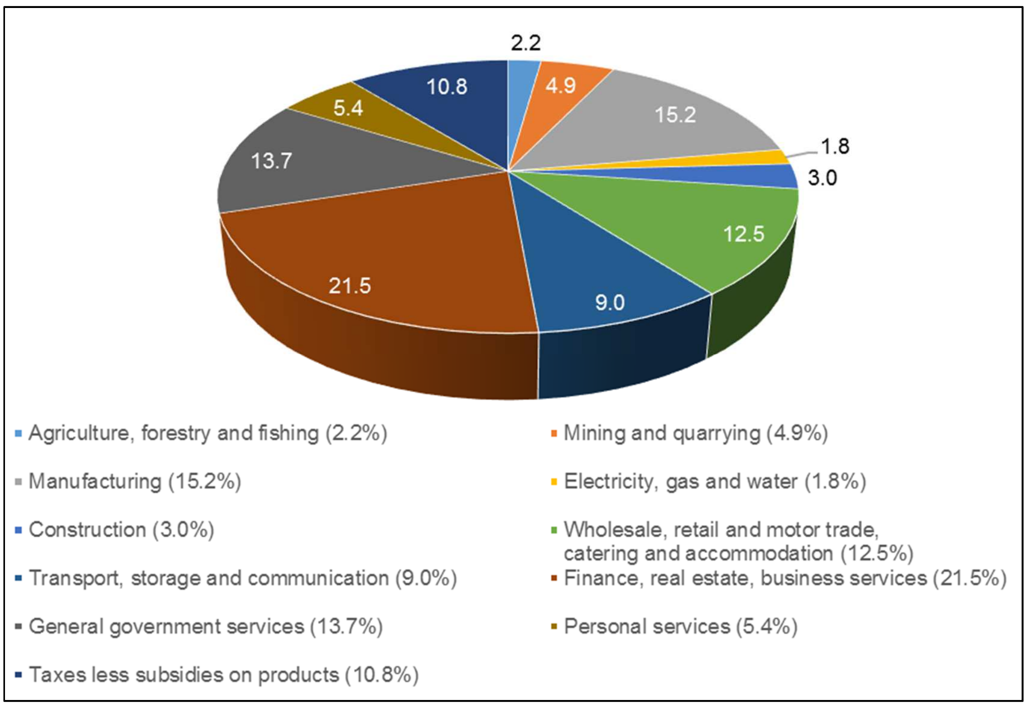


Figure 2-2: Economic sectors of South Africa as in 2013 (Media Club South Africa, 2016).

South Africa is one eighth the size of the United States covering 1.2 million km^2 of land. The country has seven climatic regions ranging from semi-desert to Mediterranean. With the difference in climate and rainfall uncertainty only 13 per cent of South Africa's land can be used for crop production. Of this 13 per cent, only 22 per cent is high-potential arable land.

Even with this situation, South Africa is self-sufficient when considering major agricultural crops. Although the contribution of the agricultural sector is only 2.2 per cent of GDP, farming remains a vital part of the economy (Media Club South Africa, 2016).

2.2.1 Economic value of roads

The relationship between economic growth and infrastructure investment became a well-studied topic since it was first published by Aschauer in the late 1980 and early 1990 (Aschauer, 1989). Numerous scholars including Fernald (1999) and Pereira & Andraz (2012) confirmed Aschauer's initial findings where others (Tatom, 1991; Gramlich, 1994) challenged his results concluding that his findings overstated the relationship between infrastructure investment and economic growth. Gramlich (1994) argued that it is unclear whether economic growth is an output from transport infrastructure development, or on the flipside of the coin, that transport infrastructure expansion results from economic development. Stated differently, most economic models do not take account of the simultaneous effects of transportation development and economic growth.

Irrespective of whether economic growth leads to the development of transport infrastructure investment or vice versa, various benefits arise from this relationship including the reduction in transport costs and increased accessibility. According to a report issued in 2014 by the National Economic Council in America (National Economic Council, 2014) the cost of inadequate infrastructure investment is evident when looking at traffic congestion, fuel costs and lost time. In 2011 commuters in Texas lost 5.5 billion hours collectively being stuck in traffic. Congestion further required commuters to purchase an extra 10 billion litres of fuel. The lost time and additional fuel costs added up to roughly $120 billion. Well-maintained roads and access to other transportation options can relieve congestion and decrease accident rates, not only saving money but saving lives.

Transportation infrastructure can be viewed as one of the most valuable assets. Because infrastructure investment requires a large amount of capital, economic models are available to determine the value of such an investment. Although limited in its capability, software such as the Highway Development and Management tools version 4 (HDM4) can be used as a decision-making tool to justify infrastructure investments. Some of the methods used by software packages are life cycle cost analysis, cost/benefit ratios, net present value and internal rate of return (Litman, 2010).

The long-term benefits of transport infrastructure investment is in most cases hard to quantify, but it is evident in the following aspects (National Economic Council, 2014):

- Less road congestion and harmful emissions due to congestion relief;
- More reliable travel times for regular commuters as well as logistic companies;

- An increase in local economic development and an increase in land value;
- Job creation in key industries;
- Reduction in transport costs, and
- Reduction in Vehicle Operating Costs (VOC) and maintenance costs.

These are some of the primary benefits of infrastructure investment but the ripples can be seen in other parts of the economy. The possibility exists that investment in infrastructure, even just the maintenance of existing infrastructure, could decrease the damage to produce, as well as other cargo, during shipment that would allow farmers to lower their prices because they do not have to counter losses for damaged products by increasing profit margins on the produce that reaches the consumer.

2.2.2 Economic value of the transport industry

Logistics is the discipline concerned with the maximisation of transport system efficiency. The principal goal of transportation is accessibility. An increase in accessibility improves the time and space utility of goods and services and ultimately increases productivity.

According to Litman (2010) claims are being made that there are strong ties between productivity and motor vehicle travel. Therefore, policies such as auto-mobile land development and subsidized road and parking facilities increase motor vehicle travel and would subsequently grow the economy. Strategies that restrict vehicle travel would, according to this view, decrease economic development. Litman (2010) disagrees with this viewpoint and presented Figure 2-3 as explanation.

Generally there are three levels of motor vehicle travel considered in Figure 2-3:

- Inadequate: Consumers have difficulty accessing basic services; business travel, service delivery and freight is inefficient;
- Optimal: Public transport systems and personal vehicle use is efficient, and
- Excessive: Traffic congestion is a major issue. Sprawled land use contributes to travel requirements and access to basic services is a challenge.

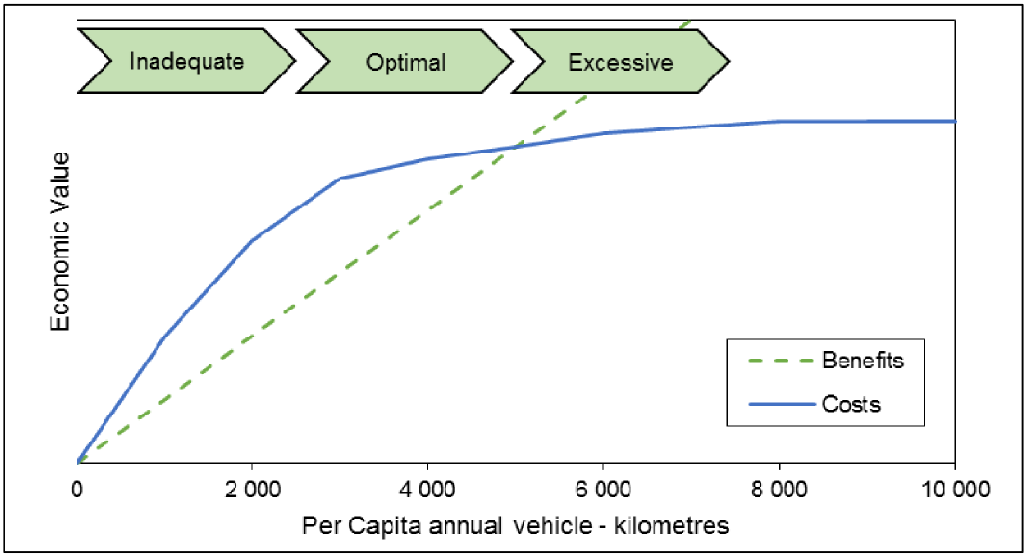


Figure 2-3: Cost benefit relationship between vehicle kilometres and economic value (Litman, 2010).

The ratio of total benefits to total costs is termed economic efficiency. An increase in a country's economic efficiency leads to an increase in productivity. There is a direct complimentary relationship between increased productivity and economic development. Figure 2-4 shows how cost savings in the transport industry affect economic development (Litman, 2010).

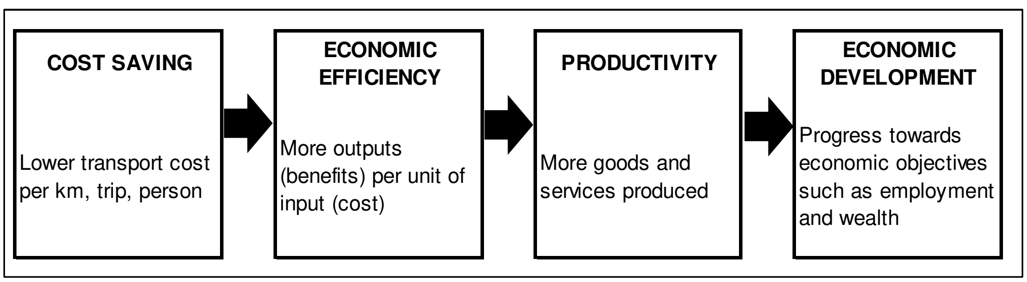


Figure 2-4: The effect of cost saving in the transport industry on economic development (Litman, 2010).

Transport has the largest influence on logistics costs in South Africa (Joubert, 2013). With roughly 70 per cent of the inland tonne-km transported by roads, cost escalations and various other challenges affect businesses and consumers alike. Figure 2-5 presents a breakdown of the different components of logistics and its cost contribution over a period of 8 years as well as the logistics sector as a percentage of the GDP. The cost components for 2015 and 2016 are estimated values.

In South Africa transportation costs as a percentage of logistics totalled 61.2 per cent in 2013 as opposed to the global average of 39 per cent. Various factors are to blame for this alarming difference, including spatial challenges as well as rising fuel prices and wage disputes (Joubert, 2013).

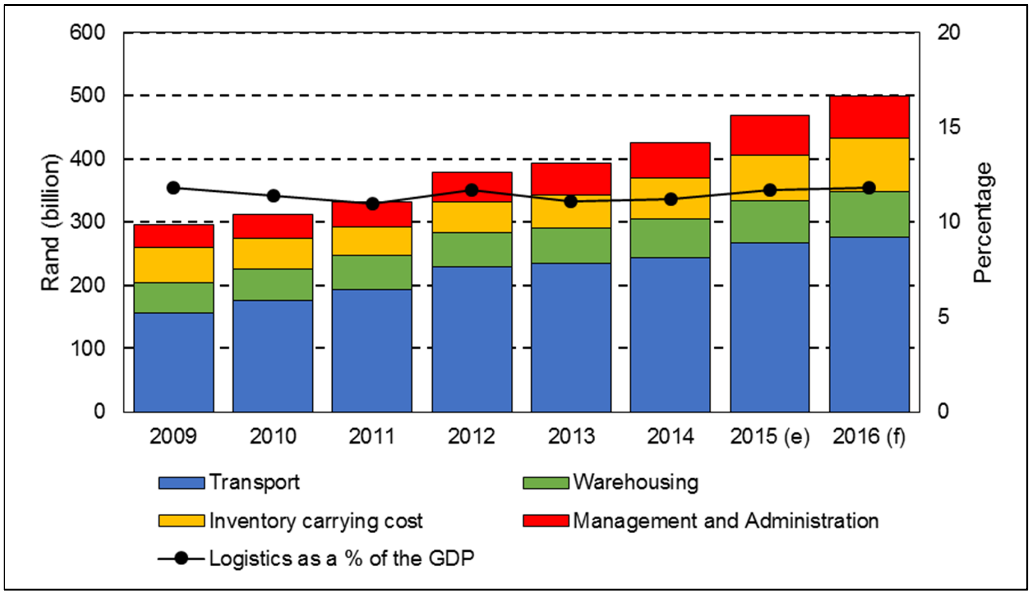


Figure 2-5: Breakdown of logistics costs in South Africa from 2009 to 2016 (Havenga et al., 2016).

Data gathered from industry and government sectors identified the following aspects as key contributors to rising transportation costs (Viljoen, 2009):

- Poor road conditions;
- Fuel costs;
- Lack of law enforcement and non-compliance;
- The unavailability of return loads and the losses associated with empty runs, and
- Congestion and the cost of delays.

Some of these factors such as rising fuel prices cannot be managed by transporters since these costs are affected by the global oil prices, but through the management of the aspects that can be controlled even small gains can have large benefits. For example, the annual return on investment for a business is 8 per cent and transportation totals to 16 per cent of all costs; when there is a reduction in transport cost of 5 per cent the profit increases by 10 per cent (Litman, 2010).

Actions that could be considered to improve transport efficiency include the following (Litman, 2010):

- The increase of legal vehicle loads or the shift from road to rail transport;
- High occupancy vehicle lanes or truck lanes to remove congestion;
- Demand management through efficient road pricing so that high-value trips enjoy priority in traffic;
- Faster loading times and decreased downtimes, and
- Improved distribution through locating stores closer to customers.

In the South African context some of the proposed options would not be viable but there is room to investigate other aspects that could lead to improvements.

2.2.3 Economic value of the agricultural sector

It is a well-known phenomenon that agriculture moves from a dominant sector in poor countries to a relatively small segment in wealthy economies. This observation is evident when the South African case is examined. In the Economic Review of the South African Agriculture the Directorate of Statistics and Economic Development (2013) states that the primary agriculture sector has grown on average 11.8 per cent per annum since 1970 compared to the 14.9 per cent growth of the economy. In essence this resulted in a drop in the agricultural sector's contribution to the GDP from 7.1 per cent in 1970 to 1.9 per cent in 2011.

The shift in the GDP contribution of agriculture is known in economic theory as Engel's Law. When a closed economy is considered and income increases per capita at stable commodity prices, expenditure of households' moves towards acquiring services and manufactured goods relative to food products (Martin & Warr, 1990).

A study done in 2008 by Ligon and Sadoulet as part of the World Bank's World Development report indicated that agricultural sector growth is more important for the poorer households in an economy than growth in the non-agricultural sectors. Cervantes-Godoy & Dewbre (2010) conducted a study that included 25 Organisation for Economic Co-operation and Development (OECD) countries and stresses the importance of economic growth for poverty reduction but also indicated that the sector mix of growth matters significantly. They concluded that agriculture plays a vital role in poverty reduction.

In their investigation, Poonyth et al (2001) used data from 1973 to 1997 to assess the importance of agricultural growth in South Africa. The study indicated (in line with arguments from development economists) that industrialization depends on agrucultural growth. As the agricultural sector expands the industrial sector will trail. Therefore in the South African context an “agricultural-led” growth strategy is essential for economic development. This sector can be classified as a leading sector and should not be underestimated as about 70 per cent of agricultural outputs are used as intermediate products (Directorate Statistics and Economic Development, 2013).

2.3 SOUTH AFRICAN ROAD NETWORK

South Africa has an extensive road network that falls under the top 10 networks, lengthwise, in the world (Kannemeyer, 2014; Nation Master, 2016). Proclaimed roads account for 618 081 km of which more than 500 000 km are non-urban. Just over 450 000 km of the proclaimed network has a gravel surfacing (Kannemeyer, 2014). The maintenance of these roads are the responsibility of various governing bodies including the South African National Roads Agency Limited (SANRAL), Provincial and Municipal government (SAICE, 2011).

Since 1998, when SANRAL was created, the National road network more than doubled to include a total of 19 704 km of paved road. Provincial roads account for 275 320 km with 66 143 km managed by metropolitans and the remaining 256 914 km is managed by municipalities (Kannemeyer, 2014).

2.3.1 National roads

The national road network managed by SANRAL connects major cities, towns and rural areas. It forms the backbone of the transportation network of South Africa and it accelerates economic development through trade by linking the country with its neighbours (Ittmann, 2013).

There are two main sources of income for the maintenance of the national road network. Toll roads constitute 15.8 per cent of the network and various concessions are responsible for the management of these roads. The non-toll roads which accounts for 84.2 per cent of the network is maintained from fund allocations made by the National Treasury. The extent of the national network is shown in Figure 2-6 (Ittmann, 2013).

Roughly 85 per cent of the road network under SANRAL’s jurisdiction is in a fair to very good condition according to Visual Condition Index (VCI) ratings (SANRAL, 2016). SANRAL is committed to manage its assets in line with the World Bank guidelines stating that no more than 10 per cent of roads should fall under poor to very poor categories (SAICE, 2011). To be able to adhere to these standards SANRAL operates a pavement and bridge management system. Data regarding traffic volumes, predicted traffic growth and road usage are also collected on a regular basis (SANRAL, 2016).

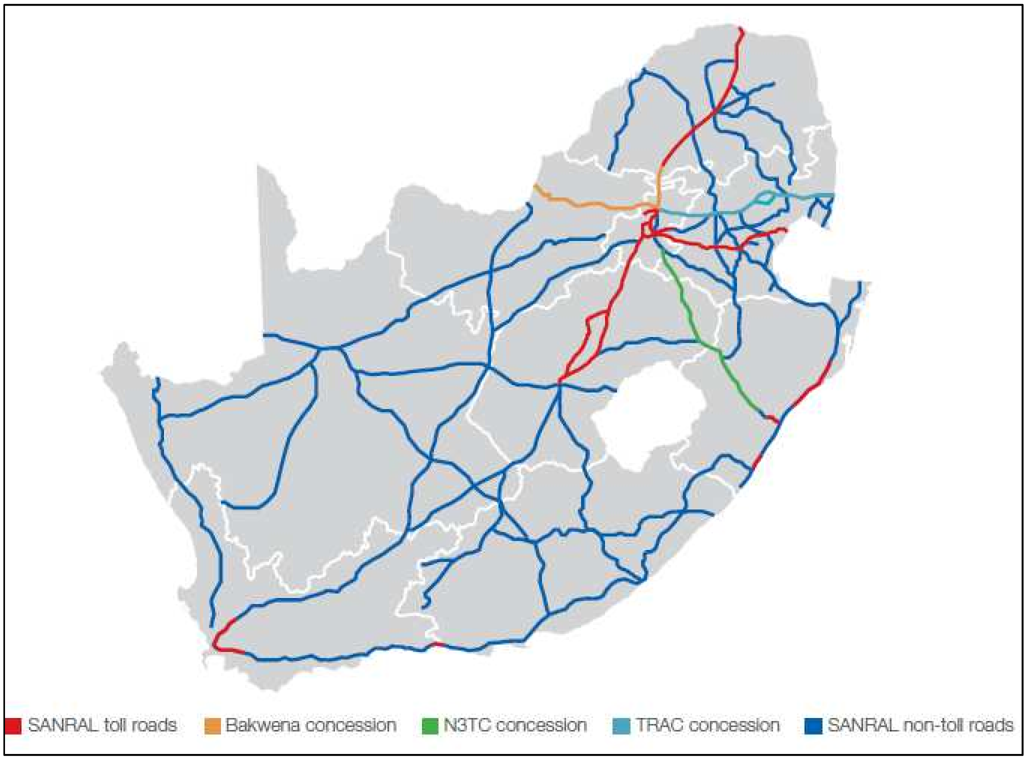


Figure 2-6: SANRAL national road network (Ittmann, 2013).

2.3.2 Provincial and municipal roads

Secondary or provincial roads are the responsibility of provincial authorities. Urban roads fall under the jurisdiction of metros or municipalities. The implementation of the Provincial Road Maintenance Grant (PRMG) became effective from 1 April 2014. Some of the required criteria stated that provinces should implement an effective asset management system (Ittmann, 2013).

Roads Agency Limpopo (RAL) manages a network of about 20 260 km of which 5 000 km is surfaced roads and the remainder is gravel roads. In the Annual report of 2014/15 RAL states that a huge backlog was identified on gravel roads and that some of the challenges faced includes the lack of skills and funding. To address this concern they have already partnered with private sector giants such as EXARRO and are finalising agreements to include others such as PPC, ZZ2 and Anglo American Platinum (RAL, 2015).

2.3.3 Pavement condition

The condition of South Africa's road network varies considerably and is dependent on the managing body responsible. The shift of rail-friendly freight onto the road network caused accelerated deterioration and some pavements are prematurely reaching the end of optimum functionality. Underinvestment in expansions and maintenance is adding to early pavement deterioration (Ittmann, 2013).

Several studies have indicated that poor road conditions increases logistics costs and have a negative influence on the logistic operations of a country. A strong correlation exist between the degree of vibrations that vehicles are exposed to and the condition of the road. Cargo damage is not the only issue presented with poor road conditions but increased maintenance and repair costs are also expected as road conditions deteriorate (Jarimopas et al., 2005; Steyn et al., 2011).

SANRAL made great efforts in maintaining the national road network over the past decade. Road conditions are still not ideal when considering the World Bank guideline which states that less than 10 per cent of the network should have a condition index in the “poor” and “very poor” categories (SAICE, 2011).The condition of the national road network for 2009 and 2013 is shown in Figure 2-7 (Ittmann, 2013).

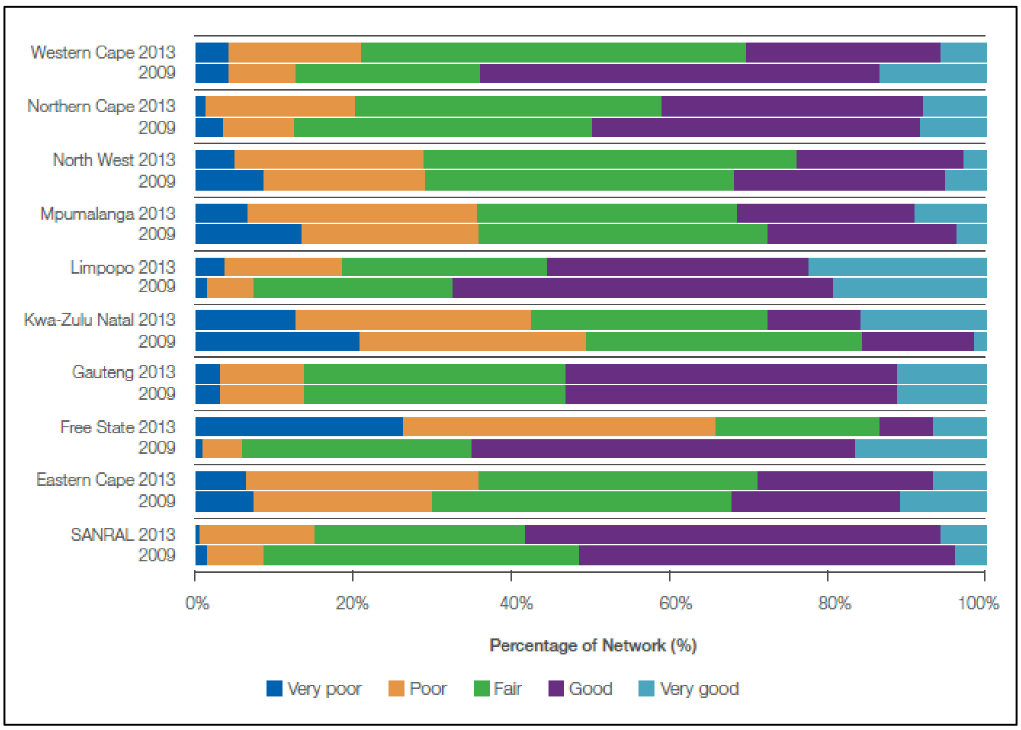


Figure 2-7: Comparison of South Africa’s road network condition for 2009 and 2013 (Ittmann, 2013).

National roads in Gauteng remained constant where provinces such as the Western Cape, Limpopo and the Northern Cape showed road condition deterioration. Mpumalanga have shown improvements in overall road condition.

According to the SAICE Infrastructure Report Card of 2011, condition data are available for 82 per cent of the provincial road network. 74 per cent of the provincial network consist of gravel roads. Condition data indicate that the network is rapidly deteriorating. Almost 80 per cent of the network has exceeded the 20 year design life. These roads can, without warning, deteriorate to a point where costly repair or reconstruction actions is the sole option (SAICE, 2011).

Only 4 per cent condition data is available for municipal road networks. It seems that the paved roads are generally in a good condition but the gravel roads have poor to very poor conditions. Skill shortages seem be one of the largest problems for municipalities and very few of them have a pavement management system (SAICE, 2011).

For the metropolitan areas 64 per cent of the condition data is available. Only 12 per cent of these networks are unpaved roads. Paved roads are generally in a good condition (SAICE, 2011).

To put the condition of South African roads into perspective the national roads maintained by SANRAL are compared to similar roads in the USA and Canada in Figure 2-8.

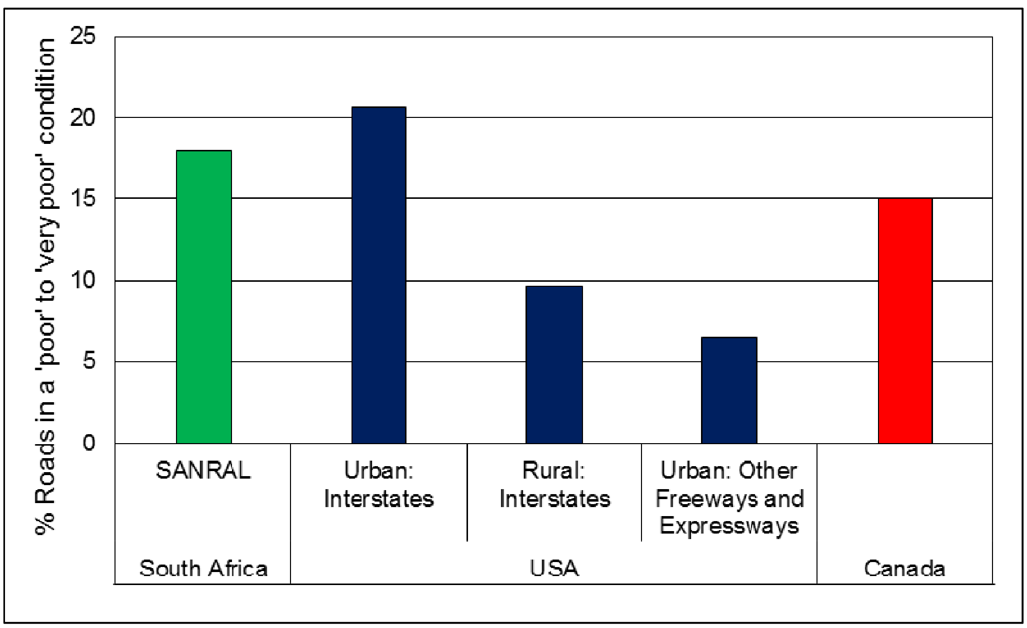


Figure 2-8: Comparison of South African road conditions to road conditions in the USA and Canada (Ittmann, 2013; Canada Infrastructure, 2016; ASCE, 2013).

It should be stressed that the data presented are from different years. Data from SANRAL was collected in 2009, United States of America (USA) data in 2008 and Canadian data are not older than 5 years. Irrespective of these differences the national road network in South

Africa has a similar percentage of roads in a ‘poor’ and ‘very poor’ condition compared to two of the countries listed under the top ten economies in the world.

2.4 VEHICLE – PAVEMENT INTERACTION

Vehicle-Pavement Interaction (V-PI) can be described as a system where the vehicle (and its components) and the pavement (and its components) exert mutual forces on one another. Pavement roughness initiates the vertical acceleration of a vehicle and in return the dynamic response of the vehicle causes pavement distress and deterioration. The way in which the pavement responds to loading is a function of the following aspects (Steyn & Monismith, 2010):

- Dynamic tyre load;
- Vehicle speed;
- Pavement strength;
- Depth at which pavement response is measured, and
- Tyre contact area.

The most important pavement components in V-PI includes the pavement roughness and the materials and structure of the pavement. The profile of the road surface changes over time and through the repeated loading with heavy vehicles. The structural strength also changes due to the accumulated effects of pavement response as well as environmental conditions (Steyn & Monismith, 2010).

The vehicle components that are important in V-PI are the tyres, suspension, sprung mass, unsprung mass, dimensions and the operational conditions. Tyres are the only point of contact between the vehicle and the pavement and therefore it plays an important role in the distribution of the vehicle load onto the pavement surface. Apart from its load distribution function, tyres support the vehicle load and acts as cushioning to absorb pavement shocks. It also develops longitudinal and lateral forces to assist with acceleration, braking and cornering (Gillespie, 1992; Steyn & Monismith, 2010).

The main functions of the suspension system includes the positioning of the tyres on the road, the connection of the wheels to the vehicle frame, transmission of forces and the isolation of the vehicle from induced vibrations (Limpert, 1982). All of the vehicle components that are supported by the suspension is called the sprung mass. The components not supported by the suspension is called the unsprung mass (Gillespie, 1992; Steyn & Monismith, 2010).

Vehicle-Pavement Interaction is affected by the vehicle dimension through the axle configuration and the percentage of the total load carried by each axle. The axle configuration determines the intervals between load applications exerted on the pavement (Pretorius, 1990; Gillespie, 1992, Steyn & Monismith, 2010).

The objective of V-PI analysis is to determine the way in which the various components interact with each other and the resultant effect of the interaction on the pavement, the vehicle and the transported cargo. In most V-PI frameworks the four components and the way in which they are viewed includes:

- Vehicle - Load history generator;
- Pavement structure - Component on which forces are exerted;
- Pavement profile - Cause of the problem, and
- The decision making process - Final evaluation criteria.

Initial interaction happens between the tyre and the pavement profile. This interaction is dependent on the pavement roughness, the tyre characteristics and the operational conditions. Because all of the components in the framework are in some way connected no component is independent of changes in any of the other components (Steyn & Monismith, 2010).

2.4.1 Road roughness and riding quality

Road roughness is the expression of irregularities in a pavement surface defined over an interval between two points (Sayers & Karamihas, 1998; Pavement Interactive, 2007). Roughness does not only affect the riding quality but also the fuel consumption and vehicle maintenance costs. Roughness is one of the primary factors used in optimisation analyses involving road quality and user cost (Pavement Interactive, 2007).

Response type roughness measurement systems has been popular since the 1940. It was difficult to obtain the same roughness value for different vehicles using response-type measurements thus, there was a need to calibrate the system. An ideal system was defined for roughness measurements using a computer. Mathematical models were developed and tested for the road meter and the vehicle. The tests conducted indicated that the same m/km index of the longitudinal profile was recorded for both models. The filter used for the mathematical model was based on a quarter-car model. As the name suggests, the model is one corner of a car and includes one tyre, represented with a vertical spring, the axle mass supported by the tyre, a damper and suspension spring and the portion of the weight of the car supported by the specific wheel. Figure 2-9 shows a schematic representation of the quarter car model (Sayers & Karamihas, 1998).

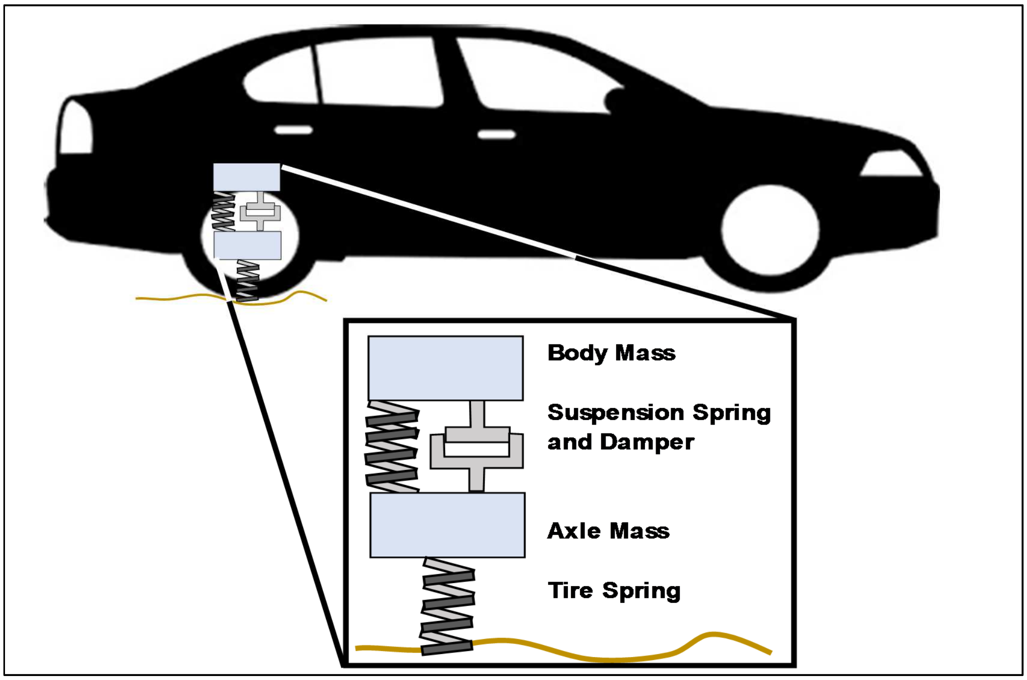


Figure 2-9: Quarter-car model (Sayers & Karamihas, 1998).

Research done by the National Cooperative Highway Research Program (NCHRP) led to the development of a specific set of parameters for the quarter-car computerised response system. This model was called the "golden car" and served to be a calibration reference such as the 1.0000-m golden bar used to calibrate other length measurement equipment.

From the quarter-car/golden car system the International Roughness Index (IRI) was developed. The IRI was the first response type profile index measure where the analysis method is independent of the profiler used, because it is defined as a property of the true profile. Figure 2-10 shows the IRI scale (Pavement Interactive, 2007).

On the left side of the graph the IRI index is shown. The bottom gives an indication of the range of IRI values that can be expected for different road conditions. The right side of the graph shows the suggested operating speed. The IRI best satisfy the criteria of being time stable, relevant, transportable and readily measurable (Steyn & Monismith, 2010).

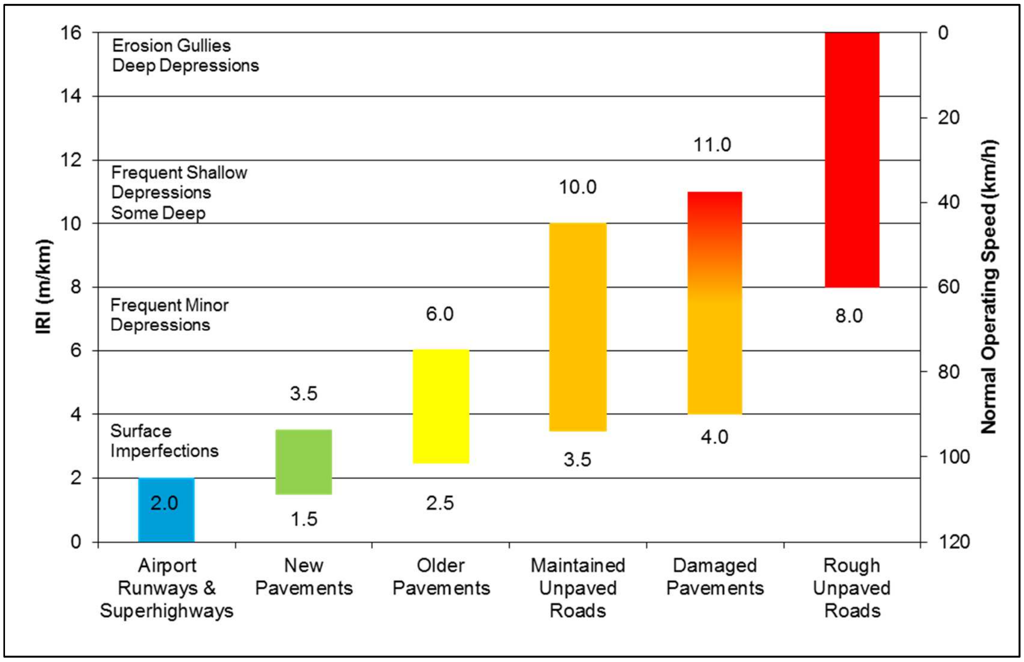


Figure 2-10: International Roughness Index (Pavement Interactive, 2007).

The measured physical response of highway vehicles are very similar to the IRI response to sinusoids. Even though the IRI is a widely used method for classifying surface roughness, the method was developed for the quarter car and the frequency response characteristics of a car would be different to that of a truck. These differences can be ascribed to factors relating to structural and suspension differences. Trucks are more sensitive to low frequency body vibrations whereas care are more sensitive towards higher frequencies (Papagiannakis and Gujarathi, 1995). Further research proved that there is good correlations with light and heavy trucks although the method was not developed specifically for trucks.

2.4.2 Vibrations associated with different road conditions

According to Steyn & Bean (2009) there is a strong relationship between road condition and the vibrations that a truck experiences when travelling on a road. This translates to the transported cargo, and vibration induced damage could be a result of poor road conditions. Jarimopas et al. (2005) indicated that there are three major frequencies that are present as a result of V-PI during transportation. These frequencies are:

- 0.1 – 5.0 Hz (body bounce);
- 5.0 – 20.0 Hz (axle hop), and
- > 20 Hz (response from the structure, road roughness and the drive train)

In various studies (Steyn et al., 2011; Pretorius & Steyn, 2012) accelerometers were used to determine the acceleration range that a truck experiences due to road conditions. To determine the dominant frequencies present a Fast Fourier Transform (FFT) was used to generated a Power Spectral Density (PSD) plot. PSD is described by Sayers &Karamihas (1998) as follows:

"*A mathematical transform exists which computes the amplitudes of the sinusoids that could be added together to construct the profile. It is called a Fourier Transform. The Fourier Transform can be scaled such that it shows how the variance of the profile is 'spread out' over a set of sinusoids. When scaled in this manner, the transform is called a PSD function*."

Pretorius & Steyn (2012) analysed the effect of accelerations generated by different road conditions on the damage to fresh produce. The study included a well maintained national road, a provincial road and a gravel road. The roughness of the national and provincial roads varied between 0.79 m/km and 2.54 m/km. The gravel roads had high roughness values of just over 8.00 m/km. The acceleration distributions as determined from the FFT analysis for the different roads were compared. As expected the widest distribution was for the gravel road followed by the provincial and national roads.

The energy that the system absorb was also determined by Pretorius & Steyn (2012). As expected, higher energy levels were recorded on gravel roads than on the national and provincial roads.

Jarimopas et al. (2005) concluded that a higher percentage damage to produce can be expected when travelling on gravel roads at high speeds. PSD values between 0.1 Hz and 5.0 Hz are significantly higher for gravel roads than for any other road type. Chonhenchob et al. (2009) evaluated frequencies generated by trucks for the shipment of fresh produce in Thailand. Roads between the growers and the packaging houses had gravel surfacing and the vibration levels observed on these roads were significantly greater than for any of the other roads.

2.4.3 Vibrations associated with different vehicles and suspension types

According to Steyn & Monismith (2010) there are three vehicle types that are predominantly being used in South Africa for freight transportation. These include a two axle rigid truck, an articulated truck with tandem axle and a tridem trailer axle, and an interlink. The suspension of these vehicles are steel springs. Figure 2-11 is a schematic representation of the different vehicle types.

The 2005 study by Jarimopas et al. measuring the vibration levels of truck transportation and damage of tangerines during transit in Thailand, indicated that 2-ton trucks caused less vibration damage to produce when compared to the 6-ton trucks for all speed levels and road surfaces. Both of these trucks were fitted with steel spring suspensions.

Four different suspension types were assessed by O'Brien et al. (1963) and the results are presented in Table 2-2.

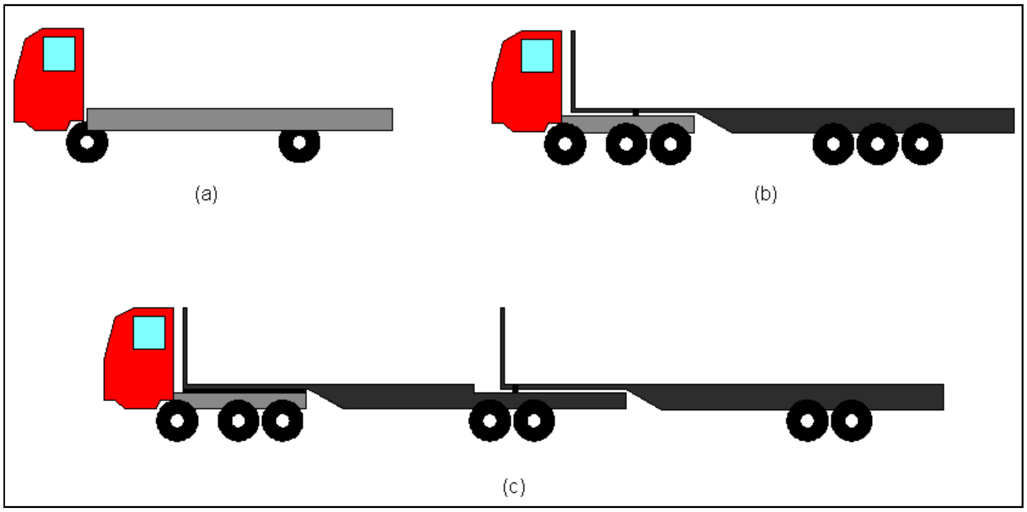


Figure 2-11: Three vehicle types used for transportation in South Africa: a) Rigid vehicle, b) Articulated vehicle, c) Interlink (Steyn & Monismith, 2010).

Table 2-2: Vibration characteristics of tomato-hauling trucks having different suspension systems (O'Brien et al., 1963).

Suspension System	**Average cycle per second**	**Acceleration**	**Displacement**
	Hz	**g**	**mm**
Air Ride	8	0.09	0.711
Constant Rate Spring	10	0.18	0.889
Rubber Ride	11	0.19	0.787
Conventional Leaf spring	12	0.20	0.711

All of the frequencies recorded for the different suspensions fall within the axle hop range. From the acceleration and displacement data it seems that the air ride suspension provides the best buffer against vibrations induced by V-PI. This result is in agreement with a study by Hinsch et al. (1993) where the accelerations of air ride and steel leaf suspensions were measured in California. For the steal leaf suspension high vertical accelerations were experienced around 3.5 Hz at the rear of the truck. This was not the case for the air ride suspension where low to moderate accelerations were experienced at 6, 9 and 15 to 18 Hz.

2.4.4 The influence of relative position on accelerations measured

Several researchers indicated that there is a difference in vibrations measured at the rear of a truck and in the middle of a truck (Hinsch et al., 1993; Pretorius & Steyn, 2012; Berardinelli et al., 2005). Similarly the vertical position where accelerations are measured would also differ. There are two views regarding the vertical position; one indicating that the most damage occurs at the top of the packages (O'Brien et al., 1963) and another view indicating that the most damage occurs at the bottom of the packages (Schoorl & Holt, 1982).

2.4.4.1 Position on vehicle

Hinsch et al. (1993) analysed steel-spring and air-ride suspensions during refrigerated truck transportation. Accelerations were measured at the rear and in the middle of the trailers. The PSD graph together with a FFT analysis indicated that the highest root mean square vertical accelerations (RMSVA) are present at the rear of the truck regardless of the suspension type. The accelerations in the middle of the steel-spring suspension truck was 36 per cent of the accelerations at the rear. For the air-ride suspension the accelerations in the middle was 59 per cent of that at the rear.

Berardinelli et al. (2005) conducted a similar study measuring the accelerations at different positions on the truck. Three piezo-electric accelerometers were fixed on the semi-trailer floor at the front, middle and back. Measurements were carried out on different stretches of a route with 70 per cent highway and 30 per cent interstate road. An FFT analysis was used to determine the Root Mean Square Vertical Acceleration (RMSVA) values from the PSD graphs. The results from this study were similar to the results from Hinsch et al. (1993) concluding that the accelerations at the rear of the truck is higher than at the other positions.

Pretorius & Steyn (2012) installed accelerometers at the front rear and the back of interlink trucks and measured the accelerations for full and empty loads. Higher accelerations were measured for empty loads. When the normalised acceleration distributions for the different positions on the trucks were compared, the results indicated that a wider range of accelerations were recorded at the rear of the truck than at other locations.

2.4.4.2 Position in packaging

Schoorl & Holt (1982) investigated the effect of road-vehicle-load interaction and indicated that some loads should not be analysed as a single mass but as a multi-layered system. This is especially true for the transportation of fruits and vegetables. The road-vehicle-load system proposed by Schoorl & Holt (1982) is shown in Figure 2-12. Although the load is unified, each container experience different forces.

Holt et al. (1981) investigated the dynamic behaviour of apples under impact conditions according to the multi-layered theory. They used a tubular container with ten apples stacked on top of each other. The column of apples were dropped onto stationary and moving surfaces to simulate impacts during transportation and handling. The drops were photographed with high speed photography equipment and bruises were measured on all contact interfaces.

The results from the study indicated the following:

- At the start of the drop apples separate and the whole column fell with small spaces between the apples;
- A sequence of collisions occurred;
- Apple flesh bruising at each contact interface took a noticeable time – this is energy dissipation;
- While some of the apples closer to the bottom of the column collided and caused bruising the apples further up the column added to the bruising as soon as they collided with the one just below, and
- When bruising at a specific interface was completed collisions with apples further up in the column did not have an effect at the specific interface.

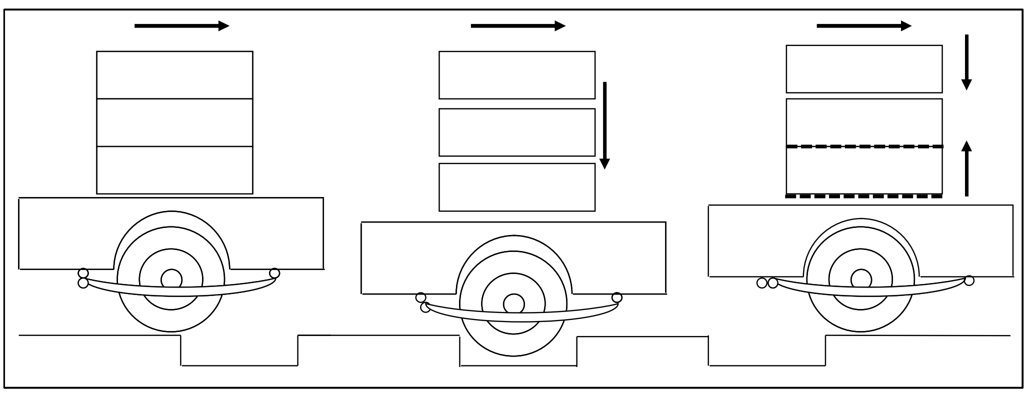


Figure 2-12: Road-vehicle-load interaction for multi-layered energy absorbing packages (Schoorl & Holt, 1982).

This multi-layered load analysis indicated that considerable damage could occur under certain conditions although the impacting surface is almost motionless. This happens when the kinetic energy is completely dissipated during the sequence of collisions. According to the multi layered theory the most damage would occur in the bottom layers of packaging with higher percentages of damage in packages at the bottom of the pallet.

Van Zeebroeck et al. (2006) also analysed columns of apples and confirmed that the column in the centre of the package shows more damage after transportation than the columns on the sides. When looking at the deflected shape of the fully loaded boxes in which the apples were transported it can be seen that the central apples in the lower half of the box is not just affected by the weight of the apple above it but it is also influenced by the apple next to the one directly above it.

O'Brien et al. (1965) stated that the majority of mechanical damage to fruit and vegetables occur if frequencies induced by V-PI are in the same range as the resonance frequencies of the column of fruit under investigation. The resonance frequency is defined as the peak in movement that can be seen with the eye around a certain frequency. These frequencies will result in peak displacement amplitudes and accelerations depending on the freedom of motion of the produce. As expected the highest freedom of motion is at the top of the packaging and it decreases with depth.

Berardinelli et al. (2005) confirmed the findings of O'Brien (1965) showing that the top rear position on the truck was responsible for the highest percentage of damage.

When considering all the literature regarding the relative position that results in the highest percentage of damage to produce it would seem that the top rear position has the highest freedom of motion and as fruit move around more they can get damaged easily. The bottom of the packages experience a higher load, and impact due to V-PI. This could cause a serious of collisions most likely to cause more damage to the produce in the bottom positions.

2.5 PACKAGING

The importance of packaging in the global food supply chain is often underrated. In most literature (Harris, 1988; Gast, 1991; Boyette et al., 1996) packaging has only three functions; containment, protection and identification. This list should in fact be more comprehensive and include the following:

*'to **protect** the product; **promote** the product; provide **information** on product usage, health and safety, disposal etc.; enable the **convenient** transportation and usage of the product; allow **utilisation** of the product through the supply chain; and support efficient **handling** of the product, again, throughout the supply chain'* (TCGF, 2010)

The question that arises most of the time when packaging design is considered is: "Where do you draw the line between food waste and more packaging?" Figure 2-13 shows the weighing between packaging and food waste, both options having a financial implication. More or better packaging could cost more but damage to produce would be less or vice versa (Verghese et al., 2013).

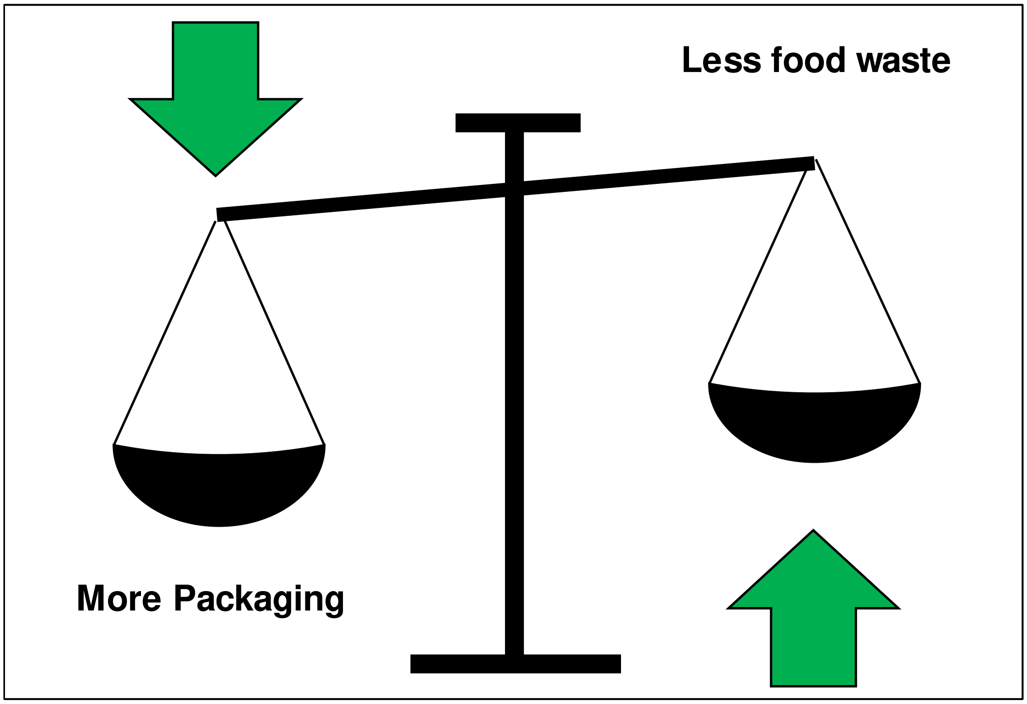


Figure 2-13: Balance between increased packaging and food waste (Verghese et al., 2013).

The cost of logistical activities and the productivity in the supply chain is significantly influenced by the choice of packaging. Transportation and storage cost can be directly related to the density and size of packaging. The cost of freight handling is depended on the unit loads. The accuracy of inventory control is reliant on the proper identification of products within containers. Customer service depends on how well the package protects the products, the ease of opening as well as the display and sale of product units. The impact that packaging has on the environment depends on the choice of material, the method of manufacturing and the reuse or disposal (Twede & Harte, 2003).

A package should create an efficient unit which can be handled by a single person. Keeping the weight of a container to a minimum will reduce the risk of it being dropped and the content being bruised. A container should facilitate weighing, handling and transportation of produce. The space within packaging should be optimised but designed in such a way that that damage to produce is reduced (Harris, 1988; Boyette et al., 1996).

In short, a package should be ‘fit for purpose’. A fit for purpose system balances technological performance, functional requirements, procurement costs and other performance criteria at each packaging level (primary, secondary and tertiary) (Verghese et al., 2013).

2.5.1 Different types of packaging available

Packaging can be divided into three groups, primary, secondary and tertiary packaging. Primary packaging is the container that the retailer or consumer receive as a unit for sale purposes. Secondary packaging consist of the additional packaging or layers whose purpose is to protect the primary packaging and its content during transportation and distribution (Verghese et al., 2013). The third level of packaging is the unification of a group of secondary packages on a pallet for ease of handling. The different levels of packaging is shown in Figure 2-14 (Dhar & Seidel, 2012).

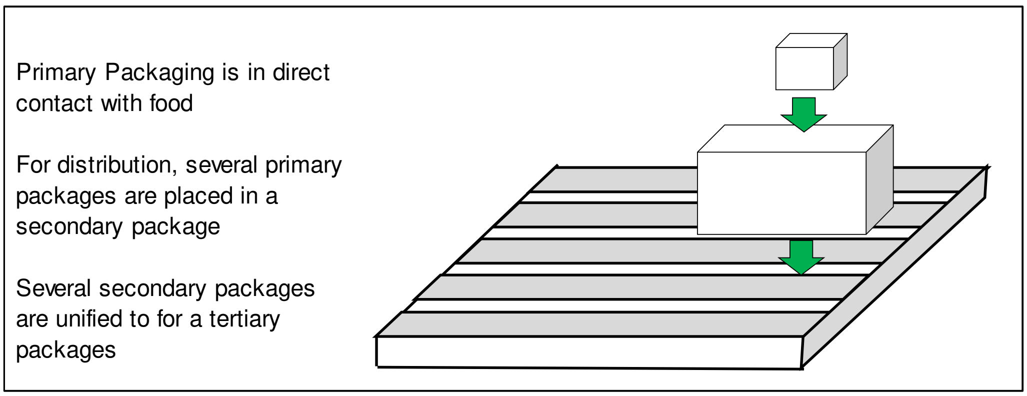


Figure 2-14: Levels of Packaging (Dhar & Seidel, 2012).

There is a vast amount of packaging materials and sizes available on the market for the transportation of fresh produce with either primary or secondary functions. Different produce has different requirements in terms of humidity, temperature and gas composition. These considerations should be priority when selecting packaging technologies and materials. Some of the containers available have been tested for their functionality for shipping produce from growers to consumers, other packaging types have been in use for several generations without evaluation (Harris, 1988). Packaging materials and types include: sacks and nets, baskets, carton or fibreboard boxes, plastic crates, wooden crates and pallet boxes.

The advantages of using the correct packaging are not limited to the reduction of bruises. Other advantages include (Schuur, 1998):

- Reduced moisture loss;
- Preventing contamination with pathogens;
- Reducing pilferage, and
- Improved marketability of produce.

2.5.2 The logistical role of packaging

In modern day society consumers demand seasonal fresh produce all year round. Packaging plays a critical role in the protection of fresh produce during transit, storage, at the retailer and at the point of consumption. Perishable goods with limited shelf life combined with consumer demands has given rise to the development of new technologies that helps to preserve freshness for longer periods (Verghese et al., 2013).

Verghese et al. (2013) summarised some of the improved packaging technologies available on the market and its function in produce protection and the limitation of food waste as presented in Table 2-3. Some of these technologies are seen as “active’ packaging, a term used to describe packaging that controls or responds to the environment of a product. Active packaging has the potential to extend the shelf life of products, giving consumers a larger window to buy and consume products and therewith decreasing potential food waste.

The logistical role of packaging is limited to only three of the packaging functions mentioned above. These inter-related functions of logistical packaging include: protection, utility and communication. As part of the total system packaging is assigned the responsibility of cost minimisation during delivery as well as the maximisation of sales (Twede & Harte, 2003).

2.5.2.1 Protection

The first logistical function of packaging is protection of the food and the consumer. The amount and type of protection that a package should provide depends on the product characteristics and the distribution environment along with its associated hazards. The product characteristics in question are those that deteriorate or damage in time. The hazards of the distribution environment include the exposure to extreme temperatures, insect infestation, dynamic forces and moisture (Twede & Harte, 2003).

Using the right packaging that maintains the appropriate ventilation and temperature, and protects the produce as it moves through the supply chain could extend the shelf life and reduce food waste in the process (Verghese et al., 2013). Research has shown that reusable plastic packaging that has been introduced with a primary or secondary function decreased the spoilage rate of some produce varieties as a result of its improved structural functionality and improved venting areas (Chonhenchob & Singh, 2003; Chonhenchob & Singh, 2005).

The relationship of the protection function of packaging can thus be conceptualised as follows (Twede & Harte, 2003):

‘Product characteristics + Logistical Hazards = Package protection’

Table 2-3: Packaging technology examples that extend the shelf life of foods (Verghese et al., 2013).

Technology	Description	Potential impact on food waste
Multi-layer barrier packaging	Packaging that contains multiple layers to provide the required barriers to moisture, gases (see MAP below) and odor. Specific requirements can be met using a combination of polymers, aluminum foil and/or coatings.	Keeping out moisture and oxygen delays product degradation.
Modified atmosphere packaging (MAP)	Gases are added to packaging before it is sealed to control the atmosphere within the pack, and then maintained by a high gas barrier film, e.g. through vacuum packaging. Carbon dioxide is added, alone or with nitrogen and sometimes oxygen, depending on the product (e.g. meat, cheese, fruit and vegetables).	Reduces respiration rates in the product and reduces growth of micro-organisms.
Edible coatings	Based on a range of proteins, lipids, polysaccharides and their composites, they can be used on fruit, vegetables, meat, confectionary and other products.	Create a barrier directly around food products (rather than external packaging).
Ethylene scavengers	A range of different technologies that involve chemical reagents added to polymer films or sachets to absorb ethylene. Used for fruit and vegetables.	Removal of ethylene delays ripening and extends the shelf life of fresh produce.
Oxygen scavengers	Substances that remove oxygen from a closed package. They are often in powder form (e.g. rust powder) in a sachet. New technologies include oxygen scavengers in the film itself. Used for sliced processed meat, ready-to-eat meals, beer and bakery products.	Oxygen accelerates degradation of food by causing off-flavor, colour change, nutrient loss and microbial attack (bacteria and fungi). Removing oxygen slows the degradation process and extends the shelf life of the food.
Moisture absorbers	Pads made from super-absorbent polymers, which absorb moisture. Used for fresh meat, poultry, and fresh fish.	Maintain conditions that are less favorable for growth or microorganisms.
Aseptic packaging	Packaging that has been sterilized prior to filling with Ultra High Temperature (UHT) treated food. This gives a shelf life of over 6 months without preservatives. Formats include liquid-paperboard, pouches and bag-inbox.	High temperatures kill microorganisms and tight seals on the packaging prevent the entry of microorganisms, gas or moisture that could promote degradation.

2.5.2.2 *Utility/productivity*

Utility is defined as the value to the user and productivity is the ratio of output to the ratio of input. An example of productivity is the number of packages loaded into the truck versus the labour and forklift time required. Packaging initiatives such as unitization and size reduction can significantly increase the output of logistical activities. Various other factors such as cube utilization and ergonomics can influence the productivity of logistics and significantly impact the time and space utility of products for the consumer (Twede & Harte, 2003).

Productivity can be summarised as follows (Twede & Harte, 2003):

'Productivity = Number of packages output / Logistics input"

2.5.2.3 *Communication*

For all practical purposes, the package symbolises the product throughout the supply chain. Important information for warehousing, shipping, grade, size, brand and any other valuable information should be visible on the package. Universal Product Codes (UPC) has become one of the widely used methods for inventory control (Boyette et al., 1996; Twede & Harte, 2003).

2.6 *TOMATO QUALITY AND SHELF – LIFE*

Tomatoes rank under the top consumed vegetable crops in the world, not just in volume but for reasons including its nutritional value and the important roll it has on human health (Willcox et al., 2003). According to Bourne (1977) tomatoes ranked first in the "relative contribution to human nutrition" when compared to 39 other fruits and vegetables. A medium sized tomato provides 40 per cent and 20 per cent of the Recommended Daily Allowance of vitamin C and A respectively not to mention the substantial amounts of potassium, calcium, dietary fibre and antioxidants present in this superfood (FHO, 1979).

Unfortunately, a considerable amount of freshly harvested tomatoes never reach the consumer due to bruising during transportation and handling. Although damaged, these tomatoes could still be used in processed tomato products.

When considering the marketability of fresh tomatoes the perspective of the consumer is key. From a consumer viewpoint tomato quality is primarily the firmness (withstanding market handling) and the appearance which includes the colour and freedom from imperfections. Although these factors are the primary way of determining tomato quality consumers are also concerned with the flavour and nutritive value (Kasmire & Kader, 1978). The last two "quality" elements will not be considered in the study but it deserves mentioning since these elements determine whether the consumer would continue to purchase tomatoes from a specific grower or if they decide to try a product from a different farm.

Several factors can affect the quality of tomatoes. These include but are not limited to (Kasmire & Kader, 1978):

- Extended time period between harvest and consumption of the product;
- Harvesting of immature fruits;
- Mechanical damage during transportation and handling, and
- Improper temperature management.

2.6.1 Tomato shelf-life

The shelf-life of a product can be defined as the time period during which food maintains its quality and consumption safety under reasonable anticipated distribution, storage and use conditions (FSAI, 2014).

The shelf life of food in general depends on the product itself, the temperature, humidity and packaging. According to Boyer & McKinney (2013) tomatoes can be stored for up to a week under the right temperature and humidity combination. This is in line with a study done by (Mizrach, 2007) where tomatoes were picked when they were light red in colour and stored at a temperature of 20ºC and a relative humidity of 85 per cent for between 7 and 8 days before turning to full red colour. During the eight day period the firmness of tomatoes were monitored using a non-destructive ultrasonic method. As tomatoes mature it naturally loses some of its firmness.

Kader et al. (1978) tested the composition and flavour of tomatoes as influenced by some postharvest treatments. Tomatoes were harvested at different maturity stages: Immature Green (IMG), Partially Mature Green (PMG), Typical Mature Green (TMG) and Light Pink (LP) and the fruits were either treated with C_2H_4 treatment or low O_2 atmosphere at different temperatures. For light pink tomatoes the number of days to achieve table ripeness varied between 6 and 14 days at 20˚C and 12.5˚C respectively. The immature green tomatoes took roughly 20 days to mature to table ripeness at 20˚C.

The effect of postharvest treatment and packaging on tomato shelf life was investigated by Nasrin et al. (2008). Chlorine treated tomatoes were stored in perforated polyethylene bags and kept at ambient temperatures. Under these conditions the shelf life was extended to 17 days in comparison to the 7 days for tomatoes not treated and stored without packaging.

In contrast to tomatoes harvested at light red colour, tomatoes harvested at mature green stage can be stored for up to 28 days at ambient conditions before changing colour to red-ripe (Tigist et al., 2013).

In most retail stores tomatoes between light red and ripe-red colours are available for purchase. It is therefore reasonable to assume that the shelf-life of tomatoes in retail stores are in the region of 7 to 10 days. Upon purchase there would still be roughly a week of storage-life left for consumers to enjoy the product, depending on the colour stage at which it was bought. Tomatoes with visible bruises and soft spots are less likely to be purchased in this period than tomatoes in perfect condition.

2.6.2 Produce characteristics that affect bruise susceptibility

Fresh produce are exposed to numerous external forces after harvesting. Mechanical damage to fruit occurs when these external forces exceed a threshold for tissue failure. Bruising is in some cases not immediately visible but does become obvious as the fruit matures (Van Linden et al., 2006).

The bruise susceptibility of fruit is summarised in the following categories:

- Internal factors:
  - Maturity - which in itself includes factors such as firmness, water status and texture (Mohsenin, 1986), and
  - Variety - where different varieties would have different cell wall strengths and elasticity as well as cell shape, size and orientation (Studman, 1997).
- External factors:
  - Impact energy,
  - Position of impact load, and
  - The peak contact force (Van Linden et al., 2006; Van Zeebroeck et al., 2007).

Tomatoes are not homogeneous fruit. Locules are filled with liquid, seeds and gas which interchange with cross wall tissue that extend from the fruit centre to the skin. Due to the difference in structure of the locules and cross walls their behaviour towards loading would be different. For different varieties of tomatoes the amount of locules and cross walls varies. Figure 2-15 shows two different tomato varieties with distinct internal structure as tested by Li (2013). Four different loading positions (as shown in Figure 2-15) and five different compressibility levels were used to test the rupture probability of the tomatoes.

The test indicated that if all variables are constant the rupture probability of the quadri-locular tomato loaded on the cross wall tissue versus the same loading on locular tissue is 14.5 times higher. This can be attributed to the fact that the elastic deformation for the quadri-locular tomato loaded on the locular tissue is significantly higher than on the cross wall tissue. The tomato can therefore ‘absorb’ more of the force when loaded on locular tissue. When the two varieties were compared the rupture probability for the trilocular tomato was higher than for the quadri-locular tomato loaded on the locules (Li, 2013).

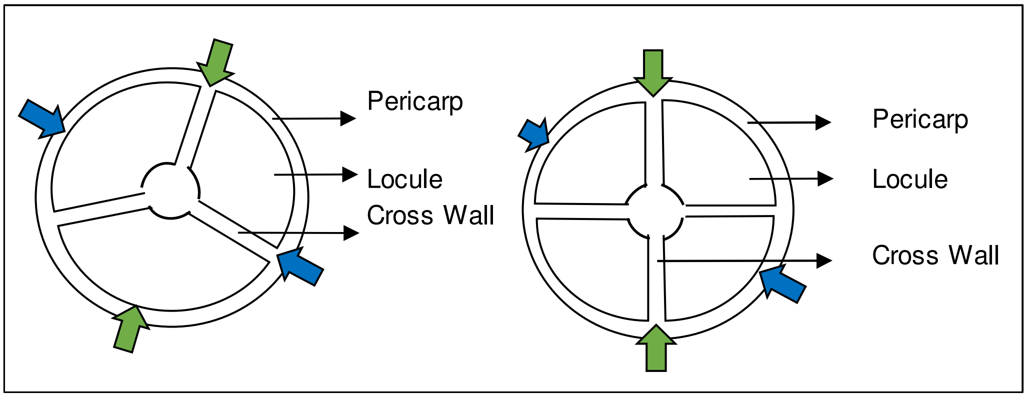


Figure 2-15: Difference in internal structure of different tomato varieties (Li, 2013).

The behaviour of tomatoes under rupture loading and loading for bruise testing would be different. Although locular loading has a smaller probability of rupture it still results in bruising leading to decreased shelf-life. Van Linden et al. (2006) and Van Zeebroeck et al. (2007) monitored the bruise development of tomatoes and concluded that impact loading on locular tissue is more harmful in terms of bruise development than the same loading conditions on cross walls.

Van Linden, et al. (2006) created a model where the probability of bruise development was measured against the impact energy (J). As expected the probability of bruise development increases as the impact energy increase. The model was developed for three different cultivars and loads were applied at two locations, over the cross walls and over the locular tissue. Probability of bruise development was in every instance higher for locular tissue than for cross walls.

Another study by Van Linden et al. (2006) compared the probability of bruise development with the contact time for various levels of impact energy. Longer contact times and higher impact energies are more likely to develop into a bruise. Contact time is influenced by the maturity of the fruit where red-ripe tomatoes had longer contact times than green tomatoes.

Several researchers observed that physical damage increases with tomato ripening (Van Linden et al., 2006; Van Zeebroeck et al., 2007). Numerous explanations were proposed for this observation including increased action of cell-wall degradation enzymes with ripening and the corresponding decrease in cell wall strength and tissue softening (Bennet, 2002). The cell walls of ripe fruit are less likely to withstand external forces and will yield sooner.

Internal and external factors cannot be viewed separately when bruise susceptibility and development is considered since these factors interact and influence each other.

It is important to know how certain fruits and vegetables respond to mechanical damage. In most fruit species a discolouration of the injured tissue is indicative of damage. Different opinions regarding the bruise identification in tomatoes exist. Van Linden et al. (2006) states that damaged tissue in tomatoes will not undergo a colour change. In the most extreme cases water will build up under the skin or the tissue will steadily softens in a period of two to three days. Steyn & Coetzer (2014) applied forces to tomatoes and measured the colour change of the tomatoes over a period of three to four days. There was a noticeable colour change at the locations that were subjected to loading.

Van Zeebroeck et al. (2007) proposed that absorbed energy should be used to quantify damage to tomatoes. Higher absorbed energy was seen as an indication of higher bruise damage. The most important factor in the prediction of absorbed energy was the peak contact force.

2.6.3 Resonance frequencies and frequencies known to cause damage

Various sources observed the effect of V-PI on the movement of fruit in the top layer of containers (O'Brien et al., 1965; Jarimopas et al., 2005). For different combinations of frequencies and amplitudes, fruit can experience vibrations approaching 1.0 g. This causes rotation, rubbing, skin discoloration and breakdown of surface tissue. O'Brien et al. (1965) suggested that the natural frequency of fruits should be calculated and compared to the vibration characteristics of the transport vehicles. It is expected that when the natural frequency of a given fruit is in the middle of the vibration range of the vehicle used for transport, resonant vibrations would occur. This will cause more in-transit damage.

Pretorius (2011) analysed the vibrations experienced on trucks and containers used for transportation of fresh produce and compared it with the resonance vibration ranges that O'Brien et al. (1965) derived. Figure 2-16 shows this comparison. For tomatoes the range calculated by O'Brien et al. (1956) is between 9 Hz and 23 Hz.

If the internal damping, hysteresis and friction of fruit and vegetables along with the damping effects of quality packaging does not lower the vibrations that produce experience, resonance would in most cases occur during transportation. This could cause a considerable amount of damage.

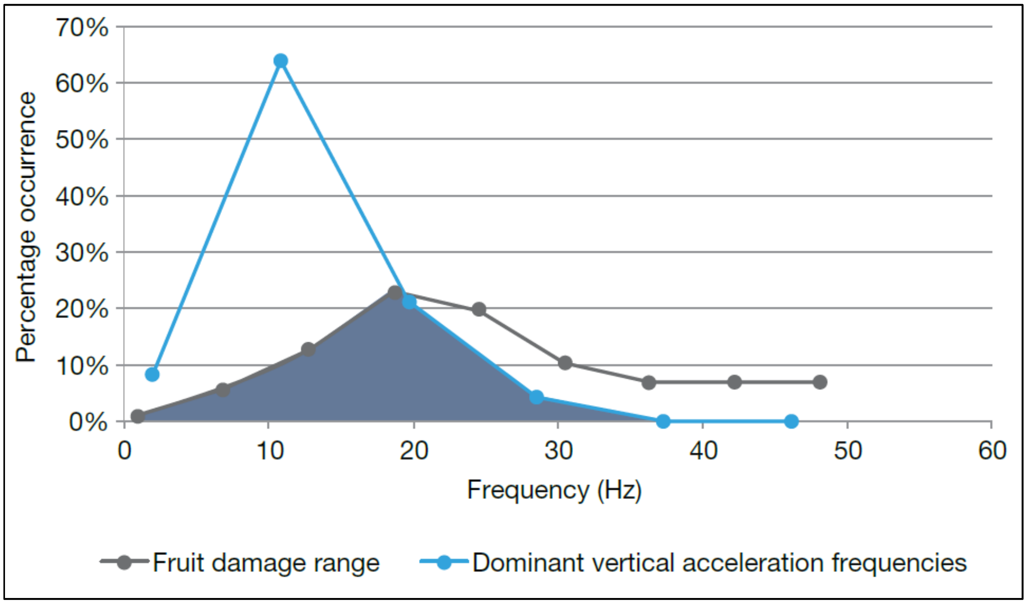


Figure 2-16: Comparison between dominant frequencies experienced by fruit cargo and the vibration range that results in fruit cargo damage (Steyn et al., 2011).

2.6.4 Transport and storage environment

The transit and storage environment under which produce is handled can potentially influence the shelf life and the quality of products that reach retail stores and consumers. Factors that are of importance include: temperature and humidity as well as post-harvest treatments and modified atmospheric conditions.

Temperature is one of the most influential factors on ripening and shelf life of tomatoes. Temperature management begins at harvest and is a continuing process until consumption. Kasmire & Kader (1978) presented the optimum temperature range for tomatoes as in Figure 2-17. This was already confirmed by Wright et al. in 1931 where they tested the effect of different temperature conditions on the storage and ripening of three varieties of tomatoes.

Tomatoes were stored at 4° C, 10° C and16 ° C and inspections were made for a period of up to 36 days. Those held at 10° C and 16° C ripened satisfactory although slow. No premature degradation and breakdown occurred. At 4° C ripening of tomatoes did not occur but the tomatoes turned white and many showed signs of tissue degradation at the end of the experiment. For longer storage periods at low temperatures tomatoes are prone to chilling injury. At temperatures above the recommended range tomatoes ripen at an abnormally accelerated rate (Wright et al., 1931).

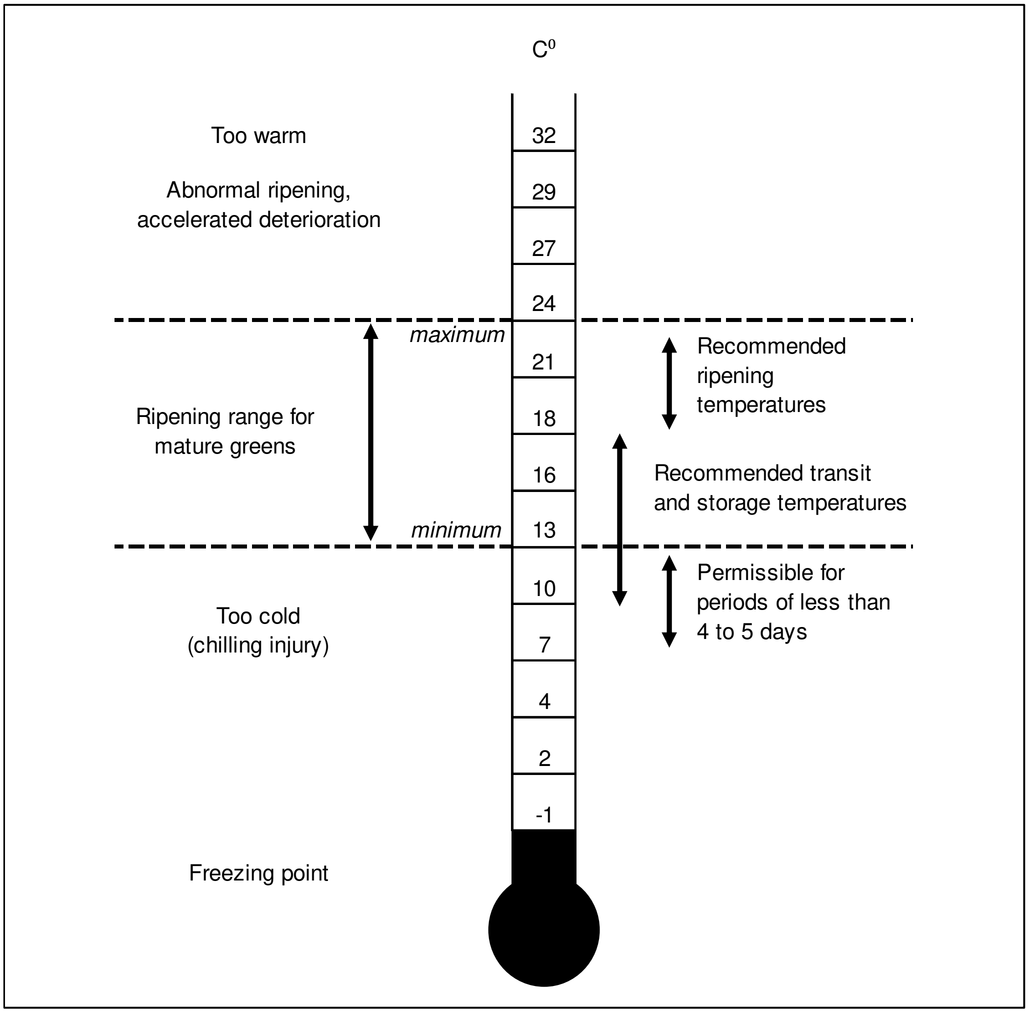


Figure 2-17: Tomato ripening and transit temperatures (Kasmire & Kader, 1978).

Water loss in tomatoes is a common appearance. Objectionable shrivelling occurs when tomatoes lose three to five per cent of their harvesting weight. Temperature and humidity can greatly influence water loss. It is recommended that tomatoes should be kept at a relative humidity of 85 to 95 per cent. Tomatoes should never be held in wet cold rooms (Kader et al., 1978).

The effect of postharvest treatment and packaging on tomato shelf life was investigated by Nasrin et al. (2008). Chlorine treated fruit were stored in perforated polyethylene bags and kept at ambient temperatures. Under these conditions the shelf life was extended to 17 days in comparison to the 7 days for tomatoes not treated and stored without packaging. Other treatments such as ethylene could be used to accelerate the ripening of mature green tomatoes. Ethylene treatment at shipping points provides a more uniform ripe product upon arrival at the destination (Kader et al., 1978).

Atmospheric modification is another method used to extend the shelf life of the product. Through the reduction of oxygen levels tomato ripening can be retarded. Carbon dioxide levels should however be controlled not to go above two per cent as this could cause uneven ripening and increased softening of fruit (Kader et al., 1978).

2.7 LOGISTICS COSTS

Logistics is concerned with the physical movement and storage of products that originate due to difference in location of supply and demand. The South African economy is transport intensive because of the spatial separation of the economic hub (Gauteng) and points of export (Ports such as Richards Bay). The efficient operation of South Africa's economic system is dependent on a well-developed and maintained transport system as well as effective logistics system. The increase in direct and indirect costs due to decreased road conditions transpires into a negative influence on economic development.

Various studies have proven that deteriorating road quality results in significant increases in repair and maintenance costs, as well as fuel and tyre consumption, which in turn, leads to an increase in company logistic costs. Figure 2-18 developed by (Steyn et al., 2011) indicates the potential effects of bad roads on logistics costs. An uneven pavement surface leads to freight and vehicle damage. To protect freight on bad roads improved packaging technology is an option although this would also have an impact on the consumer's pocket. The only economically viable option is to improve the road network condition. Such an improvement would not only influence a single transport operator but would circle to include all road users.

In the 2011 study of Steyn et al. the impact of road condition on three main groups of transport costs were assessed. The groups included road maintenance costs, road construction costs and road user costs. The outputs indicated that there is a relationship between riding quality and truck maintenance and repair costs as well as a relationship between vehicle operating costs and riding quality.

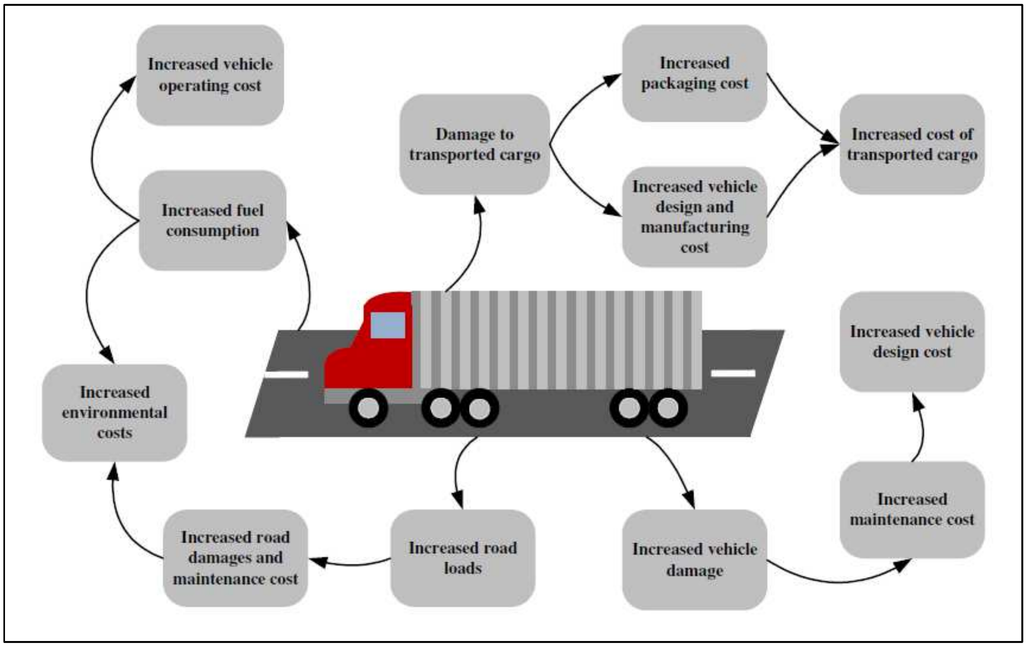


Figure 2-18: Conceptual indication of the effect of riding quality on truck logistic costs (Steyn, 2011).

2.7.1 Vehicle operating costs

Steyn & Bean (2012) calculated the total fuel consumption, tyre costs and annual maintenance and repair costs for freight transported on the 22 main corridors in South Africa based on the NCHRP720 formulas which was developed by the Transportation Research Board (TRB) for the USA. The study indicated that if road conditions should deteriorate by 10 per cent there would be an increase of 0.08 per cent in fuel costs and 0.18 per cent in tyre costs. The study by Steyn et al. (2011) already confirmed this increasing trend in 2011.

2.7.2 Vehicle maintenance and repair costs

A case study by Steyn & Bean (2009) investigated the effect of road conditions on vehicle repair and maintenance costs. The transport routes of two transporters were assessed. One of the companies only used primary networks while the other made use of primary and secondary networks. Considering Table 2-4 it is clear that the repair and maintenance costs per kilometre increase as the roughness of the road increases.

Table 2-4: Maintenance and Repair costs for different roughness values (Steyn & Bean, 2009).

Company	Route Information	Average IRI (mm/m)	Road condition rating	Average Maintenance and repair cost (ZAR/km)
A	Gauteng to Durban (N3)	2.7	Good	1.01
	Gauteng to Cape Town (N1)	3.6	Fair	1.30
B	Gauteng to Durban (N3)	2.7	Good	0.90
	Gauteng to Nelspruit (N4)	2.9	Fair	0.82
	Gauteng to Witbank (N12)	3.4	Fair	1.27
	Gauteng to Rustenburg (N4)	3.3	Fair	1.04
	Gauteng to Richards bay (N17 and N2)	3.6	Fair	1.31
	Johannesburg to Vereeniging (R82)	3.6	Fair	1.57
	Gauteng to Cape Town (N12 and N1)	3.6	Fair	1.29
	Gauteng to Botswana (N4)	3.9	Fair	1.35
	Newcastle to Gauteng (N11 and N17)	4.2	Poor	2.09
	Gauteng to construction sites	4.3	Poor	2.13

Steyn & Bean (2012) calculated the total fuel consumption, tyre costs and annual maintenance and repair costs for freight transported on the 22 main corridors in South Africa based on the NCHRP720 formulas which was developed by the TRB for the USA. The study indicated that if road conditions should deteriorate by 10 per cent there would be an increase of 3.02 per cent in maintenance and repair costs.

2.7.3 Losses suffered due to produce damage

Shipment and handling of produce could result in a variety of cuts and bruises to fresh produce. Depending on the size and visibility of the bruise, produce are either not marketable or the shelf life is reduced (Chonhenchob et al., 2009). Various authors studied the effects of road condition on the losses of produce under different conditions (O'Brien et al., 1963; Jarimopas et al., 2005; Chonhenchob et al., 2009).

Chonhenchob et al. (2009) monitored the shipment of four produce types in Thailand. These included cabbage, lettuce, pears and plums. Damage would occur as a result of rotational effects and dynamic compression from adjacent produce. It would also be affected by the shape, size, consistency and mass of the produce.

Cuts and bruises with the following dimensions were identified:

- Bruises that measured more than 1 cm^2, and
- Cuts more than 1 cm long and a minimum of 5 mm deep.

Cuts and bruises with these dimensions are known to decrease the retail price of fresh produce (Chonhenchob et al., 2009).

Roads of different condition from farms towards the packaging houses, distribution centres and retailers were used. The highest percentage damage on all monitored produce occurred on the roads towards packaging houses. These roads were gravel roads which naturally have higher roughness values than roads with asphalt or concrete surfacing.

Jarimopas et al. (2005) conducted a similar study to determine the effect that truck types, road conditions and travel velocities have on the amount of vibration damage that produce suffers after a journey from cultivators to retail stores. Damage was calculated as fruit that was unsellable at retail stores. Similar to Chonhenchob et al. (2009) gravel roads showed the most damage for all truck types and velocities. There was also an increase in produce damage as the speed of the vehicle increased.

2.8 IMPACT OF INADEQUATE ROAD MAINTENANCE

During the 1960s and 1970s African countries expanded their road networks to increase land access for new developments. These roads were considered to be the region's largest asset with a replacement cost of nearly $150 billion in 1995. Even with this investment most roads in Africa are poorly maintained and managed. Almost a third of the $150 billion investment eroded away. To restore only the economically-viable roads would require annual expenditures exceeding $1.5 billion over a ten year period (Heggie, 1995).

South African design principles stipulates that road design is based on the number of Equivalent Standard 80 kN axles (E80s) over a certain design period usually in the order of 20 years. During this period preventative maintenance such as crack sealing and pothole repairs is necessary not only to ensure that the pavement is functional and safe for road users but to prevent premature deterioration of the pavement. It is therefore essential that good road management practises are followed where pavements are monitored to ensure road conditions are kept at a required minimum. Well planned and managed actions would delay the development of defects in the pavement structure (Steyn, 2011).

Currently the methods used to fix potholes are inadequate. It is done on an emergency basis where potholes are filled with various fillers not taking into account the smoothness of the road profile. Although this method prevents the further deterioration of the substructure, in most cases, it reduce the riding quality and leads to an uneven road surface (Steyn, 2011). This increase in road roughness leads to an increase in dynamic effects experienced by a vehicle. An increase in dynamic tyre loading has a similar effect to vehicle overloading. This shortens the design life of a pavement (Steyn, 2010; Steyn, 2011).

In the Infrastructure Report Card (SAICE, 2011) it came to light that there is a skill shortage and lack of capacity in municipalities making it impossible for them to maintain their road networks. In 2007 the Department of Transport did a survey which indicated that most of the municipalities lack the basic capability to answer survey questions implying their incapability to do road maintenance and management. Of the municipalities that did reply only 36 per cent indicated that there is some form of road management system in place.

Various authors investigated the effects of deteriorating road conditions. Jarimopas et al (2005) and Chonhenchob et al. (2009) showed that roads in a poor condition increase damage to fresh produce. Steyn & Bean (2009) indicated the effect of bad roads on vehicle operating and maintenance costs. Viljoen (2009) highlighted the contribution of poor road condition to fatal road accidents. Heggie (1995) highlighted the capital cost involved in replacing poorly maintained roads and the importance of a managing structure to ensure timely maintenance and rehabilitation of roads. These are some of the direct and indirect costs of deteriorating roads to consider not to mention that if road maintenance is delayed for longer than five years the cost to repair the pavement increase from six to eighteen times (SAICE, 2011).

2.9 REVIEW SUMMARY

The economic importance of road condition has been highlighted throughout this chapter and in the references cited. If the demand curve of basic economic theory is considered and imposed on a graph showing the different components that influence the price of tomatoes (or any other produce for that matter) an output similar to Figure 2-19 is produced.

The primary X- axis shows the Road condition (IRI) values, the Y – axis shows the tomato price (R/kg) and the secondary X – axis shows the quantity of tomatoes demanded by consumers (considering the cost of other substitute and compliment products).

If roads with a riding quality of 4 [m/km] exist, and it is possible to decrease this value to 3 m/km either the profit margin can be increased, through transport cost savings, while the price of tomatoes is kept stable, or the price is decreased with the same profit margin, but the amount of produce demanded (and accompanied sales) would increase, transpiring into economic growth. This phenomenon would not only be true for tomatoes but other transported goods as well. The ‘butterfly effect’ of proper road maintenance would eventually circle towards a larger economic impact.

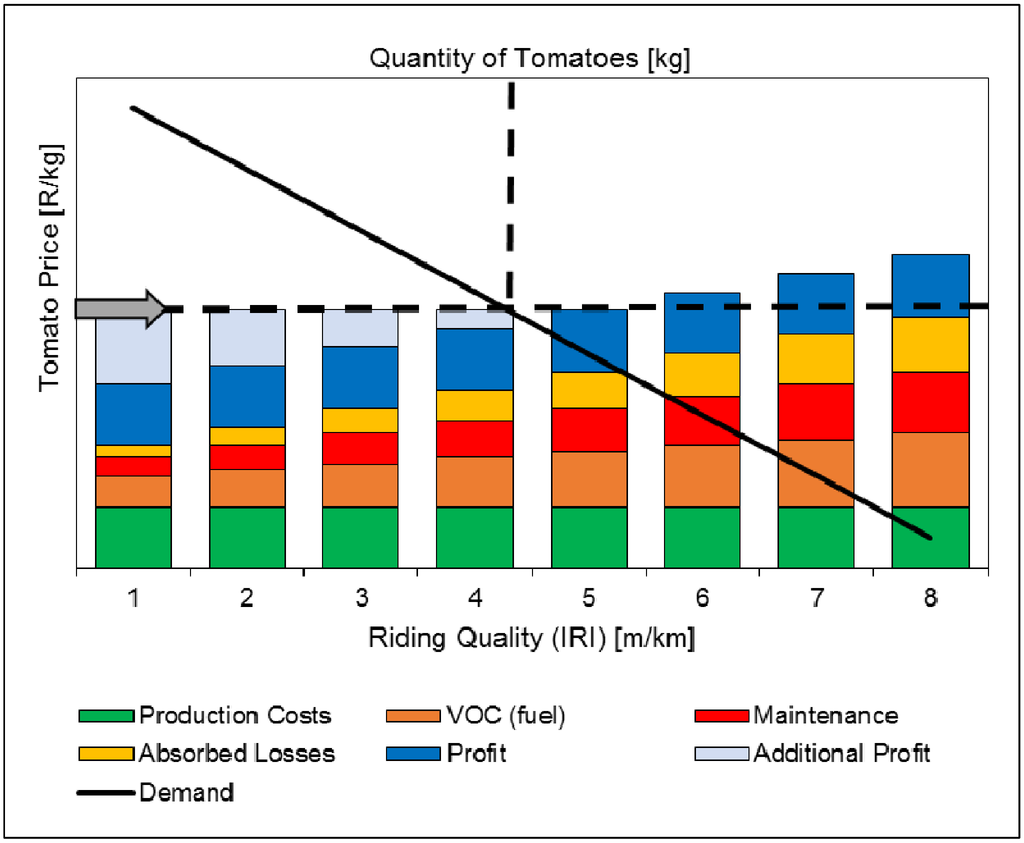


Figure 2-19: Consumer demand curve and factors influencing the price of tomatoes.

The main purpose of any business is to make profit either through cost saving or increased sales. Figure 2-20 shows that by improving the condition of the road network logistic costs can be decreased, profits from sales could be increased, the need for improved vehicle and packaging technology would be decreased and the shelf life of produce could increase. All-in-all this leads to economic growth, the development of the country and possible poverty reduction.

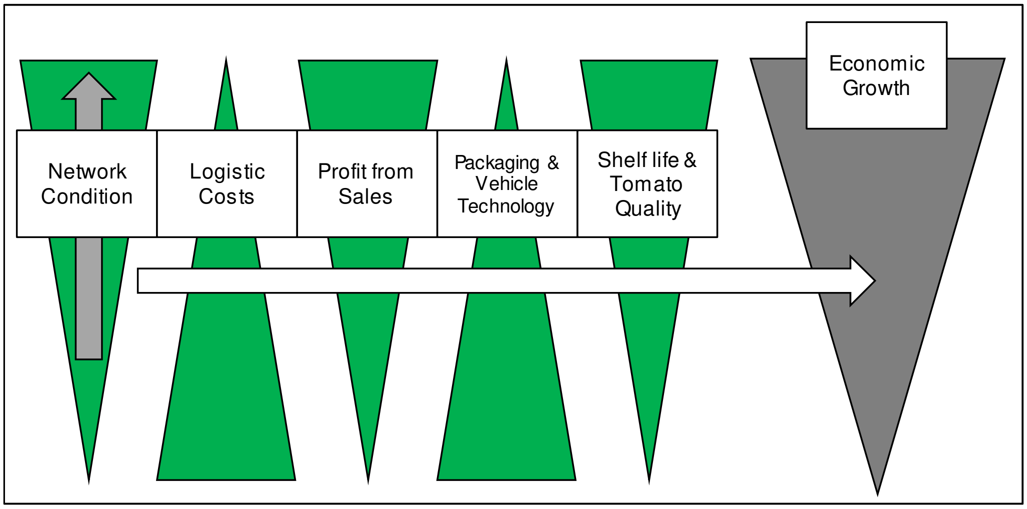


Figure 2-20: Effect of network condition improvement.

2.10 REFERENCES

ASCE, 2013. *Infrastructure Report Card.* [Online]
Available at: http://www.infrastructurereportcard.org/a/#p/roads/conditions-and-capacity
[Accessed 10 October 2016].

Aschauer, D. A., 1989. Is Public Expenditure Productive?. *Journal of Monetary Economics,* 23(2), pp. 177-200.

Bennet, A. B., 2002. Biochemical and genetic determinantsof cell wall disassembly in ripening fruit: a general model. *Hortscience,* Volume 37, pp. 3-6.

Berardinelli, Donati, V; Giunchi, A; Guarnieri, A; Ragni, L., 2005. Damage to pears caused by simulated transport. *Journal of food engineering,* Volume 66, pp. 219-266.

Bourne, M. C., 1977. Post harvest food losses - the neglected dimension in increasing the world food supply. *Cornell International Agricalture Mimeograph,* Volume 53, pp. 20-27.

Boyer, R. & McKinney, J., 2013. *Food Storage Guidelines for Consumers,* Virginia: Virginia Polytechnic Institute and State University.

Boyette, M. D., Sanders, D. C. & Rutledge, G. A., 1996. *North Carolina Department of Commerce.* [Online]
Available at: http://www.bae.ncsu.edu/programs/extension/publicat/postharv/ag-414-8/index.html
[Accessed 6 January 2011].

Canada Infrastructure, 2016. *CSCE.* [Online]
Available at: https://csce.ca/wp-content/uploads/2016/01/CIRP-2016-full-report.pdf
[Accessed 10 October 2016].

Cervantes-Godoy, D. & Dewbre, J., 2010. *Economic importance of agriculture for poverty reduction,* France: OECD Publishing.

Chonhenchob, V. & Singh, S. P., 2003. A comparison of corrugated boxes and re-usable plastic containers for mango distribution. *PackagingTechnology and Science,* Volume 16, pp. 231-237.

Chonhenchob, V. & Singh, S. P., 2005. Packaging performance comparison for distribution and export of papaya fruit. *PackagingTechnology and Science,* Volume 18, pp. 125-131.

Chonhenchob, V; Sittipod, S; Swasdee, D; Rachtanapun, p; Singh, S P; Sing, J., 2009. Effect of truck vibrations during transport on damage to fresh produce shipment in Thailand. *Journal of Applied Packaging Research,* 3(1), pp. 27-38.

Dhar, R. & Seidel, K., 2012. *Packaging for Organic Foods.* [Online]
Available at: http://www.intracen.org/projects/tccep/publications/
[Accessed 5 August 2016].

Directorate Statistics and Economic Development, 2013. *Economic Review of the South African Agriculture,* Pretoria: Department of Agriculture, Forestry and Fisheries.

Fernald, J., 1999. Assessing the link between Public Capital and Productivity. *American Economic Review,* 89(3), pp. 619-638.

FHO, 1979. *Recommended practices for the prevention of mycotoxins in food, feed, and their products,* Rome: Food and Agricultural Organisation of the United Nations.

FSAI, 2014. *Guidance Note No. 18 Validation of Product shelf-life.* 2 ed. Dublin: Food Safety Authority of Ireland.

Gast, K. L. B., 1991. *Containers and Packaging Fruits & Vegetables,* Kansas: Kansas State University.

Gillespie, T. D., 1992. *Fundamentals of vehicle dynamics,* Warrendale: Society for Automotive Engineers.

Gramlich, E. M., 1994. Infrastructure Investment: A Review Essay. *Journal of Economic Literature,* Volume 32, pp. 1176-1196.

Harris, S. R., 1988. *Food and Agriculture Organisation.* [Online]
Available at: http://www.fao.org/wairdocs
[Accessed 6 January 2011].

Havenga, J H; Simpson, Z P; King, D; de Bod, A; Braun, M,., 2016. *Logistics Barometer South Africa,* Stellenbosch: Stellenbosch University.

Heggie, I. G., 1995. *Managing and Financing of Roads, an Agenda for Reform,* Washington D. C.: World Bank Technical Paper number 275.

Hinsch, R. T., Slaughter, D. C., Craig, W. L. & Thompson, J. F., 1993. Vibration of fresh fruits and vegetables durung refrierated truck transport. *American Society of Agricultural Engineers,* 36(4), pp. 1039-1042.

Holt, J. E., Schoorl, D. & Lucas, C., 1981. Prediction of bruising in impacted multilayered apple packs. *Transactions of the American Society of Agricultural Engineers,* 24(1), pp. 242-247.

International Monetary Fund, 2016. *International Monetary Fund.* [Online]
Available at: http://www.imf.org/external/pubs/ft/weo/2016/01/weodata
[Accessed 12 July 2016].

Ittmann, H., 2013. Logistics Infrastructure Capacity. *10th State of Logistics Survey*, pp. 27-57.

Jarimopas, B., Singh, S. P. & Saengnil, W., 2005. Measurement and analysis of truck transport vibration levels and damage to packaged tangerines during transit. *Packaging technology and science,* 18(4), p. 179.

Joubert, U., 2013. The logistics piece in the economic puzzle. *10th State of Logistics survey*, pp. 2-12.

Kader, A. A., Morris, L. L., Stevens, M. A. & Albright-Holton, M., 1978. Composition and Flavor Quality of Fresh Market Tomatoes as Influenced by Some Postharvest Handling Procedures. *Journal of American Society for Horticultural Science,* 103(1), pp. 6-13.

Kannemeyer, L., 2014. *CSIR.* [Online]
Available at: www.csir.co.za/Built environment/Transport infrastructure/
[Accessed 04 September 2016].

Kasmire, R. F. & Kader, A. A., 1978. Handling tomatoes at wholesale and retail: a guide for better quality and greater profits. *Outlook,* 5(3), pp. 5-12.

Ligon, E. & Sadoulet, E., 2008. *Estimating the effects of aggregate agricultural growth on the distribution of expenditured,* s.l.: World Bank.

Limpert, R., 1982. *Vehicle system components. Design and safety..* New York: Wiley.

Litman, T., 2010. *Evaluating Transportation Economic Development Impacts,* Victoria: Victoria Transport Policy Institute.

Li, Z., 2013. The effect of compressibility, loading position and probe shape on the rupture probability of tomato fruits. *Journal of food engineering,* Volume 119, pp. 417-476.

Martin, W. & Warr, P. G., 1990. *The Declining Economic Importance of Agriculture,* Australia: Research School of Pacific Studies.

Media Club South Africa, 2016. *Media Club South Africa.* [Online]
Available at: http://www.mediaclubsouthafrica.com/africa/37-economy/economy-bg/111-sa-economy-key-sectors#agriculture
[Accessed 13 July 2016].

Mizrach, A., 2007. Nondestructive ultrasonic monitoring of tomato quality during shelf-life storage. *Postharvest Biology and Technology,* Volume 46, pp. 271-274.

Mohsenin, N. N., 1986. *Physical Properties of Plant and Animal Material. Structure, Physical Characteristics and Mechanical Properties..* New York: Gordon and Breach Science Publishers Inc.

Nasrin, T A A; Molla, M M; Hossaen, A; Alam, M S; Yasmin, L., 2008. Effect of Postharvest Treatments on the Shelf-life and quality of tomato. *Bangladesh Journal of Agricultural Research,* 33(3), pp. 579-585.

Nation Master, 2016. *Nation Master.* [Online]
Available at: http://www.nationmaster.com/country-info/stats/Transport/Highways/Total/Per-capita
[Accessed 12 July 2016].

National Economic Council, 2014. *An Economic Analysis of Transportation Infrastructure Investment,* Washington: The White House.

O'Brien, M., Centry, P. J. & Gibson , R. C., 1965. Vibrating characteristics of fruit as related to in-transit injury. *Transactions of ASAE,* Volume 8, pp. 241-243.

O'Brien, M; Claypool, L L; Leonard, L L; York, G K; MacGillivray, J H., 1963. Causes of fruit bruising on transport trucks. *Hilgardia,* 35(6), pp. 113-124.

Papagiannakis, A. T. & Gujarathi, M. S., 1995. Roughness Model Describing Heavy Vehicle-Pavement Interaction. *Transportation Research Record*, Volume 1501, pp. 50-59.

Pavement Interactive, 2007. *Pavement Interactive.* [Online]
Available at: http://www.pavementinteractive.org/
[Accessed 25 07 2016].

Pereira, A. M. & Andraz, J. M., 2012. On the Regional Incidence of Highway Investment in the USA. *Annual of Regional Science,* Volume 48, pp. 819-838.

Poonyth, D., Hassan, R., Kirsten, F. J. & Calcaterra, M., 2001. *Is agriculture sector growth a precondition for economic growth? The case of South Africa,* Pretoria: University of Pretoria.

Pretorius, C. J., 2011. *The influence of road roughness on the transportation of fresh produce. BEng Dissertation,* Pretoria: University of Pretoria.

Pretorius, C. J. & Steyn, WJvdM., 2012. *The influence of road roughness on the transportation of fresh produce.* Pretoria, Southern African transport Conference .

Pretorius, F. J., 1990. *The dynamic effects of vehicles on flecible pavements, MEng Dissertation,* Stellenbosch: University of Stellenbosch.

RAL, 2015. *Annual Report 2014/15,* s.l.: Roads Agency Limpopo.

SAICE, 2011. *SAICE Infrastructure Report Card.* [Online]
Available at: www.saice.co.za
[Accessed 21 July 2016].

Sayers, M. W. & Karamihas, S. M., 1998. *The little book of profiling,* s.l.: The Regent of the University of Michigan.

Schoorl, D. & Holt, J. E., 1982. Road-vehicle-load interactions for transport of fruit and vegetables. *Agricultural Systems,* Volume 8, pp. 143-155.

Schuur, C. M. M., 1998. *Agricultural Organisation of the United Nations.* [Online]
Available at: http://www.fao.org/docrep/x5016e/x5016e00.html
[Accessed 6 January 2011].

Steyn, WJvdM., 2010. *Some effects of inadequate road maintenance on traffic loads.* Somerset West, SARF/IRF Regional Conference for Africa.

Steyn, WJvdM., 2011. *Evaluation of Effects of Road Maintenance Actions on Applied Tyre-Loads.* Kwa-Zulu Natal, 10th Conference on Asphalt Pavements for Southern Africa.

Steyn, WJvdM. & Bean, W., 2012. The potential effects of deteriorating road conditions in South Africa. *9th State of Logistics survey*, pp. 30-38. CSIR, Pretoria.

Steyn, WJvdM., Bean, W., King, D. & Komba, J., 2011. *Evaluation of Selected Effects of Pavement Riding Quality in Logistics Costs in South Africa.* Transportation Research Board Volume 2227, pp. 138-145.Washington, Transportation Research Board.

Steyn, WJvdM. & Bean, W. L., 2009. Cost of bad roads to the economy. *6th State of Logistics Survey*, p. 24. CSIR, Pretoria.

Steyn, WJvdM., Bean, W. L., Pretorius, C. J. & Van der Walt, G., 2011. The Potential Effects of Bad Roads on Transported Cargo. *8th Logistics Survey*, pp. 11-12. CSIR, Pretoria.

Steyn, WJvdM. & Coetzer, S., 2014. *ZZ2 Evaluation and Produce Damage - Final Report,* Pretoria: University of Pretoria.

Steyn, WJvdM. & Monismith, C. L., 2010. *Analysis of Vehicle-Pavement Interaction Effects on Vehicular Loads and Transported Cargo, Prepared for University of California Pavement Research Centre. UC Davis & Berkley.* California: California Department of Transportation.

Studman, C., 1997. *Factors affecting the bruise susceptibility of fruit..* Reading, University of Reading, pp. 273-281.

Tatom, J. A., 1991. Public Capital and Private sector Performance. *Federal Reserve Bank of St. Louis Review,* Volume 73, pp. 3-15.

TCGF, 2010. *A Global Language for Packaging and Sustainability. A framework and a measurement system for our industry.,* France: Lssy-les-Moulineaux.

The Heritage Foundation, 2016. *2016 Index of Economic Freedom.* [Online]
Available at: http://www.heritage.org/index/country/southafrica
[Accessed 12 July 2016].

The World Factbook, 2016. *The World Factbook.* [Online]
Available at: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2085rank.html
[Accessed 12 July 2016].

Tigist, M., Workneh, T. S. & Woldetsadik, K., 2013. Effect of variety on the quality of tomato stored under ambient conditions. *Journal of Food Science and Technology,* 50(3), pp. 447-486.

Twede, D. & Harte, B., 2003. Logistical packagig for food marketing systems. In: R. Coles, D. McDowell & M. J. Kirwan, eds. *Food Packaging Technology.* Oxford: Blackwell Publishing Ltd, pp. 95-119.

Van Linden, V., De Ketelaere, B., Desmet, M. & De Baerdemaeker, J., 2006. Determination of bruise susceptibility of tomato fruit by means of an instrumented pendulum. *Postharvest Biology and Technology,* Volume 40, pp. 7-14.

Van Linden, V., Scheerlinck, N., Desmet, M. & De Baerdemaeker, J., 2006. Factors that affect tomato bruise development as a result of mechanical impact. *Postharvest Biology and Technology,* Volume 42, pp. 260-270.

Van Zeebroeck, M; Tijskens, E; Dintwa, E; Kafashan, J; Loodts, J; De Baerdemaeker, J; Ramon, H., 2006. The discrete element method (DEM) to simulate fruit impact damage during transport and handling: Case study of vibration damage during apple bulk transport.. *Postharvest Biology and Technology,* Volume 41, pp. 92-1.

Van Zeebroeck, M; Van Linden, V; Darius, P; De Ketelaere, B; Ramon, H; Tijskens, E., 2007. The effect of fruit properties in the bruise susceptibility of tomatoes. *Postharvest Biology and Technology,* Volume 45, pp. 168-175.

Verghese, K., Lewis, H., Lockrey, S. & Williams, H., 2013. *The role of packaging in minimising food waste in the supply chain of the future,* Melbourne: RMIT University.

Viljoen, N., 2009. Logistics Costs. *9th State of Logistics Survey*, pp. II-IV.

Willcox, J. K., Catignani, G. L. & Lazarus, S., 2003. Tomatoes and cardiovascular health. *Critical Reviews in Food Science and Nutrition,* Volume 43, pp. 1-18.

World Bank, 1994. *Annual Report,* Washington: World Bank.

Wright, C. R., Pentzer, R. C., Whiteman, T. M. & Rose, D. H., 1931. *Effect of various temperatures on the storage and ripening of tomatoes,* Washingon D C: United States Department of Agriculture.

3 METHODOLOGY

3.1 INTRODUCTION

Numerous scholars identified some of the unwanted effects that poor road conditions can have on the quality of fresh produce:

- O'Brien et al. (1963) indicated that fruit in the top of the package acquire more damage than fruit in the lower layers;
- Jarimopas et al. (2005) showed that mechanical damage to fruit during transportation is caused by in-transit vibrations;
- Chonhenchob et al. (2009) also investigated the effect of road condition indicating that gravel roads had higher vibrations causing more damage to produce; and
- Steyn & Coetzer (2014) indicated that the maturity of tomatoes influences the amount of damage to the produce.

This project focuses on the effect that road condition has on the shelf life of tomatoes. It is expected that roads with higher roughness values could cause premature deterioration in the quality of tomatoes. The in-transit conditions were monitored on trucks travelling from three farms in Limpopo, owned by the ZZ2 group, to the fresh produce market in Pietermaritzburg. These trucks drive on a variety of roads including gravel or rural roads where higher roughness values are probable along with more produce damage.

The experimental setup consisted of two phases:

1. The first phase was the in-transit monitoring of the conditions to which tomatoes are exposed when shipped from grower to the farmers market.
2. The second phase was the laboratory simulation of in-transit conditions to create a model for the prediction of shelf-life under controlled conditions.

The first phase of the project consisted of the following:

- The measurement of road roughness with a laser profilometer;
- The measurement of vertical accelerations that the vehicle and all the transported components are exposed to, and
- The measurement of the in-transit pressures applied to the tomatoes.

The second phase of the project involved an experimental setup in the laboratory. A vibration table was used to simulate the in-transit conditions while monitoring pressures applied to tomatoes. Different situations were assessed including the effect of number of layers of tomatoes as well as tomato maturity.

The second phase of the project included the following:

- Vibration table experimental setup using frequencies identified from the first phase;
- Measurement of pressures applied to the tomatoes, and
- Monitoring the colour changes at the impact location over a certain period as an indication of shelf-life.

3.2 EQUIPMENT

3.2.1 Field Equipment

Three devices were used for field data measurement. The equipment included a high speed laser profilometer for road roughness measurement, Golf Coast Data Concepts X16-1D accelerometers for the measurement of vertical accelerations and the amount of energy that the pavement/vehicle/cargo system absorbs and Tekscan i-scan pressure sensors, installed in-between the layers of tomatoes to measure the transit induced pressures.

3.2.1.1 High speed laser profilometer

To measure the roughness of the road the PaveProf profilometer from PaveTesting was used (Figure 3-1). The vehicle fitted with the profilometer travelled ahead of the trucks to Pietermaritzburg. The profilometer uses 3 laser sensors to measure pavement profiles for applications including highway and runway monitoring. The device can measure rutting, texture and surface roughness at highway speeds and to international standards.

Figure 3-1: Road surface laser profilometer.

Measurement classes

Roughness measurement has seen significant improvement over the past 50 years. All of the roughness measurement devices available on the market can be divided into one of four classes. These categories as developed by Sayers et al. (1986) are presented in Table 3-1. The laser profilometer used to measure roughness is included under Class 1 and 2.

Table 3-1: Classes of roughness measurements (Sayers et al., 1986).

Device Class	Class Requirements or Characteristics
Class 1: Precision Profiles	• High accuracy and precision • Repeatability of 0,3 m/km on paved roads • Repeatability of 0,5 m/km on all road types
Class 2: Non-precision Profiles	• Profiling device not capable of Class 1 accuracy • Road profile measurement and IRI computation necessary
Class 3: IRI Estimates from correlations	• Includes all response type devices • Road profile measurement not required • Device calibrated by correlation with known sections where IRI is known
Class 4: Subjective Ratings and Uncalibrated Devices	• Subjective roughness ratings • Non-calibrated devices

There are several advantages and disadvantages when using a laser profilometer. These are presented in Table 3-2.

Table 3-2: Advantages and disadvantages of high speed profilometers (Sayers et al., 1986).

Advantage	Disadvantage
Good Precision and consistency	Laser height sensors cannot profile gravel roads successfully
IRI values can be used to track the deterioration of the network over time	High cost involved and complex control procedures
Longitudinal and transverse profiles can be measured simultaneously	Validation is still required

Measurement Control

The precision and accuracy of measurements can be influenced by several parameters related to the pavement conditions and the environment. Pavement related influences such as crocodile cracking, transverse cracking, coarse texture, potholes and patching; and temperature and seasonal variations can have a significant influence on the repeatability of measurements especially if the operator cannot maintain the exact measurement line. Environmental factors that influence the roughness measurements include: wind, extreme temperatures, surface moisture and contaminants such as loose sand.

Equipment specification

Equipment specifications should define the minimum requirements for equipment. For the profilometer the equipment specifications is presented in Table 3-3 (COTO, 2007). Since 2007 the operating speed has however improved and the profiler can measure at speeds up to 115 km/h (PaveTesting, 2016).

Table 3-3: Equipment specifications (COTO, 2007).

Importance or Relevance	Parameter	Example Specifications for	
		Sensor Equipment	Data Acquisition System
Required	Equipment Type	Inertial Profiler	Not Applicable
	Measurement Speed	80 km/h	Not Applicable
	Resolution	0,05 mm	16 Bit
	Longitudinal Sampling Interval	50 mm	10 milliseconds
	Measuring Range	200 mm	> 200 mm
	Repeatability	0.1 mm	± Least Significant Bit (LSB)
	Operating temperature Range	0^oC to 50^oC	0^oC to 50^oC
Optional	Frequency Response	DC: -16kHz	Greater than sensor output
	Long Term Drift	< 0.3 %	< 0.003% ± 1 LSB
	Filtering	Not Applicable	Anti-alias filters with cut-off wavelength of twice the sampling interval.

Equipment validation and calibration

A typical laser profilometer system has the following components (Sayers et al., 1986):

- Measurement vehicle;
- Transducer;
- Accelerometers;
- Longitudinal distance measurement device, and
- Recording system.

The transducer, accelerometer and distance measurement systems are calibrated by the product manufacturer. The device was calibrated on standard calibration sections for which the roughness is known. According to the manufacturer instructions the calibration of this device should remain stable for an extended time period and therefore calibration of the device does not form part of the measurement process. To validate the device output a comparison is made with sections for which the roughness values are known (Sayers et al., 1986). The validation criteria for profilers are shown in Table 3-4 (COTO, 2007).

Table 3-4: Validation requirements for profilers (COTO, 2007).

Parameters	Recommended Requirements for Application Type	
	Lower Reliability	Higher Reliability
Number of sites for each relevant roughness range	1 (minimum of 3 sites)	2 (minimum of 5 sites)
Minimum site length	200 m	200 m
Repeat runs per site	6 (3 runs each at 60 km/h, 80 km/h and 100 km/h	9 (3 runs each at 40 km/h, 60 km/h, 80 km/h and 90 km/h
Repeated measurements per site	2 repeats within a day of each other on 2 selected sites	2 repeats within a day of each other on 4 selected sites
Validate filtering of long wavelengths	1 site of 1 km length	2 sites of 1 km length

Data storage and reporting format

The data collected by the profilometer are stored in csv file format with the column headings as explained in Table 3-5. The columns with the most relevance are the start and end distances, the GPS coordinates and the left wheel path IRI.

Table 3-5: Format of profilometer data.

Heading	Explanation
Start Distance	Kilometer where measurement starts
End Distance	Kilometer where measurement ends
Speed (km/h)	Vehicle speed during measurement in km/h
IRI Left	IRI in left wheel path
IRI Center	IRI in the center (not the average of left and right)
IRI Right	IRI in right wheel path
RN Left	Ride number left
RN Composite	Composite Ride number
RN Right	Ride number right
GPS	Coordinates where measurement was taken

3.2.1.2 Accelerometers

An accelerometer measures the force acting on a known mass to determine acceleration. Acceleration is the change in velocity as expressed by Newton's second law:

F (force) = m (mass) a (acceleration)

The Universal Serial Bus (USB) accelerometer X16-1D was used for acceleration measurements. Figure 3-2 shows a USB accelerometer X16-1D. This devices was selected because of the relatively low cost and the ease with which it can be used.

Figure 3-2: X16-1D data logger (GCDC, 2016).

Accelerations are measured in the X, Y and Z axis. The rate of measurement can be selected by the user with the options of 12, 25, 50, 100 and 200 Hz. The device has USB connectivity, precise time stamped data logging MicroSD memory storage, real-time data access and a low noise digital accelerometer sensor. The device can act as a standard mass storage device which contains the setup files (GCDC, 2016).

There are several limitations to using accelerometers. These limitations along with the methods used for error correction is presented in Table 3-6 (GCDC, 2016).

Table 3-6: Accelerometer limitations (GCDC, 2016).

Limitation	Correction
Offset error	Calibration of the sensor against known accelerations
Drift error	Maintain a constant environment temperature
Sensitivity error	Calibration of the sensor against known accelerations
Noise	Oversampling algorithms

Equipment specification

The technology used in the X16-1D accelerometer is based on Micro-Electro Machined Semiconductor (MEMS) technology. A simple method to determine acceleration is to measure the displacement of a spring mass system. When a force acts upon the mass, the spring will stretch a certain distance relative to the known spring constant. The force acting upon the spring mass can be calculated using the spring displacement and the spring constant. Acceleration is the force divided by the mass.

MEMS scales the spring mass concept down onto a semiconductor chip. When the sensor is exposed to an acceleration the mass moves and the distance between the interleaving 'fingers' change. The displacement of the spring mass is proportional to the electrical capacitance change between the fingers. The measured capacitance is filtered and converted to a digital output representing acceleration (GCDC, 2016). The equipment specifications are presented in Table 3-7 (GCDC, 2016).

Table 3-7: Accelerometer sensor characteristics (GCDC, 2016).

Parameter	Condition	Min	Typical	Max	Unit
Acceleration Range			±16.0		g
Sensitivity			2048		count/g
Sensitivity Deviation			±1.0		%
Nonlinearity	X,Y,Z Axis		±0.5		%FS
Zero-g Offset Level Accuracy	X, Y Axis	-150		+150	mg
	Z Axis	-250		+250	mg
Inter-Axis Alignment Error			±0.1		Degrees
Cross-Axis Sensitivity			±1.0		%

Data storage and reporting format

A new data file is created in two instances, when the number of data lines is exceeded or when the system is booted. There are several conditions that would allow for a system boot to occur, these include (GCDC, 2016):

- Pressing the on/off button;
- 5V power is restored to the system via the USB connector, and
- Removing the device from the computer with the 'rebootondisconnect" feature enabled.

Data files created have the following naming-convention: data-XXX.csv, where XXX is the sequential number starting with 001. The system has the capacity to create 999 files. A short gap in the data occurs between files as data is purged from the cache and a new file gets allocated in the storage space. Figure 3-3 represents an example of a data file (GCDC, 2016).

Within the data file, digital data from the accelerometer sensor is recorded. By recording digital data the load on the processer is reduced and the sample rate capability increases. Data errors are also avoided due to floating point calculations. To be able to use the raw data a conversion is required to express the data in g's. The recorded raw data under the Ax, Ay and Az columns are divided by a value of 2048. This conversion factor is determined by the 16 bit data, or 65536 discrete counts, which covers the full range of +/- 16g sensor. Therefore, the conversion factor is 65536/32 = 2048 counts/g (GCDC, 2016).

```
;Title, http://www.gcdataconcepts.com, x16-1d, ADXL345
;Version, 1110, Build date, Dec 30 2015, SN:CCDC4016131F31B
;Start_time, 2016-01-04, 10:25:14.000
;Temperature, -999.00, deg C, Vbat, 1444, mv
;SampleRate, 100,Hz
;Deadband, 0, counts
;DeadbandTimeout, 0,sec
;Headers, time,Ax,Ay,Az
0.003,799,650,-1773
0.013,805,661,-1808
0.023,766,687,-1844
0.033,790,670,-1818
0.042,801,663,-1808
0.052,769,657,-1786
0.062,790,683,-1795
0.072,813,719,-1853
0.081,824,670,-1784
```

Figure 3-3: Example of a data file (GCDC, 2016).

3.2.1.3 Pressure sensor

The pressure that the tomatoes exert on each other were measured using i-scan pressure sensors. The i-scan pressure sensor is a thin flexible sensor measuring the interface pressure between virtually any two surfaces. This device was selected because it was readily available. There are three major system components that includes the sensor, software and data acquisition electronics. A schematic of the pressure sensor is shown in Figure 3-4 (Tekscan, 2016).

The pressure sensor is matrix based consisting of two flexible, thin polyester sheets with conductors printed in striped patterns. One of the sheets has vertical prints and the other horizontal. Stripe spacing's can vary for different applications with the smallest being 0.6 mm and the largest 17 mm. A semi-conductive ink is applied over the conductors. At the stripe intersections individual sensing elements are formed. With the application of a force the electrical resistance in the ink coating changes inverse proportional to the normal force applied.

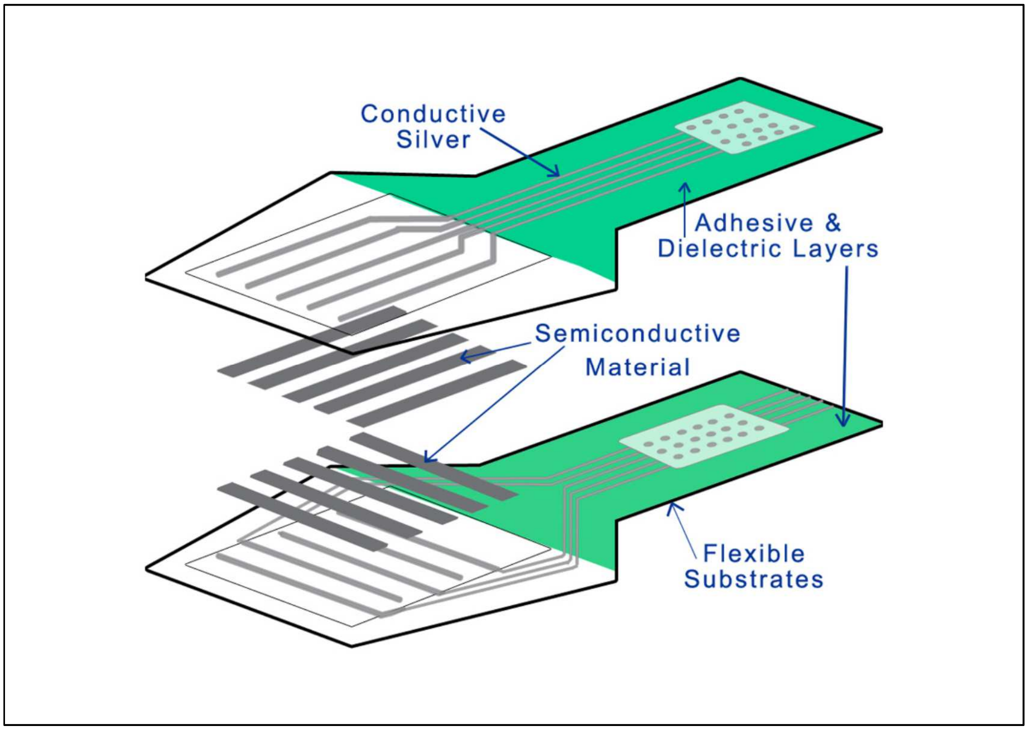


Figure 3-4: i-scan pressure sensor (Tekscan, 2016).

Equipment specification

The equipment specifications are presented in Table 3-8. Resistance of the sensing elements varies inversely with the applied load. The sensor output is linearized into digital counts (raw values) on a scale from 0 – 255. Calibration of the sensor converts the raw data into standard units such as kPa or psi (Tekscan, 2016).

Table 3-8: i-scan sensor properties (Tekscan, 2016).

Sensor Properties	Standard
Linearity	< ± 3.0 %
Repeatability	< ± 3.5 %
Hysteresis	< 4.5 % full scale
Drift per log time	< 5.0 %
Lag time	5 µsec
Operating temperature	-40º to 60ºC (-40º to 140ºF)
Thinness	0.1 mm (0.004 in.)
Sensing Element Density	Up to 248 per sq. cm (1,600 per sq. in.) Pitch as fine as 0.6 mm (0.025 in.)
Pressure Range	Up to 207 MPa (30,000 psi)

Equipment validation and calibration

With repeated loading over a period of time the individual sensing elements will to a certain degree vary in sensitivity. Through the use of an equilibration device a uniform pressure is applied to the surface of the sensor. With the help of sophisticated software a digital compensation factor is applied to each individual sensing element to normalise the sheet. This improves and extends the lifespan of the sensor (Tekscan, 2016).

Data storage and reporting format

The i-scan software is used to display pressure data in real time. It also has the functionality to export files in ".csv" format for use in other programs. A typical output is shown in Figure 3-5. The frequency at which data are recorded can be adjusted. If the frequency is set at 2 Hz, a frame similar to the one shown in Figure 3-5 is generated twice every second.

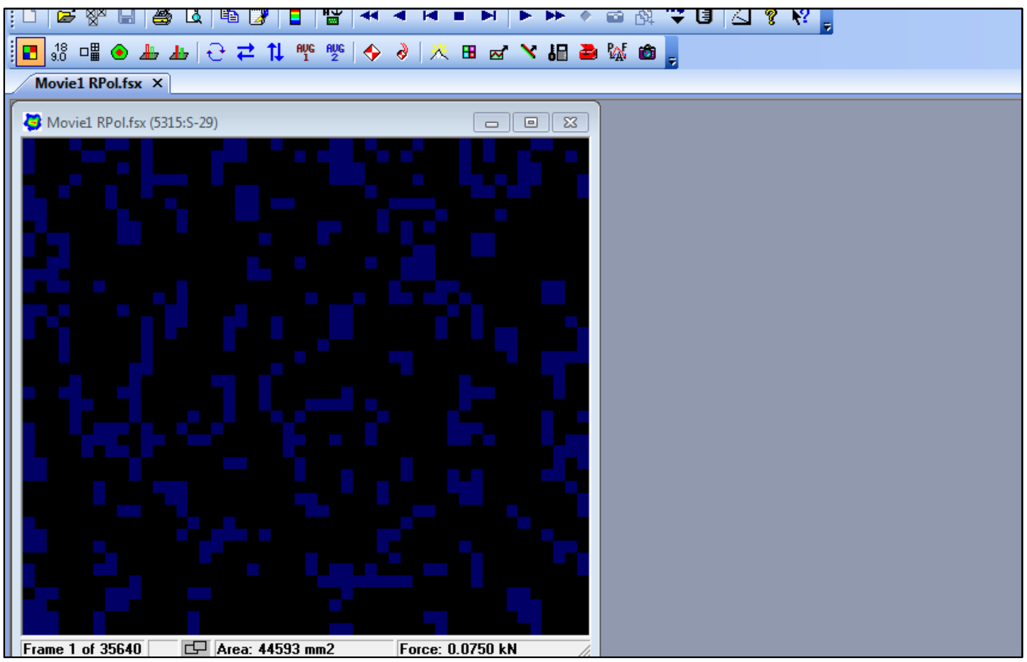


Figure 3-5: i-scan software output.

The data that are available from each frame include:

- Total force;
- Central force location;
- Peak force, and
- Pressure distribution.

Exporting the data as an ASCII file (.csv format) generates a matrix as presented in Figure 3-6. Several data frames can be exported at once to be used and manipulated as needed.

DATA_TYPE MOVIE
VERSION Tekscan Pressure Measurement System 7.60-28I
HARDWARE 110-2036
MAP_VERSION 6.5
HW_TYPE 4
VersaPogoFsx 1
FILENAME E:\Tekscan Data\Esmefour\Movie1 RPol.fsx
SENSOR_TYPE 5315
ROWS 42
COLS 48
ROW_SPACING 10.16 millimeters
COL_SPACING 10.16 millimeters
SENSEL_AREA 103.226 mm2
NOISE_THRESHOLD 3
SECONDS_PER_FRAME 0.5
MICRO_SECOND 1
TIME 2015/09/10 11:50:01.8AM
SCALE_FACTOR 0.0891168 KPa / raw
EXPONENT 1.18489
SATURATION_PRESSURE 63.306 KPa (Exponential Extrapolation)
CALIBRATION_POINT_1 0.0311655 (KNewtons) 2239 (Raw Sum) 375 (Number of Loaded Cells)
CALIBRATION_MODE_1 Point
CALIBRATION_POINT_2 0.0219081 (KNewtons) 1334 (Raw Sum) 211 (Number of Loaded Cells)
CALIBRATION_MODE_2 Point
CALIBRATION_POINT_3 0.0124152 (KNewtons) 807 (Raw Sum) 112 (Number of Loaded Cells)
CALIBRATION_MODE_3 Point
CALIBRATION_INFO E:\Tekscan Data\Esmefour\Movie1 RPol.fsx
SENSITIVITY S-29
MAP_INDEX 0
SUBMAP 0
START_FRAME 1
END_FRAME 1
UNITS KPa
MIRROR_ROW 0
MIRROR_COL 0
ASCII_DATA @@

Fra	0		2015/09/1(			Raw Sur	###																																								
1	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	3	1	0	0	0	0	0	5	0	0	0	0	0	2	0	0	0	2	1	0	0	0
1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	7	2	1	0	0	0	0	0	0	1	2	2	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	1	1	3	0	0	0	0	0	0	0	0	2	0	0	0	0	1	2	0	0	0	0
0	0	0	0	2	0	0	0	0	0	0	4	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	2	0	0	0	0	1	8	0	1	0	3	1	0	0	0	0
1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	2
1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	9	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	1	3	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0
0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	7	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	4	0	2	2	0	1	0	0	0	0	0	0	1	0	0	0
2	1	0	0	0	0	0	0	4	0	0	0	2	3	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	1	0	7	2	0	0	0	1	2	0	0	2	0	0	0	0	8	6	0	0	0	0	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0
1	0	0	3	0	0	0	0	0	0	1	0	1	0	0	0	0	5	0	0	0	6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	6	2	0	0	0	0	0	0
0	0	0	4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1
0	0	0	3	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	13	0	0	0	0	0	0	0	0	1	0	0	1	0	1	6
0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	2	2	0	0
0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	1	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
1	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	14	2	0	0	0	0	0	0	0	0
0	0	0	0	2	1	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	1	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	0	0	0	0	4	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	2
0	0	0	0	1	0	1	1	1	0	1	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	0	0	0	0	0	5	0	0	0
1	0	0	0	0	0	1	4	0	0	4	1	0	0	2	3	0	0	0	0	0	0	4	10	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
2	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	9	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	5	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	5	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	6	0	1	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	3	0	0	0	0	0	0	0	1	0	0	4	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	1	1	1	1	2	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
0	0	3	0	0	0	0	0	8	2	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	11	0	0	0	0	0
1	1	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
2	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
0	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3-6: ASCII file format.

3.2.2 Laboratory Equipment

Four devices were used for laboratory data measurement. The equipment included:

1. A Spectral Dynamics Medium Force Vibration System to simulate in transit vibrations;
2. Tekscan i-scan pressure sensors to measure inter-tomato pressures that can be related to the in-transit measurements during the field data collection phase;
3. A Hunter Lab Miniscan spectrometer to measure the colour change at the location of impact on the tomatoes, and
4. A X16 – 1D accelerometer to relate the energy that the system consume with the in- transit energy measurements.

3.2.2.1 Vibration table

The Model SD-8360LS4-17 Vibration test system is a wide frequency band Electrodynamic device. It is designed in such a way to test small to medium payloads specifically for the requirements as specified by the aviation, automotive, medical, military and electronic manufacturing industries (Figure 3-7) (Spectral Dynamics, 2010).

Figure 3-7: Spectral Dynamics medium force vibration system (Spectral Dynamics, 2010).

Equipment specification

The equipment specifications for the vibrator is presented in Table 3-9 (Spectral Dynamics, 2010). It should be noted from the table that it is not possible to test at a frequency of 2.5 Hz since it is the natural frequency of the thrust axis. Testing at this frequency could damage the equipment.

Table 3-9: Equipment specifications (Spectral Dynamics, 2010).

Property	Specification
Usable Frequency	DC to 2 700 Hz
Maximum Displacement (p-p)	100 mm
Maximum velocity	2 m/s
Maximum acceleration	85 g
Fundamental Resonance Frequency (Bare Table)	2 400 Hz (nom.) ± 5%
Body suspension Natural Frequency (Thrust axis)	2.5 Hz
Vertical Load Support	500 kg
Table Diameter	440 mm
Operating Room Temperature	0 to 45 ºC
Humidity	0 to 85%, non-condensing

Equipment validation and calibration

To control the frequency at which the vibrator operates two accelerometers gathers information on the accelerations that are transmitted to the vibration table. The information is assessed by a computer which adjust the vibrator settings to ensure the correct frequency is maintained throughout the test. To ensure the amplitude of the machine is correct a laser is used to measure the peak to peak distance of the table movement. Information is sent to the control system to adjust the amplitude to ensure consistency throughout the test.

3.2.2.2 Colour meter

The colour meter records the colour of a sample in terms of the Hunter L, a, b colour scale as presented in Table 3-10. The change in colour scale is measured in terms of the delta values which are the differences between two L, a, or b values. The total change in colour can then be calculated as the Root Mean Square (RMS) of the L, a, and b values. Unfortunately this does not give an indication of which of the three parameters changed (HunterLab, 2016). For this reason the RMS method was not used during the analysis.

Table 3-10: Description of Hunter colour scale paramenters (HunterLab, 2008).

Axis	Attribute	Maximum	Minimum
L	Light/Dark	100: reflecting diffuser	0: Black
a	Red/Green	+: Red	-: Green
b	Yellow/Blue	+: Yellow	-: Blue

Equipment specification

The equipment specifications are presented in Table 3-11. It is recommended that the instrument be used in a workspace with subdued or medium illumination and no drafts. For specification level performance the ideal operating temperature range is between 21^{0}C to 28^{0}C and the humidity should be between 10% and 90% (HunterLab, 2016).

Table 3-11: Equipment specifications for Hunter Lab Miniscan (HunterLab, 2016).

Instrument Performance	Standard
Spectral Data	Range: 400 – 700 nm Reporting interval every 10 nm
Bandwidth and Half-height	10nm
Wavelength Accuracy	≤ 0.75 nm
Photometric Range	0 – 150% reflectance
Photometric Resolution	0.01% reflectance
Measurement speed (at 25ºC)	≤ 1.5 seconds
Measurement Storage Capacity	750 readings 100 product setups
Operating temperature	10ºC to 40ºC (50ºF to 104ºF)

Equipment validation and calibration

To set up the top and the bottom scale for the neutral axis the MiniScan has to be standardised every four hours as per the manufacturer instructions. The bottom of the scale (zero) is set first by simulating a situation where all the light is absorbed by a sample. The black glass or light trap is placed at the sample port for this calibration. To set the top of the scale the light reflected back from the white tile in the calibration set is measured.

It is also recommended that the MiniScan be standardised with significant changes (greater than 15ºC) in ambient temperature. It is also important that the standards used during the standardisation process are clean and in a good condition for the standardisation to be successful. The calibration cylinder along with two calibration standards are shown in Figure 3-8 (HunterLab, 2016).

Figure 3-8: Calibration cylinder and standards (HunterLab, 2016).

Data storage and reporting format

The format in which measurements are displayed is shown in Figure 3-9. Individual measurements could be saved and afterwards viewed, deleted, printed or filtered according the needs of the user.

Figure 3-9: Colour measurements as displayed on MiniScan screen (HunterLab, 2016).

3.3 EXPERIMENTAL SETUP

3.3.1 Field Measurements

The laboratory tests required inputs that were collected during the analysis of the field data therefore the field measurements formed the first part of the experiment. Accelerometers and pressure sensors were installed in containers with tomatoes of three different maturities; red, pink and green, as indicated in Figure 3-10.

Figure 3-10: Maturity levels of tomatoes as indicated by colour (from LHS red, pink green).

3.3.1.1 Survey Location and Riding quality measurements

The road sections on which trucks travelled during the field experiment is shown in Figure 3-11. There are three distinct sections consisting of a gravel road (red), the provincial road (green) and the N1 highway (blue). Road roughness measurements were monitored and collected every 10 m using the PaveProf profilometer (see section 3.2.1.1). Roughness values are expected to be higher on the gravel roads than on the provincial and national roads.

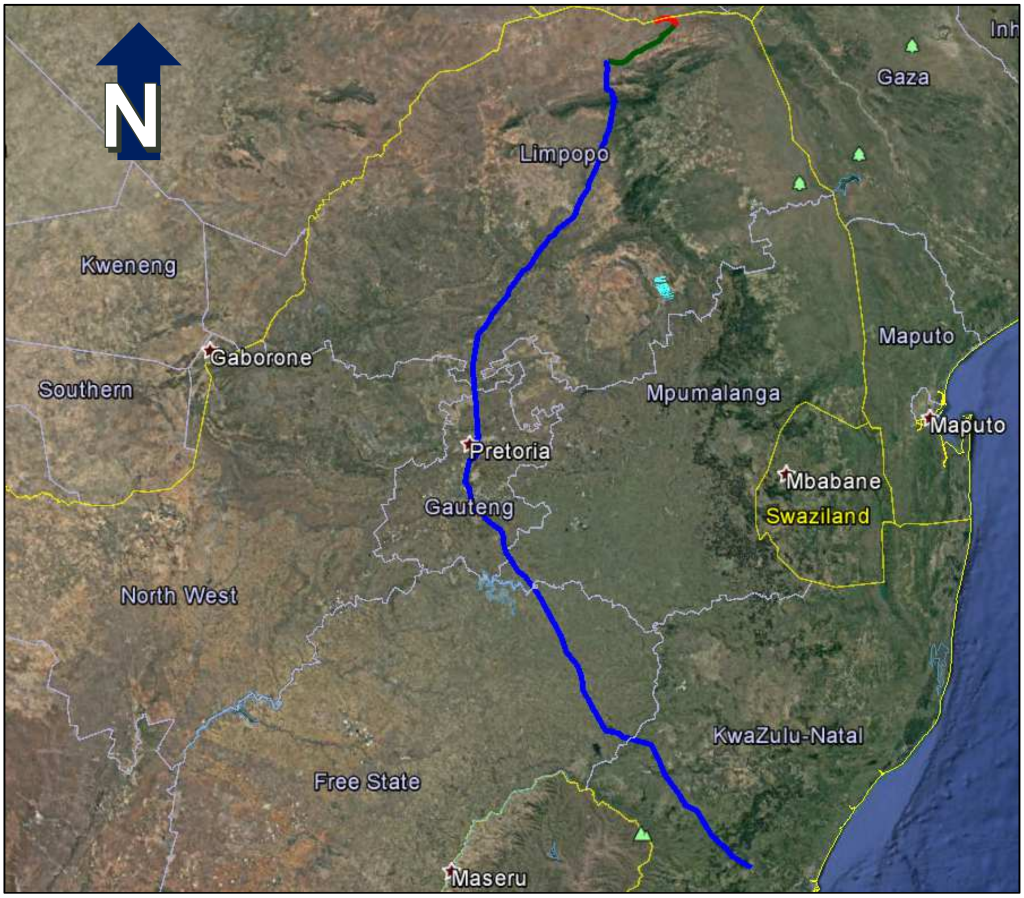


Figure 3-11: Road sections travelled during field experiment.

The trucks used are only allowed to travel at a maximum speed of 80 km/h. The distance of travel is over a thousand kilometres and therefore trucks depart from the packaging house late in the afternoon and arrive at the market during the early hours of the morning. The vehicles that were used during the experiment are standard interlink trucks that are part of the ZZ2 fleet.

3.3.1.2 Acceleration measurements

Accelerometers (see Section 3.2.1.2) were installed on the packaging and the truck for data collection. There were two different types of packaging that were considered. The first type is a halfbin (Figure 3-12) that is mostly used for the shipment of tomatoes from the farms to the central packaging house. A halfbin can have eight to ten layers of tomatoes on top of each other and the package has a significant weight.

The second packaging type considered was the standard ZZ2 box (Figure 3-13) that can hold up to three layers of tomatoes. This package is light and easy to handle.

The installation of accelerometers on the packaging is shown in Figure 3-12 and Figure 3-13. Containers were placed on the upper two rows of the pallets. As identified from the literature the top positions has more freedom of motion than the rest of the pallet and higher vertical accelerations can be expected. As a control measure accelerometers were installed on the body of the truck. The accelerometers were set to measure at a rate of 50 Hz.

Figure 3-12: Installation of Accelerometers on halfbins.

Figure 3-13: Installation of Accelerometers small boxes.

The accelerometers have a 'real time' clock which was linked to the clock on the Global Positioning System (GPS). This information was vital to determine the location on the road at which a certain acceleration was experienced. It was also used to locate groups of data points that could not be used for analysis since the trucks were standing still at locations such as toll gates, weighbridges and petrol stations.

3.3.1.3 Inter- tomato pressure monitoring

To determine the forces that act on the tomatoes during transportation, pressure sensors (see Section 3.2.1.3) were installed in-between layers of fruit. The sensors were set to measure at a frequency of 2 Hz. Sensor installation is shown in Figure 3-14 Figure 3-15.

Figure 3-14: Installation of pressure sensor in halfbins.

Figure 3-15: Installation of pressure sensor in small boxes.

3.3.2 Laboratory Setup

The second phase of the experiment consisted of laboratory work. The frequencies at which testing had to be done was determined from the accelerometer analysis of the field experiment.

Tomatoes had to be transported from the packaging house to the laboratory without being damaged prior to testing. To ensure that the tomatoes arrive intact only three layers were placed in each box separated by a layer of bubble wrap. This setup is shown in Figure 3-16.

It is impossible to eliminate tomato damage in total during transportation therefore each tomato was inspected for damage prior to testing.

Figure 3-16: Transportation of tomatoes to minimise damage.

3.3.2.1 Installation of Pressure Sensors

To simulate the in-transit conditions of the halfbins and the boxes three experimental containers with two, four and six layers of tomatoes were analysed. Only 32 tomatoes were used per box which made up the two lower layers. The laboratory boxes are smaller than the boxes used in the field experiment. This difference is not important since the investigation was focused on the number of tomatoes stacked on top of each other and not the amount of tomatoes in each row.

For the boxes containing the four and six layers a rubber mat was placed on the second layer and sand bags were positioned on top of the rubber mat. The mass of the sand was determined by weighing ten random selections of 16 tomatoes and taking the average. The 16 tomatoes weighed between 1.5 kg and 1.8 kg. An average of 1.7 kg was used for every additional layer to be added on top of the two layers of tomatoes. The pressure sensors were installed between the two lower layers. The experimental setup is shown in Figure 3-17 to Figure 3-19.

Figure 3-17: Placement of first layer of tomatoes and pressure sensor.

Figure 3-18: Placement of second layer of tomatoes and rubber mat.

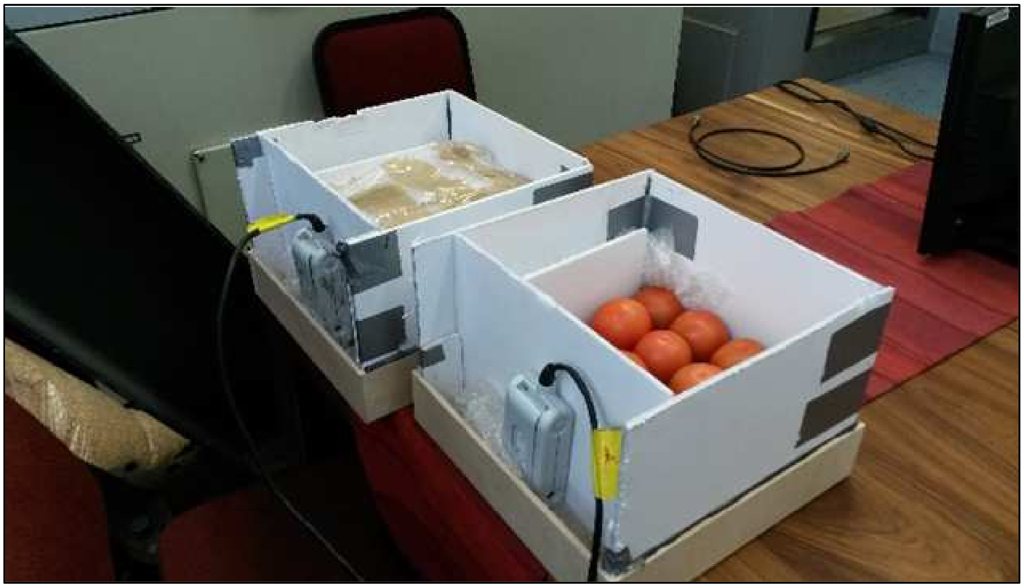


Figure 3-19: Boxes with the two and four layer setups.

3.3.2.2 Vibration Table Setup

The frequencies that were selected for testing was 2.5 Hz (body bounce) and 13 Hz (axle hop). Difficulty was experienced when testing at 2.5 Hz since this is the natural frequency of the thrust axis on the vibration table. After a few seconds of operating the equipment at this frequency the apparatus starts resonating. This can cause damage to the equipment. No data were collected during the 2.5 Hz experiment. After several attempts it was decided to only test at 13 Hz. The experimental setup is shown in Figure 3-20.

The three boxes (1) with the two, four and six layers were placed on top of the vibration table (3) and were fixed with ratchet cables that would ensure that the boxes do not move around as if they were paced on a pallet. The pressure sensors (2) were connected to the computer (4) and the frequency of measurement was set at 2 Hz. This frequency was selected to ensure that the data can be compared to the field data. The frequency, amplitude and time settings for the vibration table (5) was adjusted for the requirements of each experiment. After every experiment four tomatoes were selected for colour and condition monitoring.

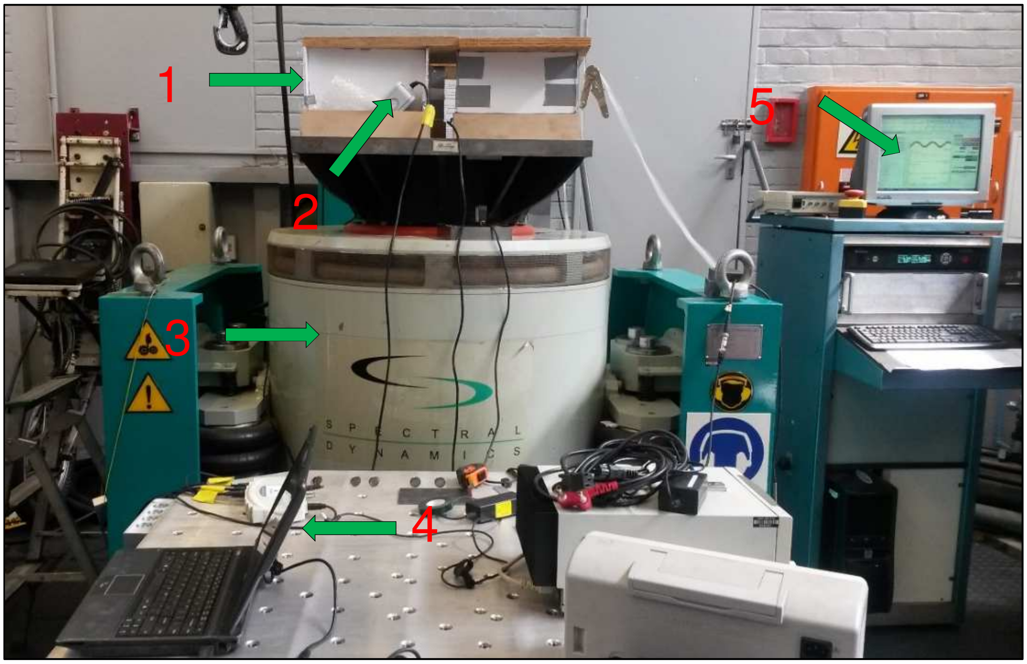


Figure 3-20: Vibration table experimental setup.

3.3.2.3 Colour Measurements

The purpose of the colour and condition monitoring process was to determine the shelf life and marketability of the tomatoes as viewed from a consumer perspective. There are only two methods for consumers to assess whether they would be willing to purchase tomatoes from a retail shelf. These include the physical appearance such as the freedom from visual imperfections as well as the firmness of the tomatoes and the presence of soft spots.

Four to five control tomatoes were selected to monitor colour change in undamaged tomatoes. All the experimental tomatoes were placed in a room with a controlled temperature of 18ºC. Tomatoes were monitored for up to ten days using Setup 2 of the Hunter lab Miniscan colour meter.

3.3.2.4 Consumer perspective

For calibration purposes a matrix was constructed asking one question: “Would you purchase this tomato if it was on the retail shelf?” For a ‘yes’ answer the binary number ‘0’ was allocated to the reading. If the answer is ‘no’ the number ‘1’ was allocated. A shelf life of 10 days were assumed for tomatoes and the loss of shelf life was calculated from the matrix.

3.3.3 Data Utilisation

The diagram in Figure 3-21 shows a schematic of the methodology that was followed and how the outputs from the field experiment was used as input parameters for the laboratory experiment.

The process was as follows:

- The laser profilometer was used to determine the roughness along the route from the farms in Limpopo to the fresh produce market in Pietermaritzburg;
- One kilometre sections were identified with different roughness values. A guideline where an average roughness (IRI) for any section less than 2.5 m/km was seen as 'good' and marked in green, between 2.5 m/km and 5 m/km was seen as 'average' and marked in yellow and above 5 m/km was seen as 'poor' and marked in red. These guidelines were selected using Figure 2-10;
- For these identified sections the acceleration data were used to identify the dominant frequencies that would be used as input values for the laboratory experiment. The system energy was also calculated and compared to laboratory data;
- For the same sections as previously identified the load applications on the tomatoes were determined using the pressure sensors. This set of data was compared to the data that were collected during the laboratory experiment;
- The dominant frequencies along with three different amplitudes and three time settings were used as input values for the vibration table;
- Boxes with two, four and six layers of tomatoes at three ripeness stages were placed on the vibration table and tested for all the frequency/amplitude/time settings;
- Five control tomatoes were selected for comparison with tested tomatoes;
- Three or four tomatoes were selected from each experiment and were observed over a period of 10 days. Colour measurements were assessed and the tomatoes were monitored for damages as observed by a consumer, and
- The reduction in shelf life was noted and plotted against the time tomatoes were exposed to a certain frequency/amplitude combination.

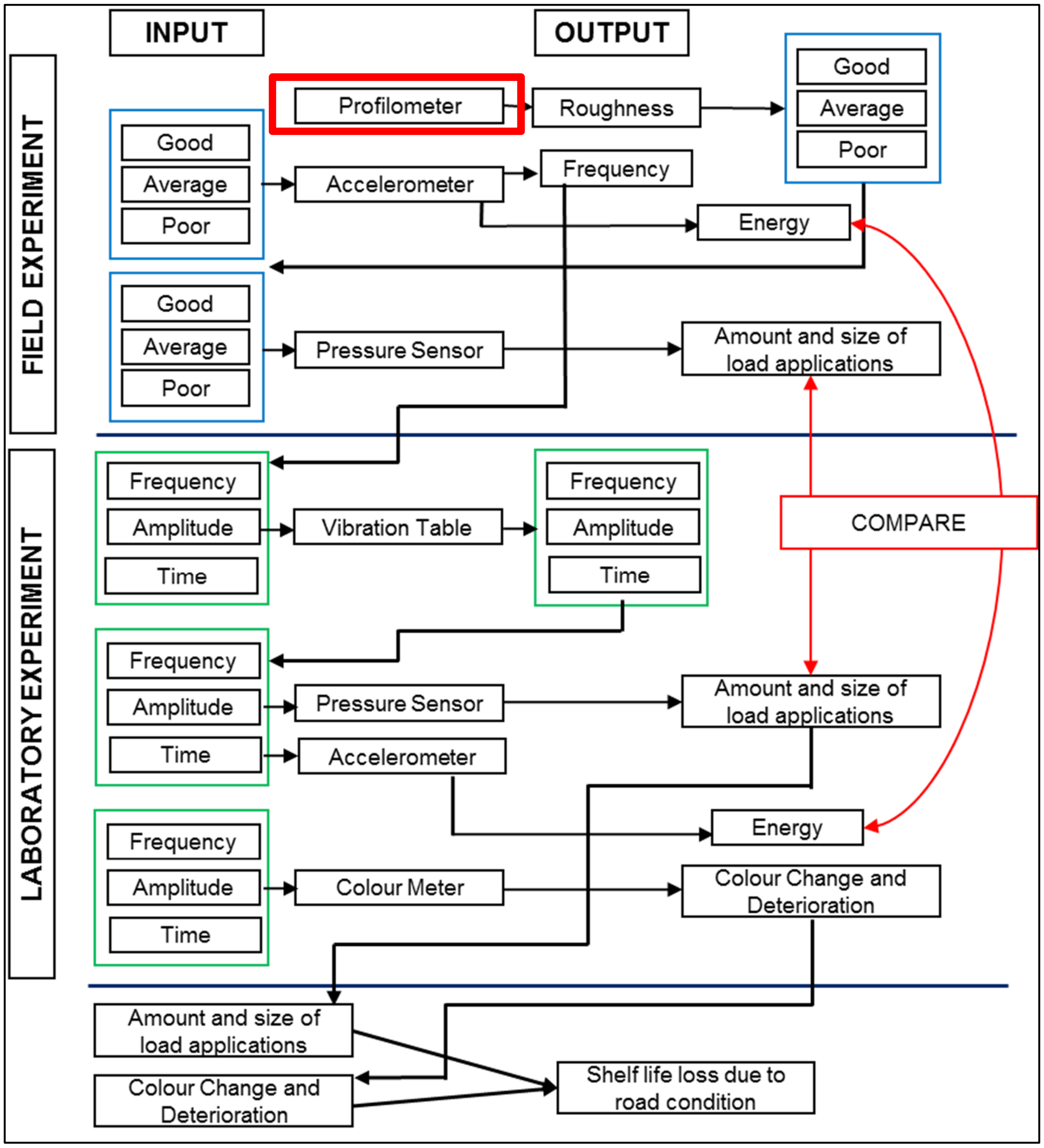


Figure 3-21: Schematic representation of methodology.

3.4 LIMITATIONS

There are several limitations that were identified during the study. These include:

Field Experiment

- A significant amount of data were collected although only small representative sections will be selected for analysis;
- The study does not include the effect of different vehicle and suspension types;

- Batteries on the accelerometers had to be changed frequently to ensure the proper functioning of the equipment, and
- Although the humidity and temperature were monitored during the field investigation these effects were excluded from the study.

Laboratory Experiment

- To be able to compare the pressure sensor data for the field and laboratory measurements the same sample frequency must be used for both studies;
- It is possible to do the calibration and equilibration of the pressure sensors after data collection but if the sensor breaks during or after the experiment the data cannot be used, and
- The vibration table cannot operate at 2.5 Hz since this is the resonance frequency of the machine. No other vibration equipment was available.

3.5 SUMMARY

For the purpose of this study five devices were used for data collection in two different phases. For comparison purposes between the field data and the laboratory data it is essential that the settings of the equipment used in both phases are similar. Several limitations regarding the operation of the equipment were discovered as data sets were collected.

3.6 REFERENCES

Chonhenchob, V; Sittipod, S; Swasdee, D; Rachtanapun, p; Singh, S P; Sing, J., 2009. Effect of truck vibrations during transport on damage to fresh produce shipment in Thailand. *Journal of Applied Packaging Research,* 3(1), pp. 27-38.

COTO, 2007. *Guidelines for Network Level Measurement of Road Roughness,* South Africa: Committee of Transport Officials.

GCDC, 2016. *GC data concepts.* [Online]
Available at: www.gcdataconcepts.com
[Accessed 23 August 2016].

HunterLab, 2008. *HunterLab.* [Online]
Available at: www.hunterlab.com
[Accessed 24 October 2016].

HunterLab, 2016. *HunterLab.* [Online]
Available at: http://www.hunterlab.com/miniscan-ez-user-manual.pdf
[Accessed 05 September 2016].

Jarimopas, B., Singh, S. P. & Saengnil, W., 2005. Measurement and analysis of truck transport vibration levels and damage to packaged tangerines during transit. *Packaging technology and science,* 18(4), p. 179.

O'Brien, M; Claypool, L L; Leonard, L L; York, G K; MacGillivray, J H., 1963. Causes of fruit bruising on transport trucks. *Hilgardia,* 35(6), pp. 113-124.

PaveTesting, 2016. *PaveTesting.* [Online]
Available at: http://www.pavetesting.com/high-speed-profilometer
[Accessed 13 August 2016].

Sayers, M. W., Gillespie, T. D. & Paterson, W. D. O., 1986. *Guidelines for Conducting and Calibrating Road Roughness Measurements,* Washington D C: World Bank.

Spectral Dynamics, 2010. *Spectral Dynamics.* [Online]
Available at: http://www.spectraldynamics.com
[Accessed 22 September 2016].

Steyn, WJvdM. & Coetzer, S., 2014. *ZZ2 Evaluation and Produce Damage - Final Report,* Pretoria: University of Pretoria.

Tekscan, 2016. *Tekscan.* [Online]
Available at: www.tekscan.com
[Accessed 23 August 2016].

4 DATA COLLECTION AND PROCESSING

4.1 INTRODUCTION

In this chapter the method of data collection and processing is discussed. As previously mentioned:

- A field and laboratory experiment were conducted during this analysis.
- A laser profilometer was used to collect road roughness data at 10 m intervals.
- Accelerometers were used to determine dominant frequencies that trucks and cargo were exposed to.
- The pressure that is exerted by tomatoes on the adjacent fruit and the order of magnitude in which the pressure change due to road condition were monitored with pressure sensors.
- The inputs for the laboratory experiment were derived from the field data.
- A vibration table, pressure sensors, accelerometer and colour meter were used in the second phase of analysis.
- The output from the laboratory study is a model to determine the effect that road condition has on the shelf life of tomatoes.

4.2 FIELD WORK

The purpose of the field experiment was two-fold:

Firstly a connection between road roughness and dominant frequencies had to be established.

Secondly it was necessary to determine if a difference in road condition would cause tomatoes to exert larger/smaller forces on each other and if the frequency and magnitude of the force application would change.

Even a small frequent force application could fatigue the tomato cell walls and a bruise could appear.

4.2.1 Profilometer data collection

Roughness measurements were collected at 10 m intervals. Each data point has a GPS coordinate that was used to plot the roughness measurements in an online global mapping program (Figure 4-1). The road was divided into manageable sections as shown in Figure 4-1.

The sections are as follows:

- Gravel Road (0 – 1);
- Provincial Road (1 – 2);
- Provincial Road to Louis Trichardt (2 – 3);
- Louis Trichardt to Pietersburg (3 – 4);
- Pietersburg to Modimolle (4 – 5);
- Modimolle to N1/R21 Interchange (5 – 6);
- N1/R21 Interchange to R24/N3 Interchange (6 – 7);
- R24/N3 Interchange to Viliers (7 – 8), and
- Viliers to Pietermaritzburg (8 – 9).

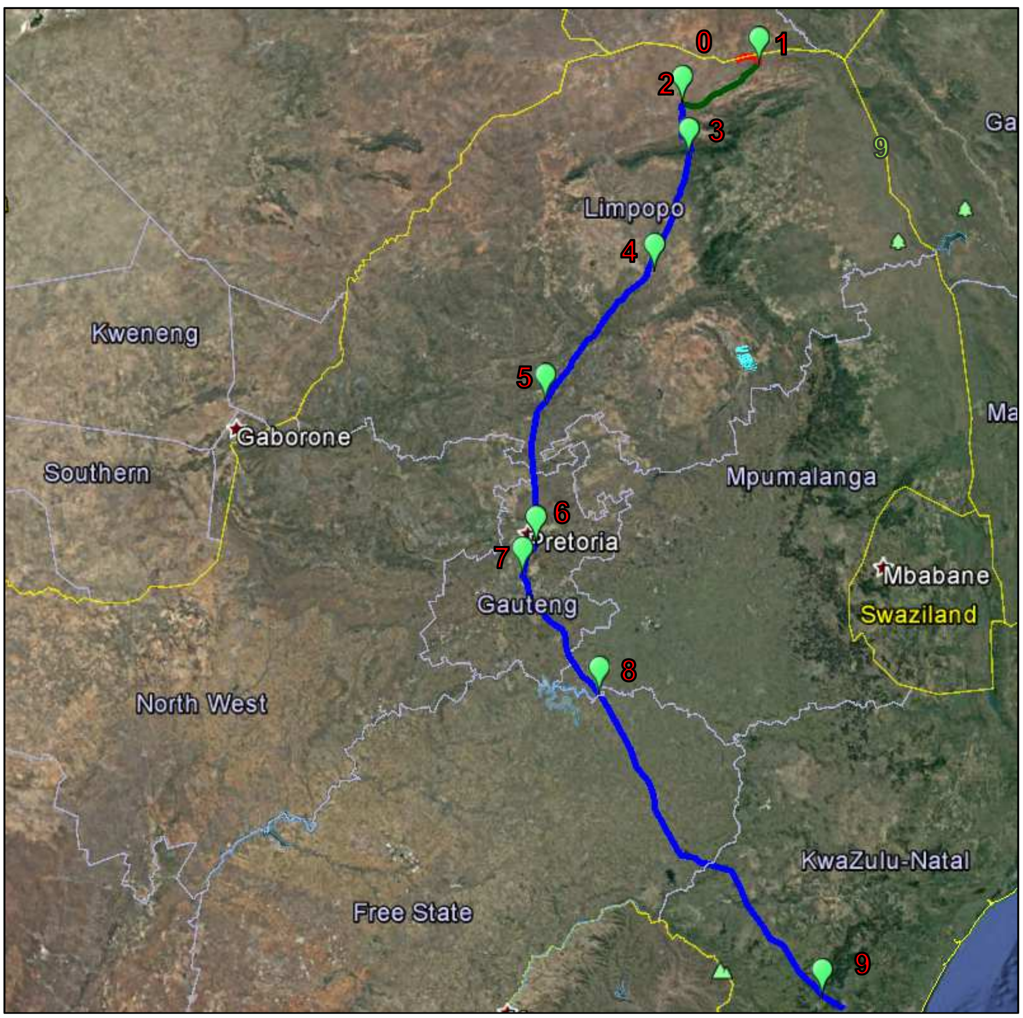


Figure 4-1: Division of road sections.

Although only one route is indicated in Figure 4-1, similar results were obtained from the other routes. Figure 4-2 is a schematic showing the different farms and the routes to the central packaging house as well as the location of the fresh produce market.

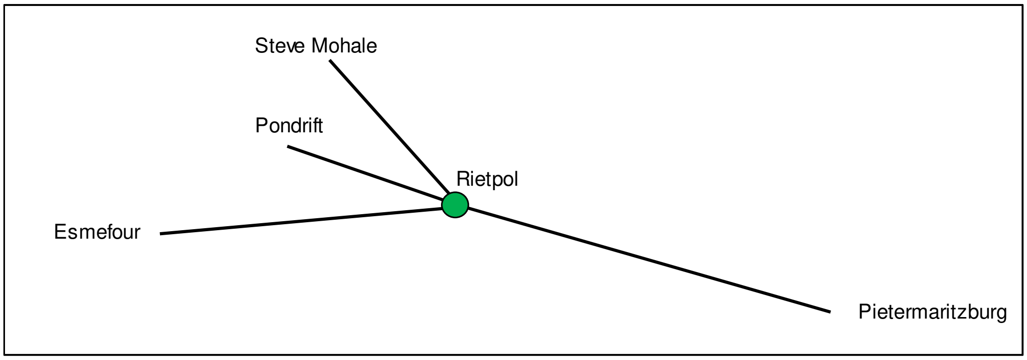


Figure 4-2: Schematic showing the different farms, the central packaging house and the farmers market in Pietermaritzburg.

The roughness values of the different routes from the farm to the packaging house at Rietpol, near Polokwane in the Limpopo province, are compared in Figure 4-3.

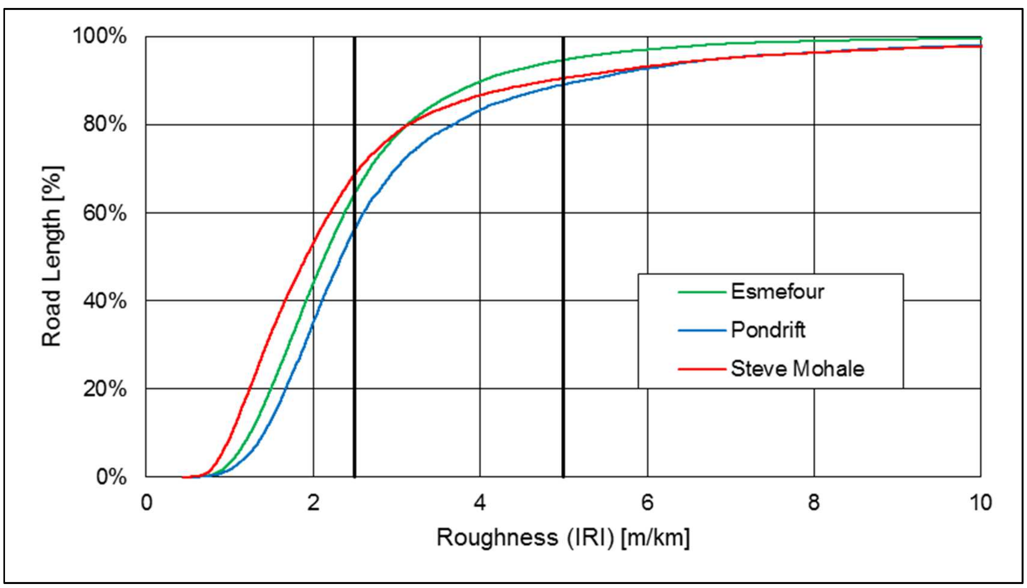


Figure 4-3: Roughness values comparison for the different roads.

The following can be noted from Figure 4-3:

- 63 per cent of the Esmefour road has roughness values less than 2.5 m/km;

- 95 per cent of the Esmefour road has roughness values less than 5.0 m/km;
- 58 per cent of the Pondrift road has roughness values less than 2.5 m/km;
- 90 per cent of the Pondrift road has roughness values less than 5.0 m/km;
- 70 per cent of the Steve Mohale road has roughness values less than 2.5 m/km, and
- 91 per cent of the Steve Mohale road has roughness values less than 5.0 m/km.

The length of the different roads are:

- Esmefour - 331.93 km
- Pondrift - 68.49 km
- Steve Mohale - 108.12 km

4.2.2 Accelerometer data collection

Accelerometer data were collected at 50 Hz and stored in several 'csv' files. All the data files were copied into a single excel file and the 50 Hz measurements were averaged to one second measurements to ease the workability of the data. The time measurements from the accelerometer files were linked to the time and position measurements from the GPS. As with the roughness measurements the data for the accelerometers were plotted in Google Earth and divided according to the same sections as the roughness data.

4.2.3 Selection of road sections

Roughness and accelerometer measurements were presented on graphs. To ease the identification of road sections the following roughness parameters were selected:

- < 2.5 Good (green);
- 2.5 – 5.0 Average (yellow), and
- > 5.0 Poor (red).

These parameters are in line with the guidelines presented in Figure 2-10.

Pavements with a roughness value of less than 2.5 m/km includes newly surfaced and well maintained pavements.

Pavements with a roughness value between 2.5 m/km and 5.0 m/km includes older surfaced pavements and well maintained gravel roads.

Pavements with roughness values above 5.0 m/km constitute pavements (paved and unpaved) that are not maintained.

Figure 4-4 represents the data for the gravel road section (0 – 1 on Figure 4-1). The selection of road sections with different roughness values are shown. The accelerometer measurements and the travelling speed is also visible on the figure.

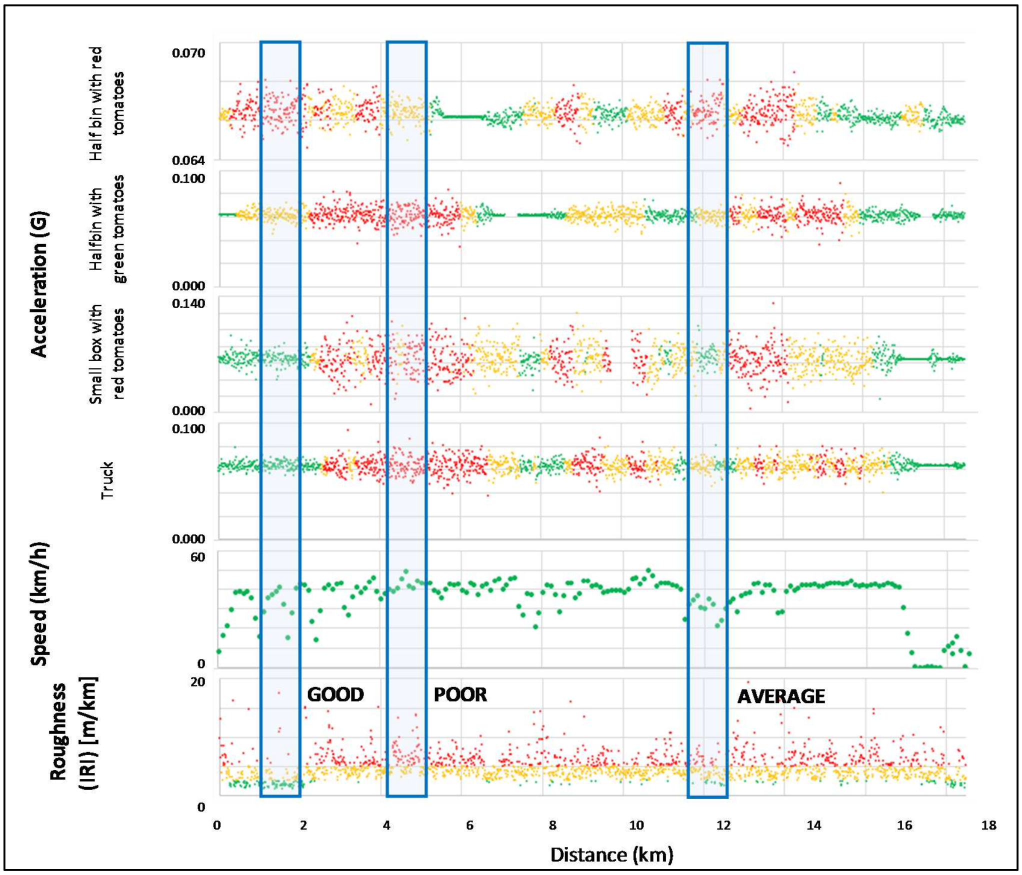


Figure 4-4: Roughness and accelerometer measurements.

4.2.4 Dominant frequencies

For each of the road sections identified the dominant frequency was determined. This was done with the XLR8R software that accompanies the accelerometers. The raw data is presented in Figure 4-5.

An FFT analysis was performed through the program as shown in Figure 4-6. The output from the FFT analysis is a PSD graph showing the frequency range that the accelerometer measured and the amount of energy input observed at the various frequency measures.

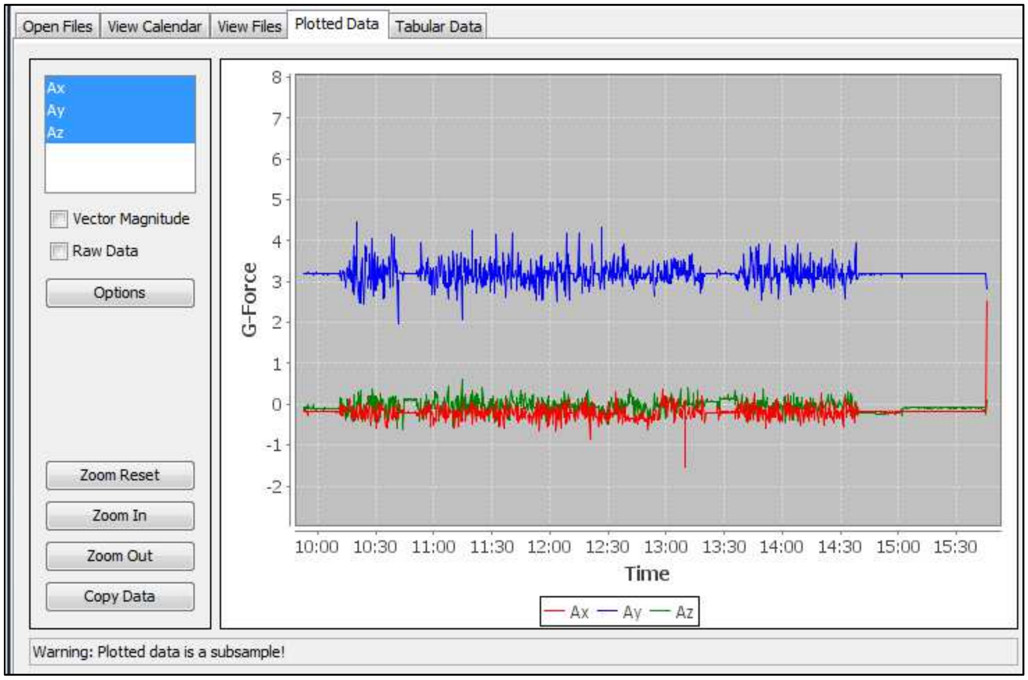


Figure 4-5: Graphical presentation of the data in XLR8R.

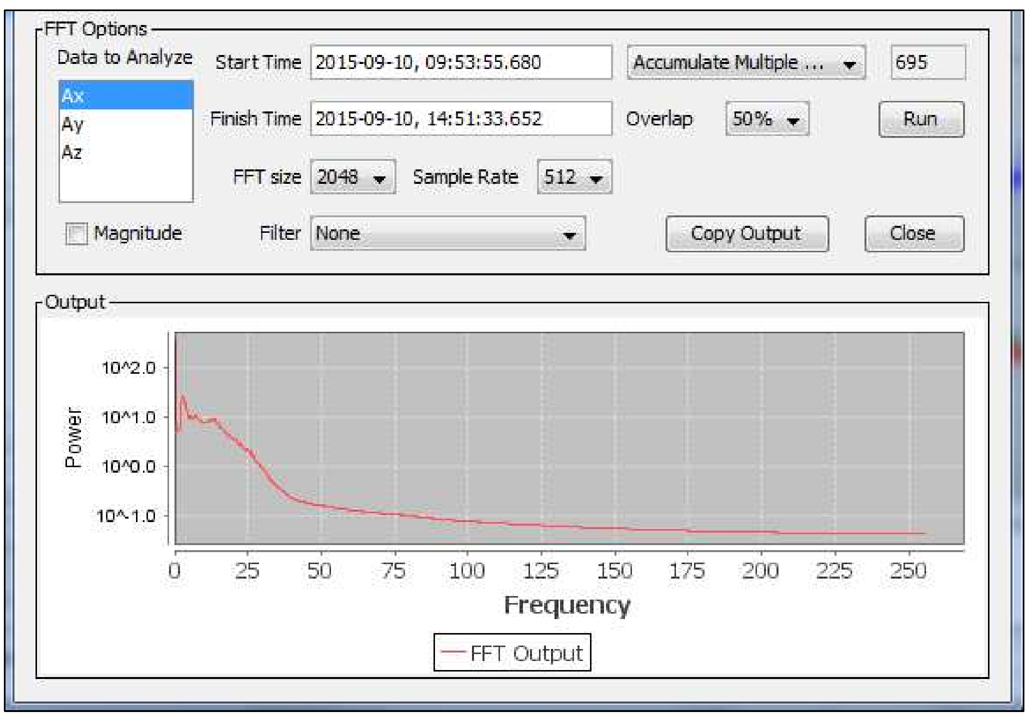


Figure 4-6: FFT analysis from XLR8R.

The frequencies were compared with the roughness values as shown in Figure 4-7. There is no established or percieved relationship between frequency (Hz) and roughness (IRI, m/km). It is clear that the data are divided into higher and lower values. This correlates with the body bounce (lower Frequency values) and axle hop (higher frequency values) as indicated in Section 2.4.2.

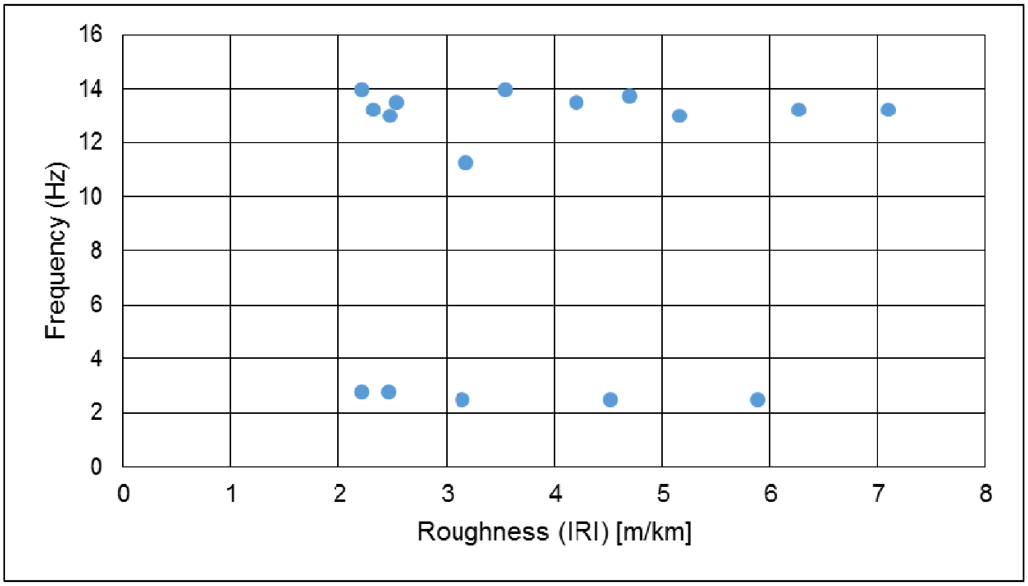


Figure 4-7: Relationship between frequency and roughness for halfbins.

Since the amplitude cannot be accurately calculated from the PSD graph, the power values were compared with the roughness as shown in Figure 4-8. There is a linear relationship between power and frequency. Because of this relationship the total energy was investigated as presented in Section 4.2.5. Energy and amplitude can be related.

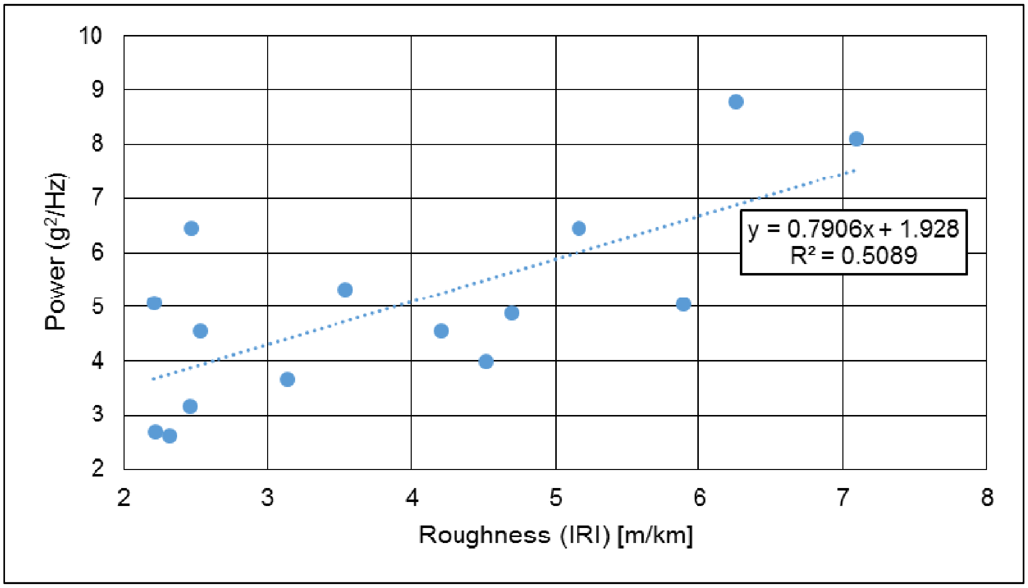


Figure 4-8: Relationship between power and roughness for halfbins.

4.2.5 Energy calculation

The data generated by the FFT analysis using the XLR8R software, were equal length frequency classes in intervals of 0.25 Hz. The energy absorbed by the system was determined through calculating the area under the PSD plot. The midpoint rule was used to determine this area. The midpoint rule calculates the average of two consecutive PSD values and multiplies the result with the adjacent difference in frequencies. These areas were summed to calculate the total area. A graphical presentation of the method is shown in Figure 4-9.

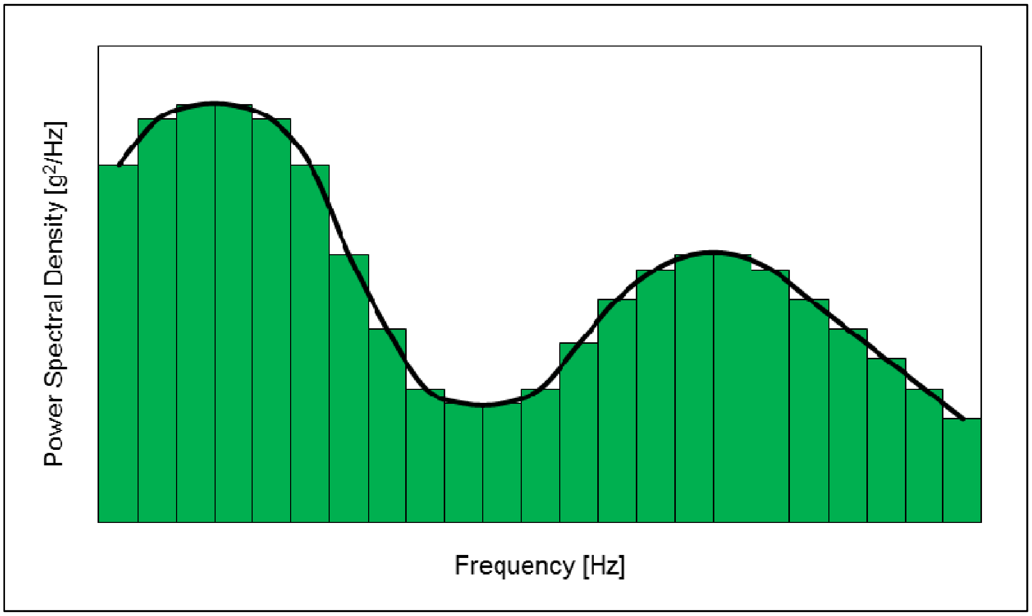


Figure 4-9: Midpoint rule to calculate the area under a curve.

The total energy at different roughness values were compared and a linear relationship was derived as shown in Figure 4-10.

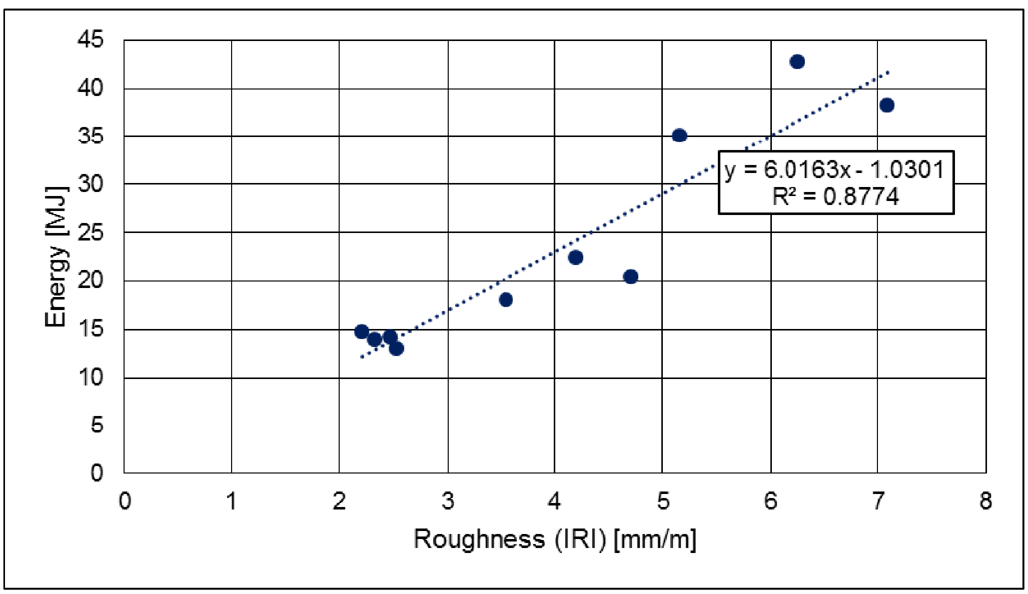


Figure 4-10: Linear relationship between energy and roughness

4.2.6 In-transit pressure measurements

For all the road sections the pressure data had to be identified. The data were extracted using the Tekscan i-scan software as seen in Figure 4-11. The frames that had to be exported were determined by comparing the GPS timestamp to the pressure sensor timestamp for every section. The data were saved as an ASCII file that can be opened using Microsoft Excel.

When the pressure sensors are placed in-between the tomatoes the sensors register a ‘base’ pressure due to the static weight of the tomatoes on top of it. To accurately determine the ‘transport induced’ pressures the ‘base’ pressures were removed by subtracting these pressures from each data frame.

The amount of Tekscan frames that would give an accurate representation of the data for each section had to be determined. The amount of frames for all sections had to be exact to be able to compare the datasets with each other. The measurements were recorded at 2 Hz, therefore there were two data frames for every second.

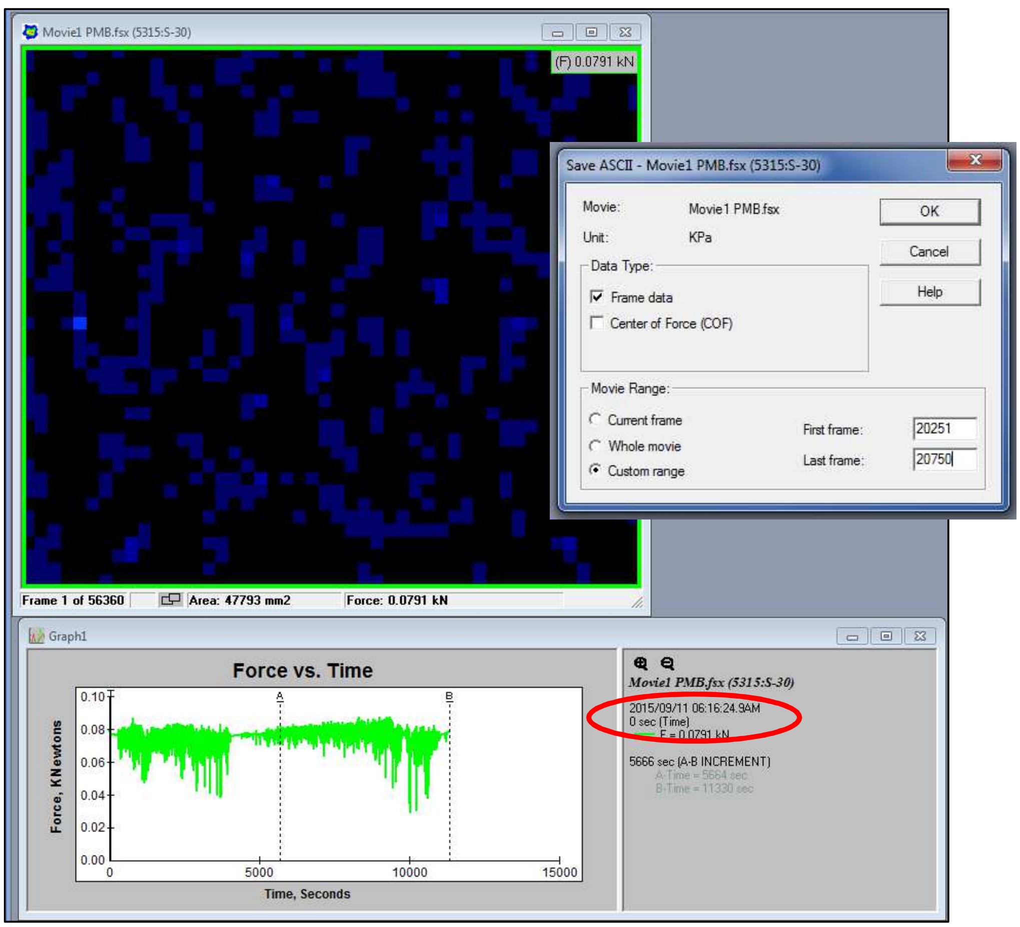


Figure 4-11: The i-scan software - identification of the amount of frames for analysis.

In Figure 4-12 the cumulative pressure change per second is plotted against the pressure that the tomatoes were exposed to during transportation. Although convergence of the data set is evident from 80 seconds upwards, most of the one kilometre sections only have 60 s of data available. For the analysis 60 seconds of data (120 frames) were selected as optimum. The output of this study is a graph showing the amount of pressure changes experienced per minute versus the roughness of the road (see Figure 4-13).

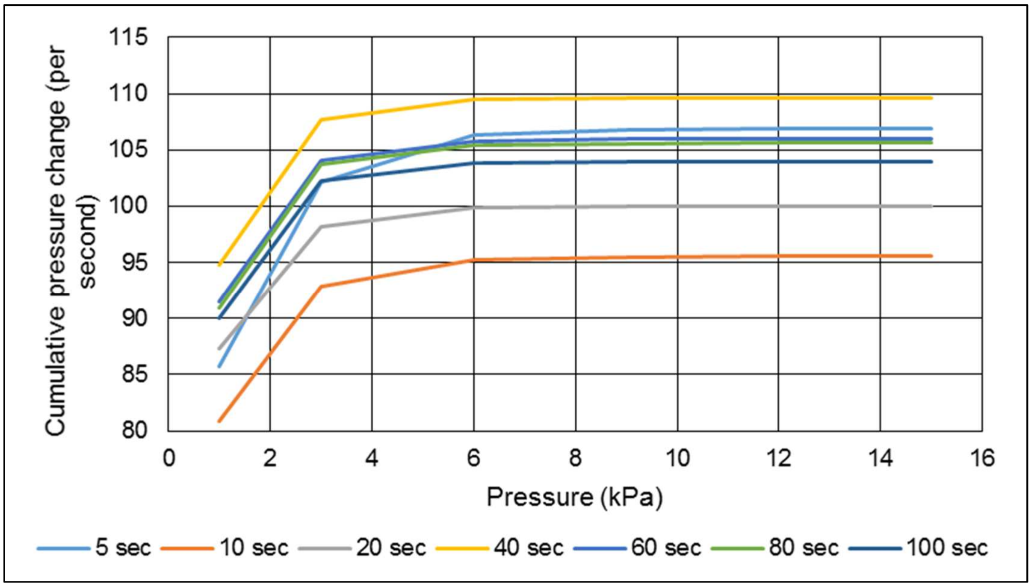


Figure 4-12: Determination of optimum number of frames per road section.

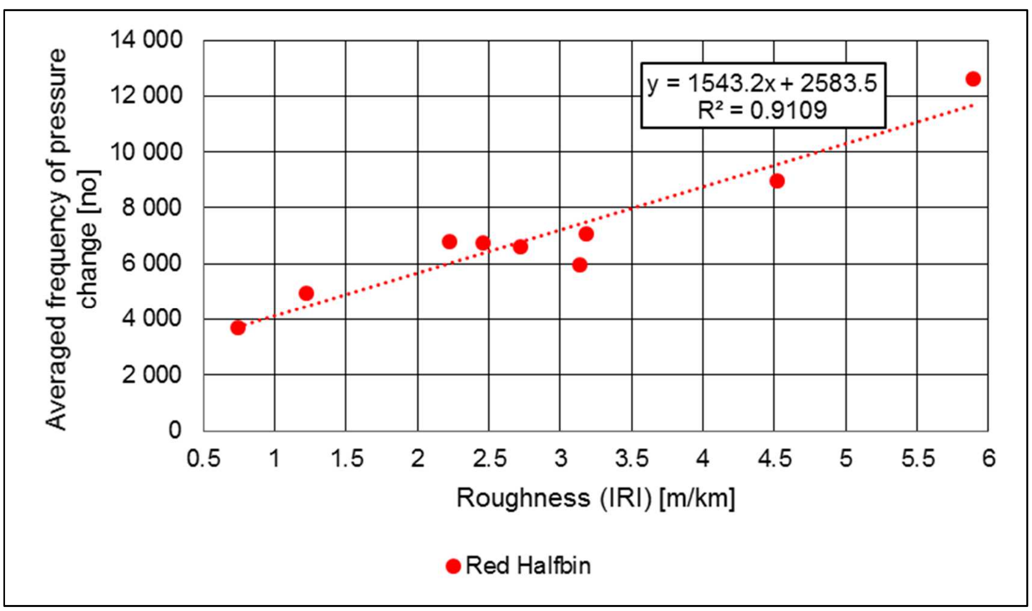


Figure 4-13: Pressure change per minute versus roughness.

4.3 LABORATORY WORK

Data from the field measurements were used to determine the inputs for the laboratory experiment. The frequency analysis for the field work indicated that two frequencies were dominant during transportation. These frequencies are 2.5 Hz and 13 Hz. The vibration table is however limited in its frequency output capabilities therefore only 13 Hz was selected for analysis.

It is however expected that less damage would be observed with a frequency of 2.5 Hz in comparison to 13 Hz. With a frequency of 2.5 Hz there is only 2.5 possible 'events' where damage can occur per second. This is significantly less than the 13 possible 'events' per second at a frequency of 13 Hz.

Since there was a linear relationship from the energy/roughness graph as discussed in Section 4.2.5, three different amplitudes were selected for the laboratory analysis

Energy is directly proportional to amplitude squared. Therefore as amplitude increases so does the total energy. This in turn can be related to the roughness of the road.

The equation for potential energy is presented below:

$E_p = \frac{1}{2}kx^2$ ....**Equation 4.1**

The equation for kinetic energy is presented below:

$E_k = \frac{1}{2}mv^2$ ....**Equation 4.2**

The total mechanical energy is the sum of the potential and the kinetic energy as presented below:

$E_t = E_p + E_k = \frac{1}{2}kx^2 + \frac{1}{2}mv^2$ ....**Equation 4.3**

In the above equation *x* is the displacement of the mass *m*, which has a velocity *v* at any given point. *k* refers to the spring constant. The total mechanical energy is constant throughout the motion since there is no friction or damping because the frequency and amplitude is controlled.

When the mass (*m*) is at its maximum displacement at the exact time where the velocity (*v*) is zero, and all the energy is potential energy and the displacement (*x*) is equal to the amplitude (*A*), the equation change as follows:

$E = \frac{1}{2}kx^2 + \frac{1}{2}m(0)^2 = \frac{1}{2}kA^2$ ....**Equation 4.4**

From this equation it is clear that energy is directly proportional to the amplitude squared.

4.3.1 Experimental matrix for laboratory analysis

The experimental matrix is presented in Table 4-1. All the frequency/amplitude/time combinations were analysed in the case of the pink tomatoes. This was to determine the relationship between the various inputs and outputs. For the green and red tomatoes only two of the three frequency/amplitude/time combinations were examined.

Table 4-1: Experimental matrix.

Frequency		**13 Hz**								
Amplitude		**2.5 mm**			**5 mm**			**7.5 mm**		
Seconds		**60**	**600**	**6000**	**60**	**600**	**6000**	**60**	**600**	**6000**
Green	2 Layers	x	x	x				x	x	x
	4 Layers	x	x	x				x	x	x
	6 Layers	x	x	x				x	x	x
Pink	2 Layers	x	x	x	x	x	x	x	x	x
	4 Layers	x	x	x	x	x	x	x	x	x
	6 Layers	x	x	x	x	x	x	x	x	x
Red	2 Layers	x	x	x				x	x	x
	4 Layers	x	x	x				x	x	x
	6 Layers	x	x	x				x	x	x

4.3.2 Energy calculation and comparison to in-transit measurements

Several one minute sections were selected from the 2.5 mm, 5.0 mm and 7.5 mm amplitude data. The XLR8R software was used to develop a PSD curve for all the data sets. The midpoint rule was used to determine the energy from the PDS graph and the average energy was calculated for the different amplitudes. The linear relationship derived in Section 4.2.5 was used to determine the roughness (IRI) value that coincide with the different amplitudes.

4.3.3 Pressure calculations

Similar to the calculations in Section 4.2.6, the averaged frequency of pressure change was calculated for the different amplitudes and times. In Section 4.3.2 the different amplitudes were related to road roughness (IRI).

Figure 4-14 shows the averaged frequency of pressure change as related to the roughness of the road for one of the laboratory experiments. There is a good linear relationship between the calculated roughness values and the averaged frequency of pressure change.

The graphs from the laboratory experiment (Figure 4-14) were compared with the in-transit graphs (Figure 4-13) to determine the correlations. This included three laboratory graphs for two, four and six layers as well as two in-transit graphs for small boxes and halfbins. The small boxes should be compared to the two and four layer laboratory graphs and the halfbins should be compared to the four and six layer laboratory graphs.

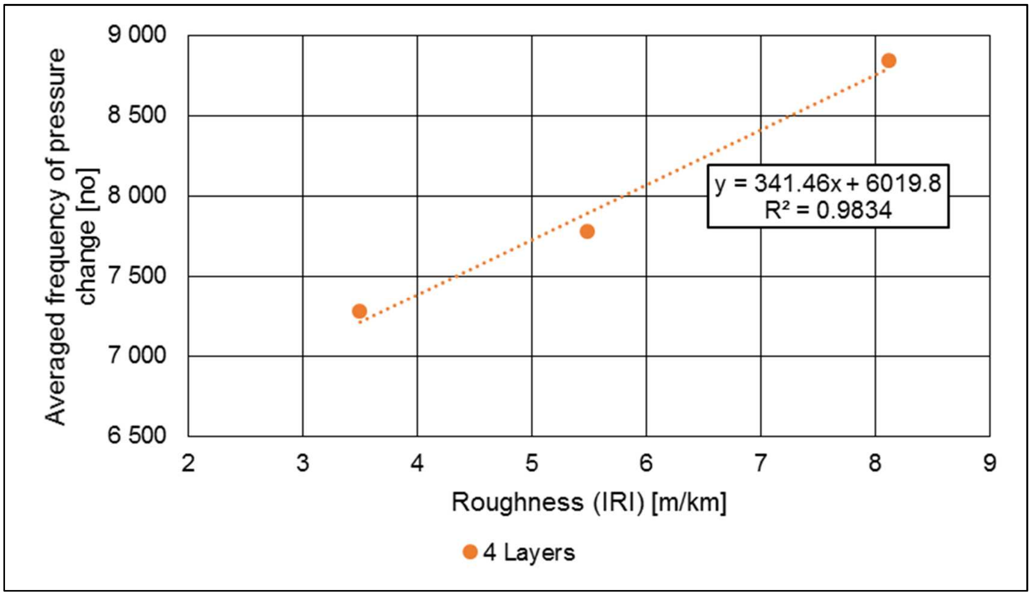


Figure 4-14: Pressure change per minute versus roughness.

4.3.4 Colour monitoring

The Hunter Lab miniscan was used for colour measurements. The Hunter L, a, b colour space is organised in a cube format as shown in Figure 4-15. The minimum value for 'L' is zero corresponding to the colour black and the maximum value is 100 which is a perfect reflecting diffuser. The 'a' and 'b' values have no specific numerical limits. A positive 'a' and 'b' value corresponds to the red and yellow colour and the negative 'a' and 'b' values corresponds to a green and blue colour.

From each of the experimental setups three to four tomatoes were selected for colour monitoring. Each reading represents the average of three measurements. The measurements were compared to the measurements of control tomatoes. For the green tomatoes two measurements were collected, one on the location of a bruise and one on a location where the tomato was not bruised. The average bruised and 'not-bruised' green tomato measurements along with the average measurements of the control tomatoes are shown in Figure 4-16 to Figure 4-19.

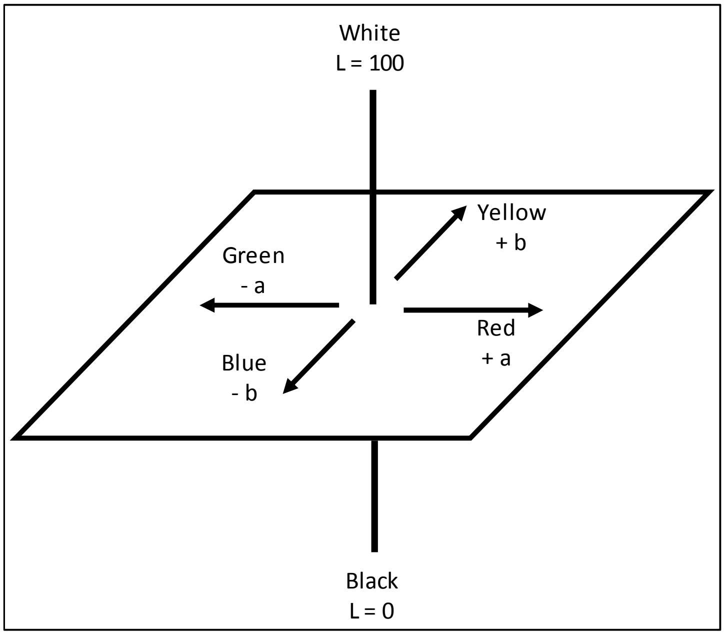


Figure 4-15: Hunter L, a, b colour space (HunterLab, 2008).

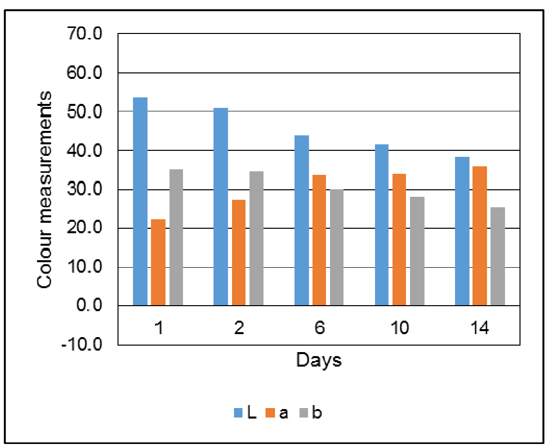


Figure 4-16: Colour measurement on 4 layers, 6000 seconds, bruise location.

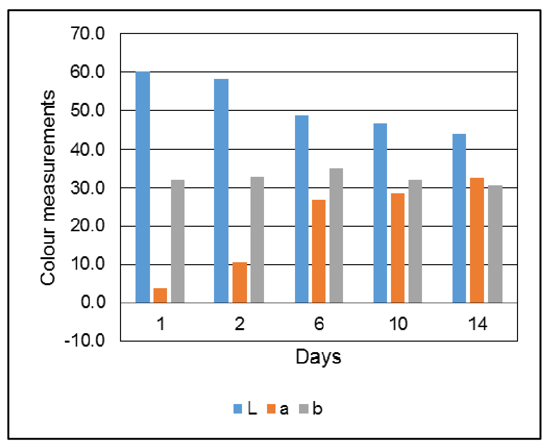


Figure 4-17: Colour measurement on 4 layers, 6000 seconds, not bruised.

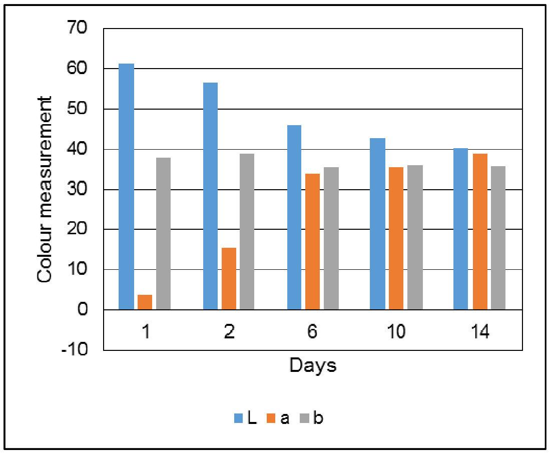


Figure 4-18: Colour measurement on control tomato, position one.

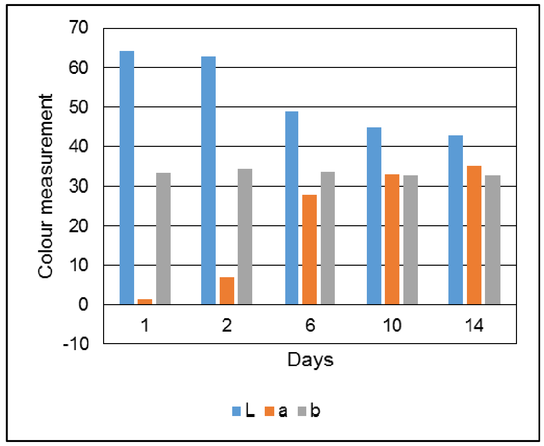


Figure 4-19: Colour measurement on control tomato, position two.

4.3.5 Consumer perspective

A binary marketability matrix was constructed asking the question: "Would you purchase this tomato if it was on the retail shelf?" For a 'yes' answer the number '0' was allocated to the reading. If the answer is 'no' the number '1' was allocated.

A shelf life of 10 days were assumed for tomatoes and the loss of shelf life was calculated from the matrix. If three out of the four tomatoes scored a '1' and one scored a '0' it was interpolated between the days to find the reduction in shelf-life for instance, if the measurement on day four is 0, 0, 0, 0 and on day 7 it is 1, 1, 0, 0 the tomatoes would not be marketable on day 6. An example of a marketability matrix is presented in Table 4-2.

Table 4-2: Marketability matrix.

Days	2 layers			4 layers			6 layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	1	1	1	0	0	0	0	0	0
2	X	X	X	0	0	0	0	0	0
6	X	X	X	1	0	0	1	1	0
10	X	X	X	X	1	1	X	X	1
14	X	X	X	X	X	X	X	X	X

The marketability matrix and the colour measurements were compared to determine if the colour measurements can be used as a guideline for tomato quality.

4.4 EXPERIMENTAL MODEL

The purpose of the experiment was to determine if it is possible to estimate the loss in shelf life due to the roughness of the road. The experimental model was developed as follows:

- The energy generated at different roughness values were compared to the energy generated at different amplitudes. A representative roughness value for the different amplitudes were calculated (See Section 4.3.2).
- The frequency of pressure change at the different roughness and amplitude values were compared to determine if the field and laboratory experiments obey similar rules (See Section 4.3.3).
- The marketability matrix and colour changes were related to damage and loss in shelf life (See Section 4.3.4 and Section 4.3.5).

The output of this study is shown in Figure 4-20. The shelf life (or loss thereof) is shown on the Y-axis and the road roughness is shown on the X-axis. The red, blue and green lines represent the duration of travel in seconds.

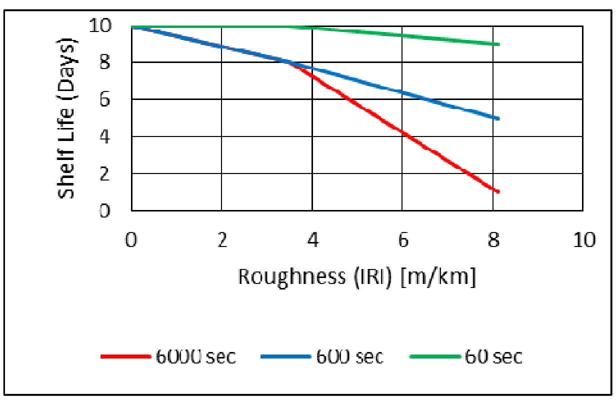


Figure 4-20: Experimental model for Green tomatoes, 2 layers.

4.5 REFERENCES

HunterLab, 2008. *HunterLab.* [Online]
Available at: www.hunterlab.com
[Accessed 24 October 2016].

5 DATA ANALYSIS

5.1 INTRODUCTION

The importance of infrastructure and the timely maintenance thereof was highlighted in the first chapter. Poor road conditions do not only influence the consumer but can have a negative impact on a country's economy.

One of the economic sectors that is especially negatively influenced by poor road conditions is the agriculture sector. In most cases the first road section on the journey from grower to fresh produce markets has a gravel surfacing.

Although the IRI scale was not specifically developed for trucks, data on road IRI is readily available and easy to measure. For this reason the IRI scale was used as a guideline for road condition.

Improper maintenance actions, or in severe cases no maintenance, has left these roads in high roughness conditions. High road roughness increases vehicle operating and maintenance costs.

The chances of delivering damaged produce to the market increases with an increase in roughness and it decrease the economic value of produce. This study therefore evaluates the influence of road condition on the quality of tomatoes that reach the consumer.

The first part of the experiment included the collection of field data. Several one km sections with different roughness values were identified. The lowest road roughness value (measured as IRI) was 0.74 m/km and die highest was 7.09 m/km.

For each of the sections the accelerometer data was assessed using the XLR8R software. A Fast Fourier Transform analysis was performed to give a Power Spectral Density graph. The area under the graph was determined using the midpoint rule to give the total energy.

Data from the pressure sensors indicated that with the increase in roughness the tomatoes are exposed to more stress cycles more frequently and the distribution of the force applied during the stress cycles also increases.

The accelerometer data that were collected during the laboratory analysis were used together with the field data to determine the relative roughness values of the different amplitude setting. This was done based on the total energy using the midpoint rule as presented in Section 4.2.5. Several limitations, as discussed in this section, were identified during the laboratory analysis.

The experimental model was designed based on a marketability matrix that models the decision of the consumer on whether to purchase a tomato or to not do so. Ultimately it is a subjective matter and each consumer would react differently towards the colour and firmness of the tomato in question.

5.2 FIELD DATA

5.2.1 Road sections

Several road sections were selected for analysis based on the average roughness value of the one km section. The roughness values along with the surface type and the condition category is presented in Table 5-1.

Table 5-1: Road section selection based on roughness.

Roughness (IRI) [m/km]	Surface Type	Condition
0.74	Surfaced	Good
1.60	Surfaced	Good
2.21	Surfaced	Good
2.22	Surfaced	Good
2.32	Surfaced	Good
2.46	Surfaced	Good
2.47	Surfaced	Good
2.53	Surfaced	Average
3.14	Gravel	Average
3.18	Surfaced	Average
3.54	Surfaced	Average
4.20	Gravel	Average
4.52	Gravel	Average
4.70	Surfaced	Average
5.16	Gravel	Poor
5.89	Gravel	Poor
6.26	Gravel	Poor
7.09	Gravel	Poor

The data sets were evaluated to determine if there is conformance to a normal distribution. Figure 5-1 shows the roughness distribution for a gravel road with an average roughness of 4.52 m/km. The distribution is bell shape but does not conform to the ideal normal distribution where 68 % of the data falls within the first standard deviation, 95 % of the data falls within the second standard deviation and 99.7 % falls within the third standard deviation. It is however still feasible to use the average as an indicator of the road condition because the distribution is bell shaped.

All of the road sections were assessed in this manner and all followed a normal distribution. It is interesting to note that the higher the average roughness value the wider the range of roughness values present in the distribution and the close it come to the ideal normal distribution.

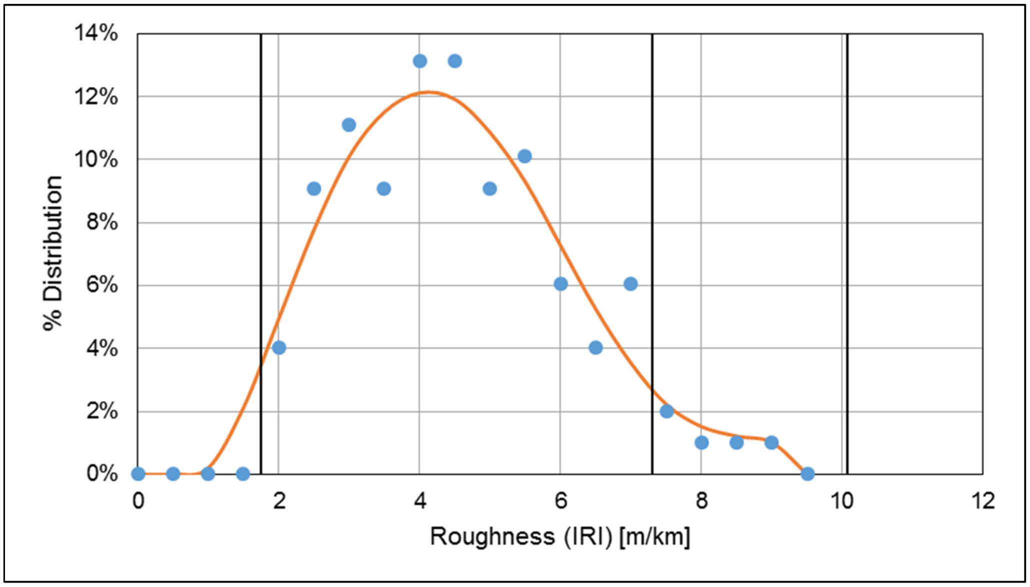


Figure 5-1: Normal distribution of roughness data for a gravel road with an average roughness of 4.52 m/km.

These 18 road sections were the foundation of the analysis for this project. A variety of roughness values and surface types were covered. Extreme roughness values were not noted on the road sections that were travelled and is therefore not included as part of this study. It would however be advised to consider extreme cases in future studies.

The maximum travelling speed of the vehicles was 80 km/h. The travelling speed does influence the outputs from accelerometer and pressure sensors. For future studies these effects should be considered.

5.2.2 Frequency and amplitude analysis

All of the accelerations measurements has a frequency and an amplitude. The frequency represents the amount of 'occurrences' every second and the amplitude represents the maximum displacement from the point of origin. Figure 5-2 shows the difference between frequency and amplitude. The frequency of Wave 1 is higher than that of Wave 2 and the Amplitude of Wave 2 is higher than that of Wave 1.

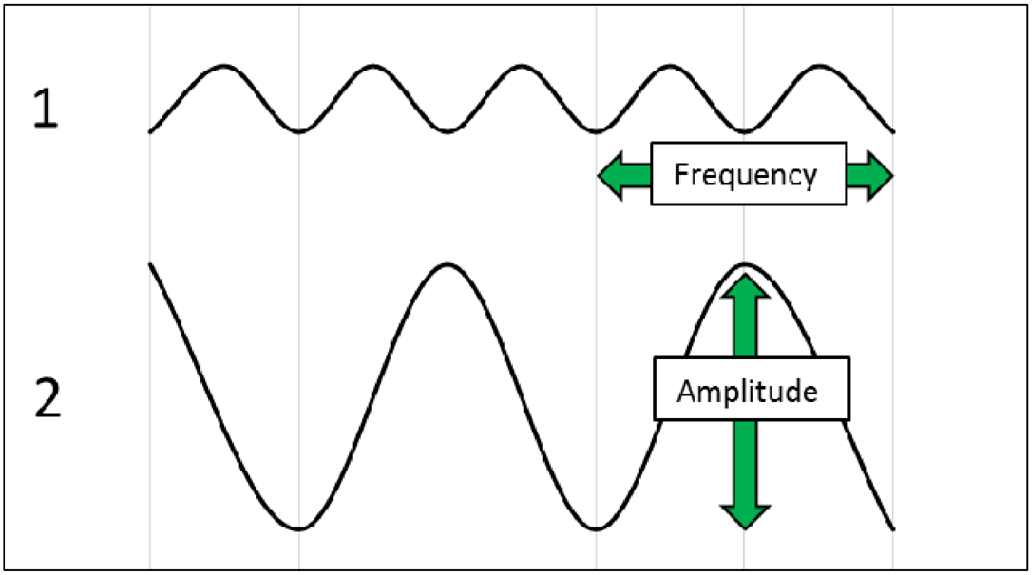


Figure 5-2: Frequency and amplitude.

5.2.2.1 Dominant frequencies

There were two frequencies identified from the PSD graphs that were perceived as dominant (Figure 5-3). These frequencies were:

- Around 2.5 Hz – body bounce frequency range; and
- Around 13 Hz – axle hop frequency range

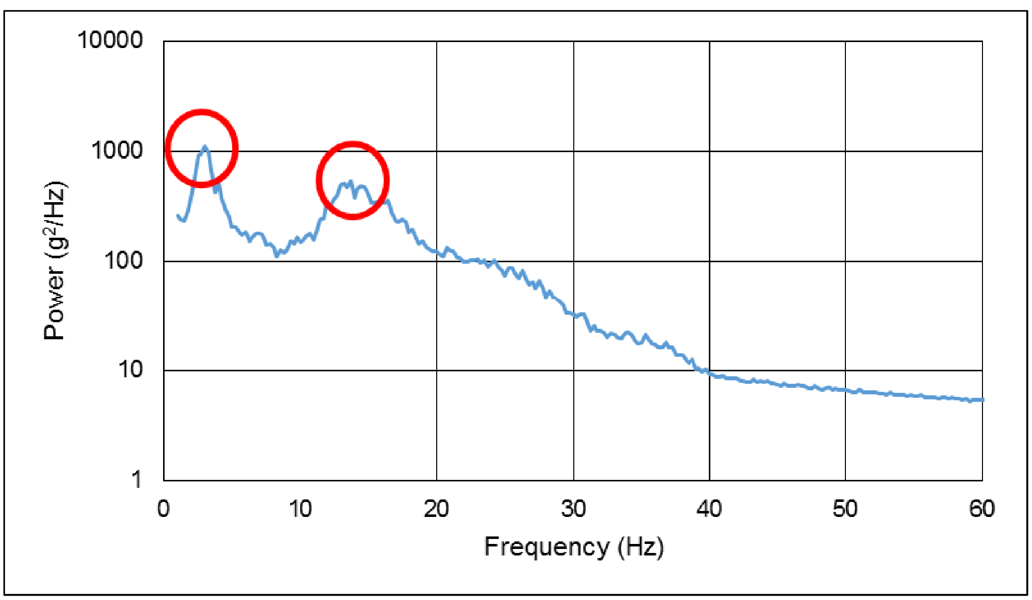


Figure 5-3: Power Spectral Density graph.

5.2.2.2 Total energy versus roughness

As shown in Figure 4-7 and Figure 4-8 there is a relationship between the highest power value on the PSD curves and the average roughness of the road sections. Figure 5-4 shows the relationship between power and frequency.

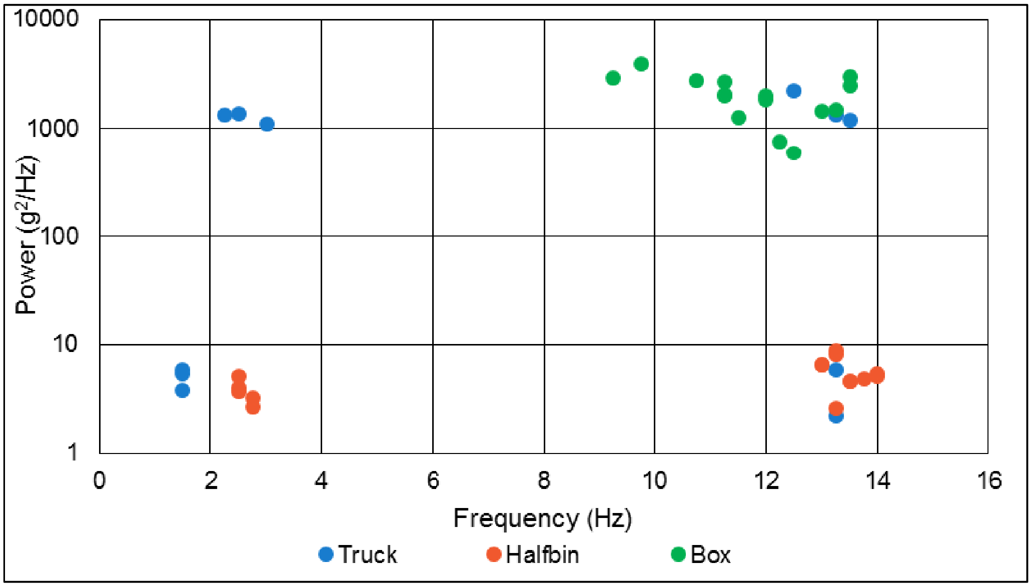


Figure 5-4: Comparison of frequency and power for the different road sections.

Figure 5-4 shows that the small boxes experience the high frequencies from axle hop as dominant. For the frequency and roughness value ranges of the small boxes the Z-axis power value is relatively high. The power value is a representation of the energy that the system absorbs, or put differently, a higher power value indicates that less energy is required for the system to accelerate vertically.

These findings are in line with previous studies done by O'Brien (1965), Berardinelli et al (2004), Jarimopas et al (2005) and Pretorius and Steyn (2012) indicating that although pallets unify a large amount of boxes, the boxes still respond individually to vertical accelerations (especially the top boxes of the pallet).

The half bins experience both body bounce and axle hop frequencies as dominant, although the power value is low. The half bins weigh significantly more than the small boxes and more energy is required to vertically accelerate the larger mass.

The accelerometers placed on the truck also experience body bounce and axle hop frequencies. Dependent on the speed and the position of the accelerometer, more or less energy is transferred to the system.

Although more energy is required to accelerate the half bins and the vertical movement of the bins are limited there are still internal pressures between the tomatoes in the different packaging that plays an important role during the development of a damage model. The bottom layer of the half bins has at least six to eight layers of tomatoes on top of it, whereas the small boxes only has two layers. It is expected that the tomatoes in the half bins would experience higher contact stresses than those in the boxes.

Due to the relationship between the power values and the road roughness the total energy was investigated. This linear correlation along with the 'R^2' value was computed using the trend line function in Microsoft Excel. A linear regression model is used to determine the position of the line. Two different graphs were developed. As previously discussed, the higher the mass the more energy would be required to accelerate the system vertically. The halfbins would therefore show smaller power values and the total energy that the system absorb would be less. Based on the available accelerometer data the two energy graphs are shown in Figure 5-5 and Figure 5-6.

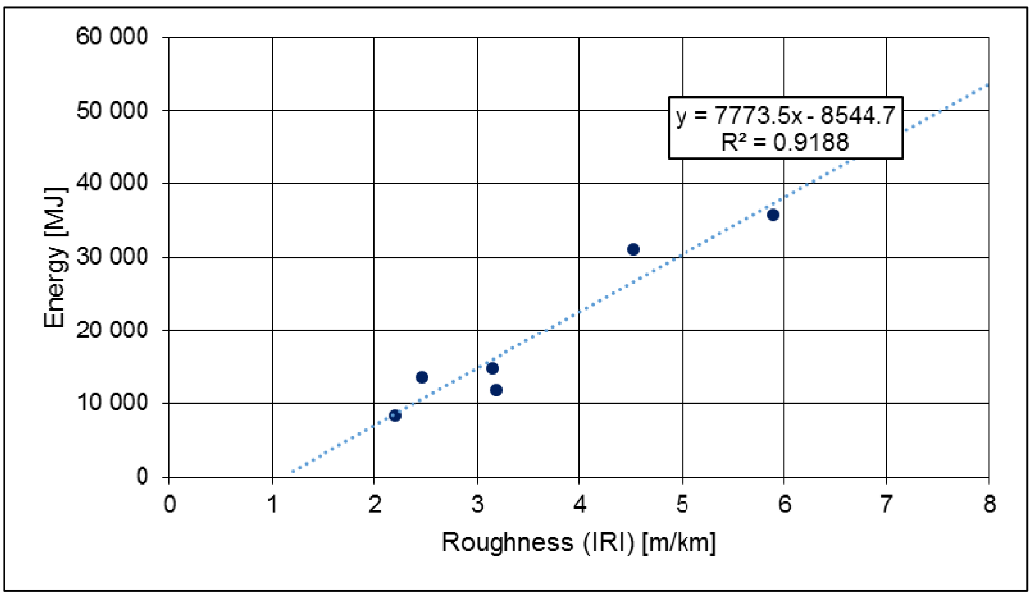


Figure 5-5: Energy versus roughness graph for small boxes.

For both the small boxes and halfbin a linear relationship exist between total energy and roughness. As the roughness of the road increased so did the total energy that the system is exposed to.

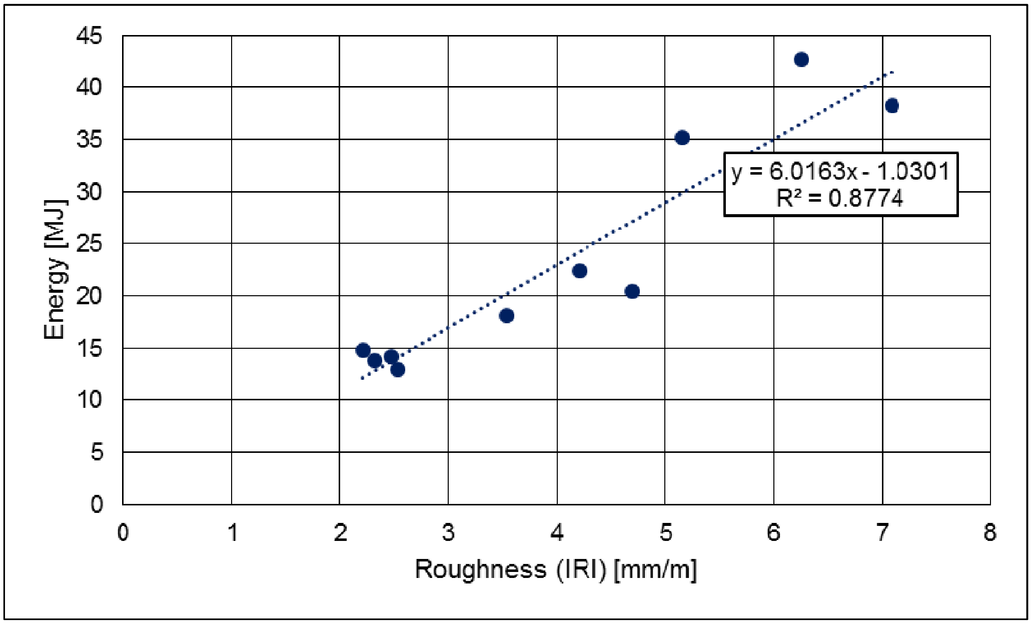


Figure 5-6: Energy versus roughness graph for halfbins.

5.2.3 Pressure analysis

Figure 5-7 show the field pressure analysis data. Six different data sets were collected. Three for the small boxes and three for halfbins containing green, pink and red tomatoes in each container. The data for the pressure sensor in the 'pink' small box were excluded from the analysis because the pressure sensor stopped functioning early during measurements.

From Figure 5-7 it can be seen that there is a linear correlation between frequency of pressure change and road roughness. This linear correlation along with the 'R^2' value was computed using the trend line function in Microsoft Excel. A linear regression model is used to determine the position of the line. As the roughness of the road increase the amount of pressure cycles that the tomatoes are exposed to increase accordingly. Tomatoes in halfbins are exposed to more pressure cycles when compared to tomatoes in small boxes. This could be because the tomatoes in the small boxes has a higher freedom of motion. They are not constrained by several tomatoes on top of them.

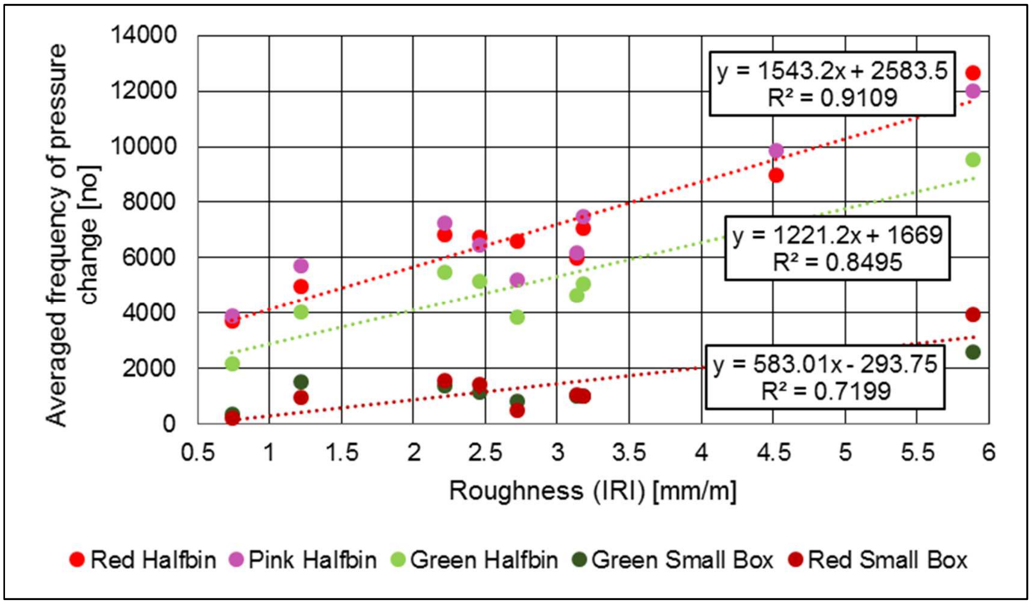


Figure 5-7: Frequency of pressure change versus roughness.

Roads in a poor condition does not only show higher pressure changes but the pressure changes are larger in magnitude. Table 5-2 shows the distribution of the magnitude of pressure change in accordance to the road roughness. From this table it can be concluded that the amount of pressure cycles that a tomato experiences increases as the roughness increases and the force distribution that is applied to the tomatoes becomes wider to include forces larger in magnitude.

Table 5-2: Distribution of pressure change.

Road Roughness (IRI) [mm/m]	Frequency of Pressure change (stress cycles)	% Pressure change in category		
		< 1 kPa	1.1 kPa - 3 kPa	>3 kPa
0.74	366	99%	1%	0%
2.46	1125	92%	8%	0%
3.14	1005	84%	15%	1%
4.52	1739	87%	12%	1%
5.89	2579	78%	19%	3%

5.3 LABORATORY DATA

5.3.1 Amplitude analysis

As described in Section 4.3.1 and Section 4.3.2 three amplitudes were selected for the laboratory analysis. Because of the nature of the experimental setup the energy versus road roughness graph from the small box analysis (Section 5.2.2.2) was used to calculate equivalent road roughness values as shown in Figure 5-8. This linear correlation along with the ‘R^2’ value was computed using the trend line function in Microsoft Excel. A linear regression model is used to determine the position of the line.

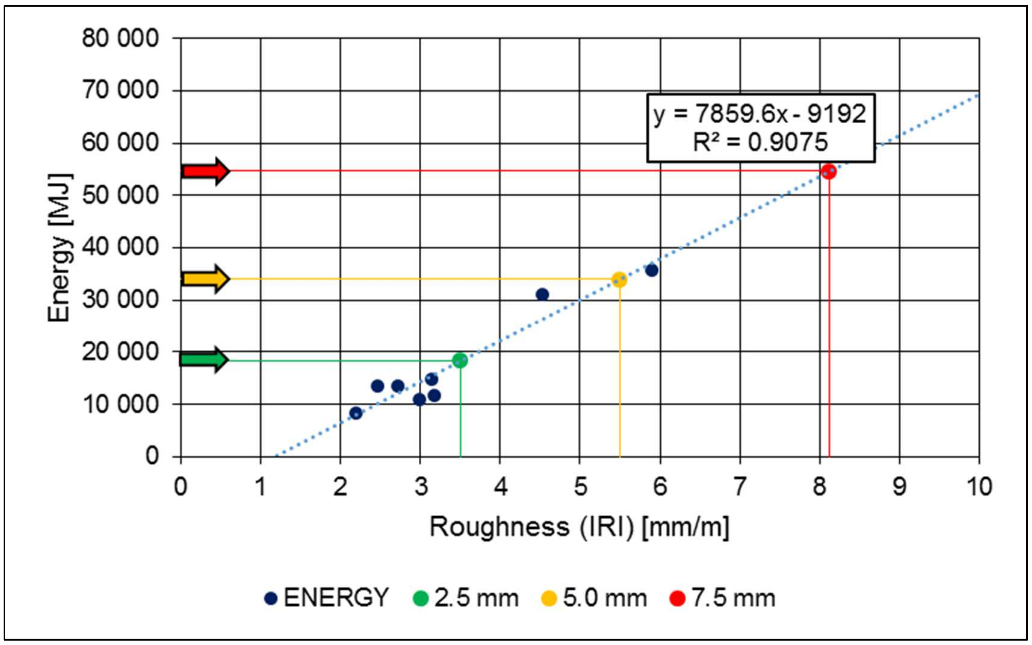


Figure 5-8: Calculation of roughness values using the total energy.

The linear relationship for small boxes were selected because the weight of the containers (filled with tomatoes) corresponds to that of a small box rather than a halfbin. Further evaluation in this regard would be required.

From the graph amplitudes of 2.5 mm, 5.0 mm and 7.5 mm equal field road roughness values of 3.50 m/km, 5.49 m/km and 8.12 m/km respectively.

5.3.1.1 Limitations

For the laboratory experiments the accelerations generated creates a constant predictable ‘wave’ as shown in Figure 5-2. The laboratory analysis was conducted at a frequency of 13 Hz.

It is however important to note the limitations when using a single frequency for laboratory experiments. As a truck travel over an irregular road surface it gives rise to a variety of frequencies, all at different amplitudes. Using a single frequency generates an expected number of events per second and all the events are equal in magnitude.

The comparison of PSD graphs for an amplitude of 2.5 mm and a roughness value of 3.14 m/km, which have similar energy outputs, are shown in Figure 5-9. It is imperative to note how different these distributions are, both having a dominant frequency of 13 Hz. This difference should be considered when analysing the pressure data.

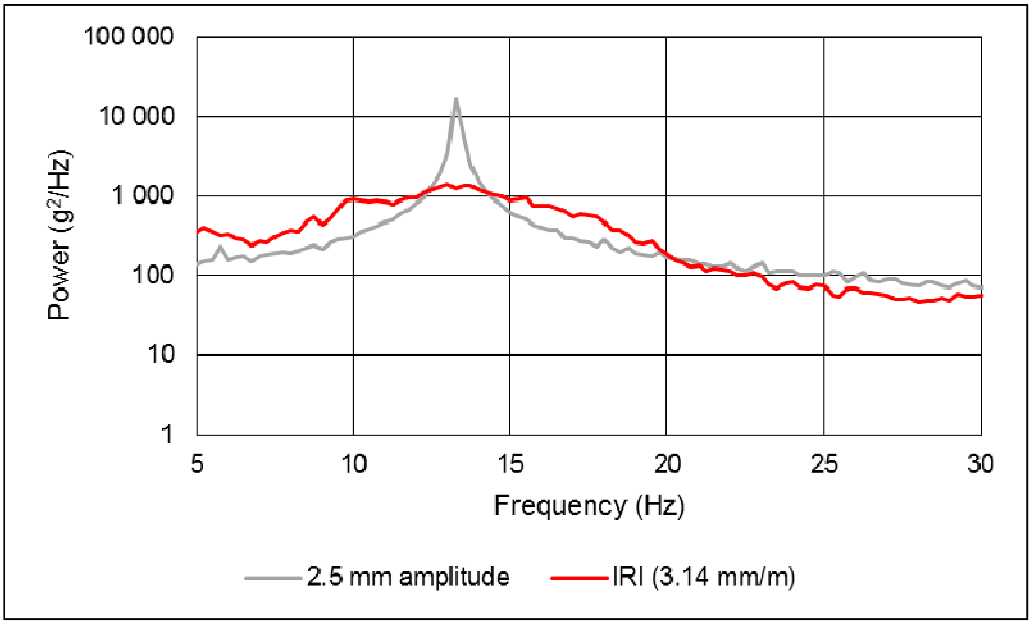


Figure 5-9: Comparison of field and laboratory PSD outputs.

5.3.2 Pressure Analysis

Figure 5-10 show the laboratory pressure analysis data. Three different data sets were collected. One data set for two layers, four layers and six layers stacked on top of each other.

From Figure 5-10 it can be seen that there is a linear relationship between frequency of pressure change and the amplitudes that were converted into road roughness. This linear correlation along with the 'R^2' value was computed using the trend line function in Microsoft Excel. A linear regression model is used to determine the position of the line. As the roughness of the road increased so did the amount stress cycles that tomatoes are exposed to when considering the two and four layer analysis. The six layer analysis behaves differently and the frequency of pressure change stays relatively constant irrespective of the road roughness. This behaviour differs from what was observed in the field analysis.

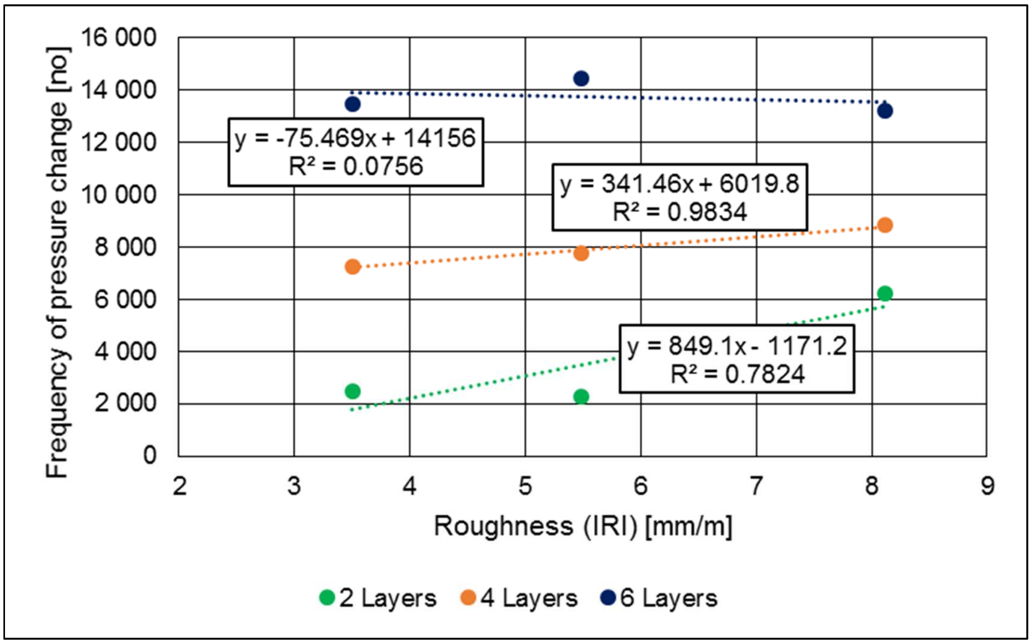


Figure 5-10: Frequency of pressure change versus roughness for laboratory analysis.

Table 5-3 contains the average magnitude of the pressure change for two, four and six layers as per two of the three amplitudes (presented as roughness values in the table).

There are two important factors to note:

- The first is that as the road roughness increased so did the average magnitude of the pressure change, and
- The second is that as the number of layers increase the average magnitude of the pressure change decrease.

This is in line with the information in the literature study. The fruit in the upper layers has more freedom of motion than the fruit in the bottom layers and tends to bruise more easily because of this.

Table 5-3: Average magnitude of pressure change for different roughness values.

Layers	Road roughness (IRI) [m/km]	
	3.5	8.12
2	4.26	13.75
4	1.88	2.01
6	0.002	1.27

5.3.2.1 Correlation between in-transit and laboratory pressures

The field and laboratory analysis for pressure data are presented in Figure 5-11. From this graph it can be seen that there is a similar relationship for the two layer laboratory analysis and the small box field analysis. The four layer laboratory analysis correlates closely with the halfbin field analysis except for the last data point as indicated by the green arrow in Figure 5-11.

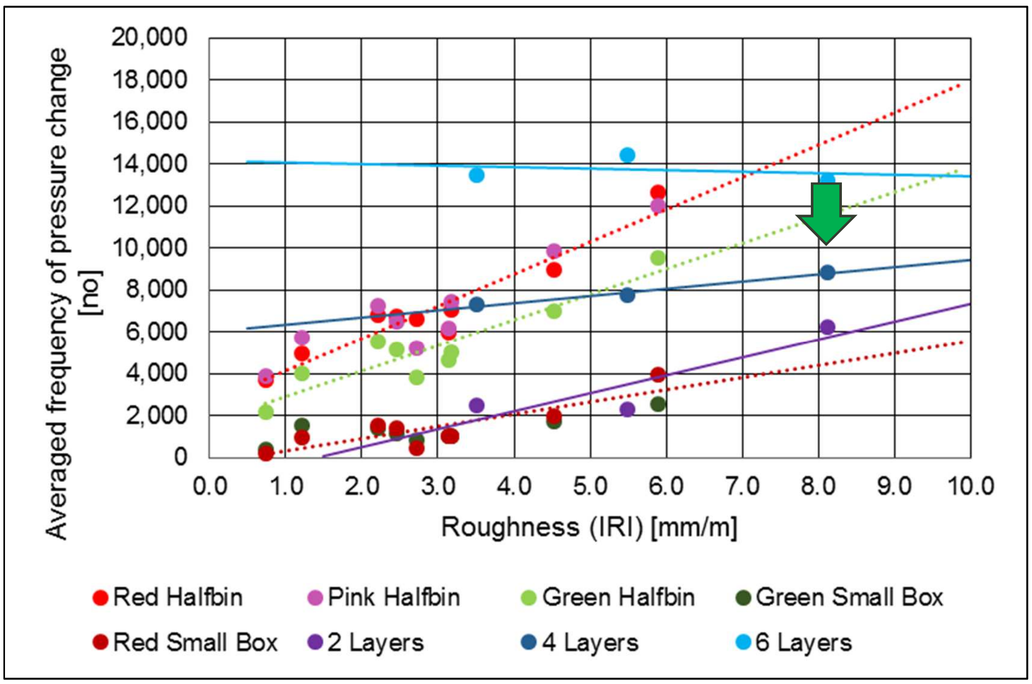


Figure 5-11: Correlation between field and laboratory pressure analysis.

For a visual comparison of the laboratory and field analysis refer to Figure 5-12, Figure 5-13 and Figure 5-14 on the next page. When considering the field data it is clear that the pressure on the tomatoes in the halfbins are more constant than those in the small boxes. This could be a result of the constraining effects of the layers of tomatoes placed on top of the tomatoes that were examined. These tomatoes do not have significant up and down motions and experience a relative constant pressure. The four and six layers analysis behave similar to the halfbin measurements and the two layers analysis behave in the same manner as the small box measurements.

In Section 5.2.3 it was stated that the frequency of pressure change is higher for halfbins than for small boxes. The amount of stress cycles is higher in the halfbins than in the small boxes but the applied stresses are smaller in the halfbins than in the small boxes.

There are however several differences between the laboratory and the field measurements. As can be seen from the four and six layers analysis and as previously mentioned, the single frequency used in the laboratory gives rise to a predictable pattern in the pressure graphs.

Peak to peak (or maximum pressure change) pressures for the two layers analysis are higher and more random than for the four and six layers analysis. This is similar to the small box analysis.

The pressure changes for the halfbins, four and six layers analysis are much more constant. It should be noted that the sensor used for the six layers analysis was less sensitive than for the two and four layers analysis and the pattern is therefore slightly different than expected.

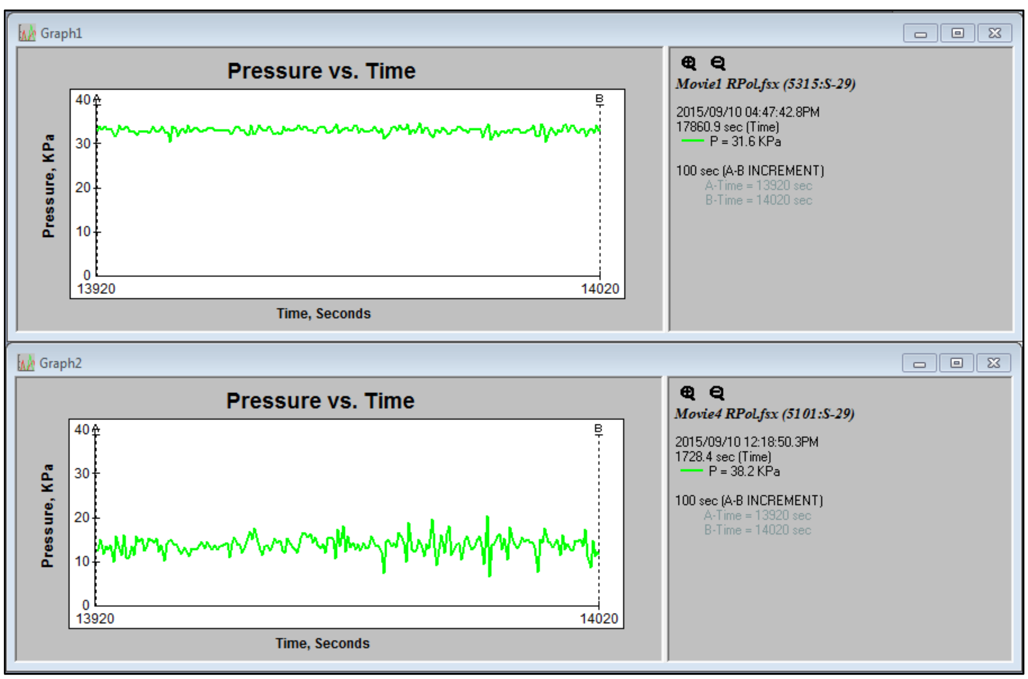


Figure 5-12: Visual representation of 100 seconds pressure measurements for a small box (top) and a halfbin (bottom).

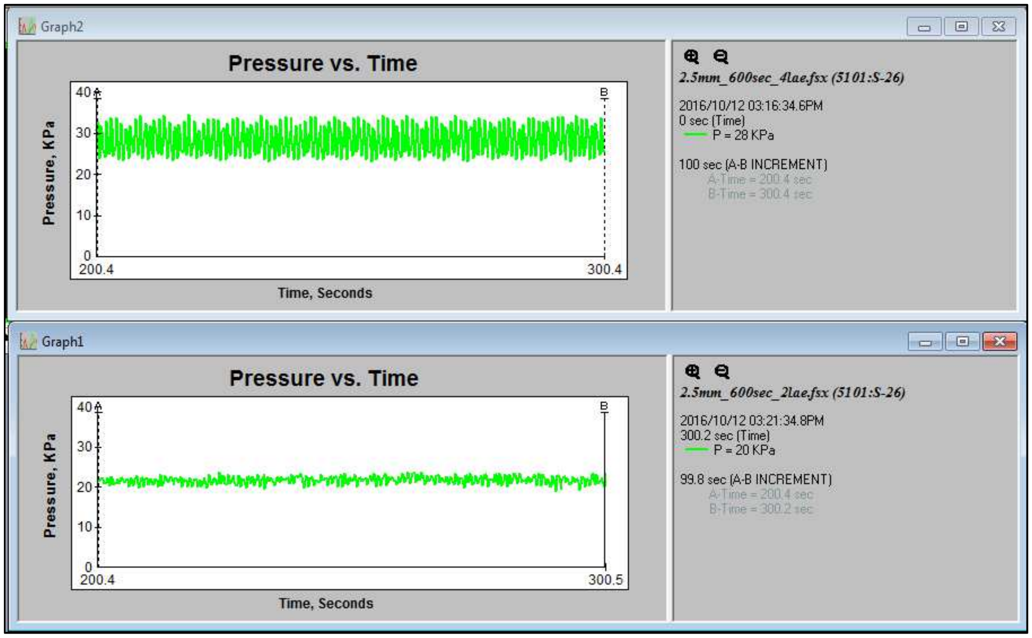


Figure 5-13: Visual representation of the pressure during ten seconds of the laboratory analysis for two (top) and four (bottom) layers.

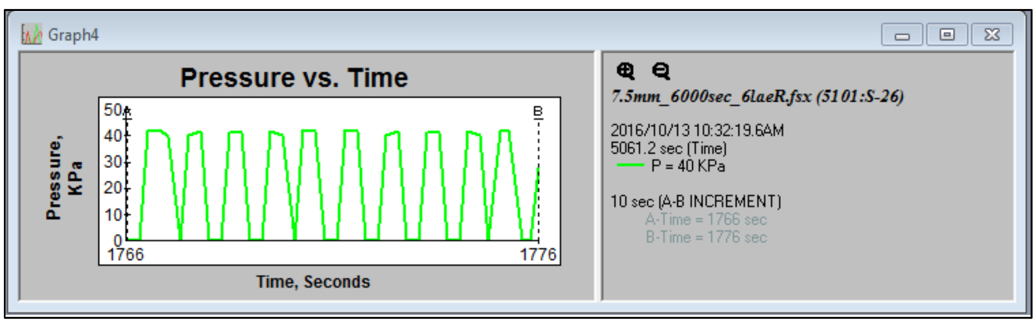


Figure 5-14: Visual representation of the pressure during ten seconds of the laboratory analysis for six layers.

5.3.2.2 Limitations

There are several limitations to consider during the laboratory pressure analysis. These limitations include but are not limited to the following:

- The frequency distribution of the laboratory experiment gives rise to predictable events as previously mentioned.
- The use of sand bags to represent the weight of tomatoes could jeopardise the accuracy of the pressure data because it behaves as a single unit whereas the behaviour of stacked tomatoes could differ. This was however done to limit the amount of tomatoes required for each experiment.

- The use of small containers during the laboratory experiment could be limiting as it behaves similar to small boxes. As seen in the field experiment the small boxes and halfbins respond differently to the energy input from V-PI.

- The frequency that was used to collect pressure data was set at 2 Hz. This differs to the frequency outputs from the laboratory and field experiment. Due to this difference it is possible that some events were not recorded.

5.4 COLOUR MEASUREMENT

5.4.1 Red tomatoes

After the laboratory analyses three of the red tomatoes from each experiment were selected and monitored for a period of 13 days. Four control tomatoes were selected before the analyses. The averages of the 'L', 'a' and 'b' readings for the three experimental tomatoes and the four control tomatoes were calculated. Figure 5-15 to Figure 5-18 show some of the results.

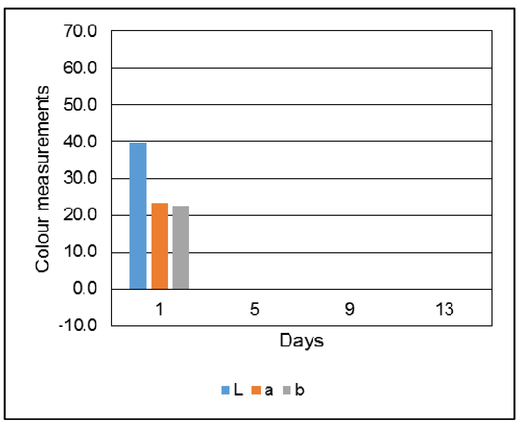


Figure 5-15: Colour measurement on 2 layers, 6000 seconds, 7.5 mm amplitude.

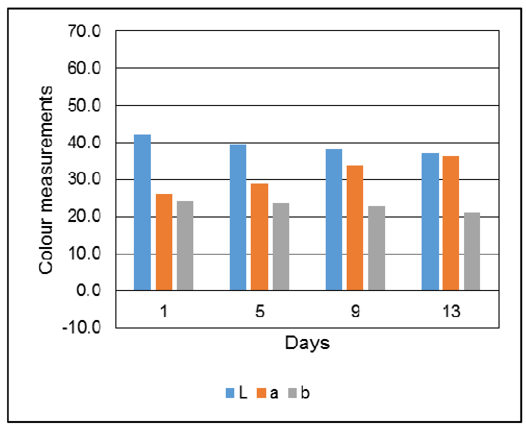


Figure 5-16: Colour measurements on 4 layers, 6000 seconds, 7.5 mm amplitude.

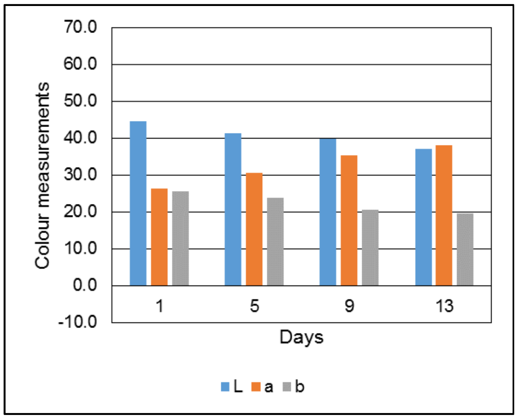


Figure 5-17: Colour measurement on 6 layers, 6000 seconds, 7.5 mm amplitude.

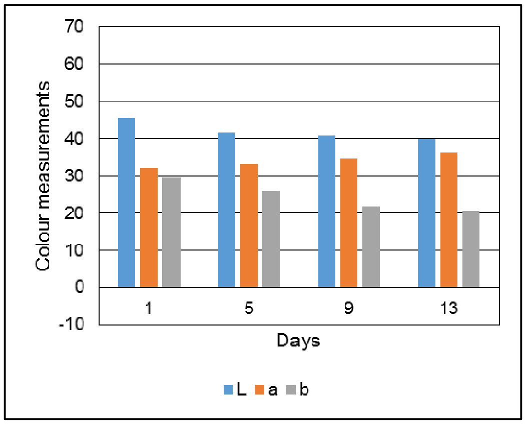


Figure 5-18: Colour measurement on control tomatoes.

There are small differences in the rate of colour change between bruised and control tomatoes but no clear trend was visible. Colour changes in bruised tomatoes are similar to the normal rate of non-bruised tomatoes. All colour measurement graphs for red tomatoes are presented in Appendix A.

5.4.2 Pink tomatoes

After the laboratory analyses four of the pink tomatoes from each experiment were selected and monitored for a period of 12 days. Five control tomatoes were selected before the analyses. The averages of the 'L', 'a' and 'b' readings for the four experimental tomatoes and the five control tomatoes were calculated. Figure 5-19 to Figure 5-22 show the results from one of the experiments.

No significant difference in the colour measurements were noted between the various analyses and the control tomatoes. Colour measurements were therefore inconclusive. The rate of colour change was calculated and are presented in Figure 5-23 to Figure 5-25. There are small differences in the rate of colour change between bruised and control tomatoes but no clear trend was visible.

Colour changes in bruised tomatoes are similar to the normal rate of non-bruised tomatoes. Section 4.3.5 addresses the gap in colour measurement data with a subjective consumer perspective model.

All colour measurement graphs for pink tomatoes are presented in Appendix B.

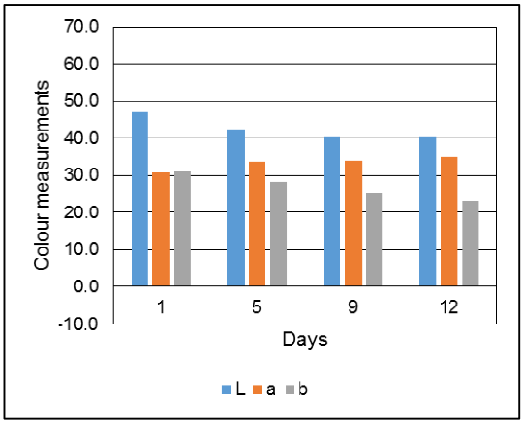


Figure 5-19: Colour measurement on 2 layers, 6000 seconds, 5.0 mm amplitude.

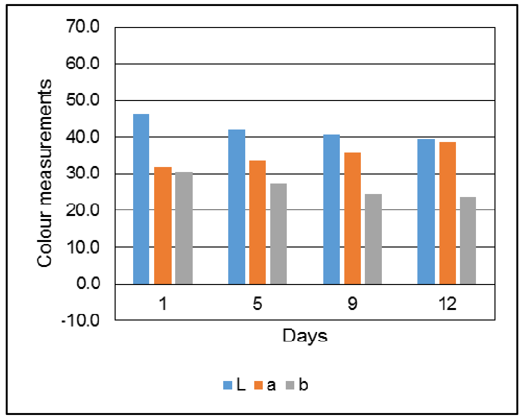


Figure 5-20: Colour measurement on 4 layers, 6000 seconds, 5.0 mm amplitude.

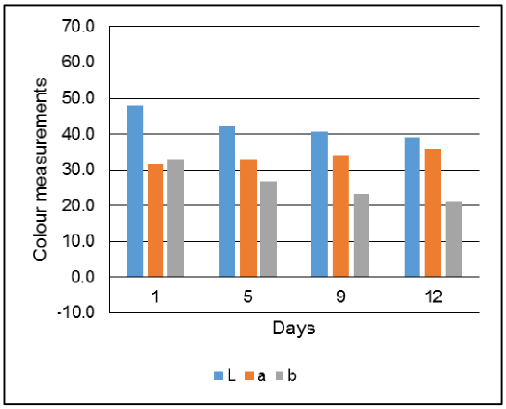


Figure 5-21: Colour measurement on 6 layers, 6000 seconds, 5.0 mm amplitude.

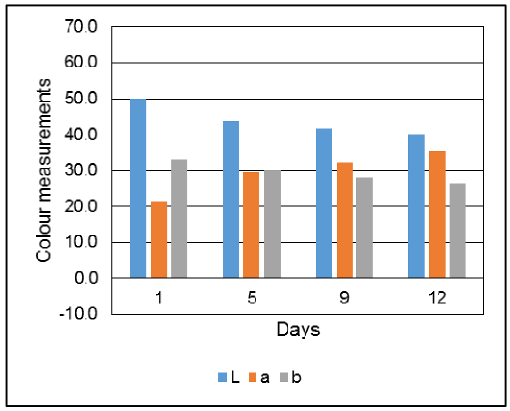


Figure 5-22: Colour measurement on control tomatoes.

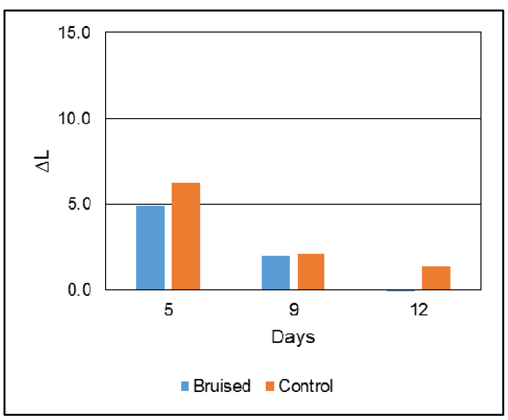


Figure 5-23: Change in L-parameter colour measurement for 2 layers, 6000 seconds, 5.0 mm amplitude.

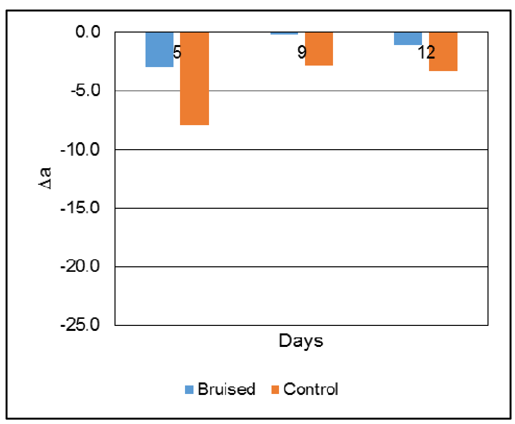


Figure 5-24: Change in a-parameter colour measurement for 2 layers, 6000 seconds, 5.0 mm amplitude.

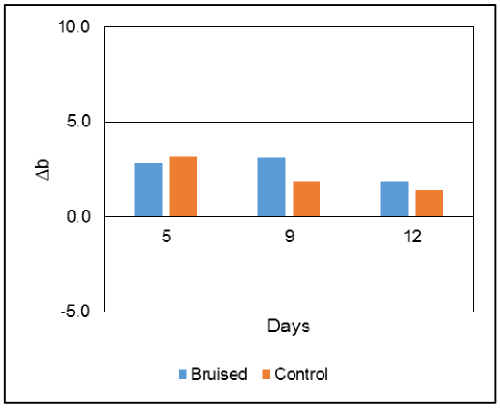


Figure 5-25: Change in b-parameter colour measurement for 2 layers, 6000 seconds, 5.0 mm amplitude.

5.4.3 Green tomatoes

After the laboratory analyses three of the green tomatoes from each experiment was selected and monitored for a period of 14 days. Four control tomatoes were selected before the analyses.

Two positions on all the tomatoes were monitored for colour changes. The first measurement was at the location of a bruise and the second was at a non – bruise location. The averages of the 'L', 'a' and 'b' readings for the three experimental tomatoes and the four control tomatoes were calculated. The 6000 sec and 7.5 mm amplitude; and the 60 sec 2.5 mm amplitude analysis are the two extreme cases that were evaluated and these findings are presented in Figure 5-26 to Figure 5-39.

Tomatoes in the two layer, 7.5 mm amplitude and 6000 sec analysis had grown mould on the damaged spots between day two and day six. These tomatoes were excluded from further measurements.

On average the tomatoes used for the 6000 sec and 7.5 mm amplitude has an 'L' measurement that is ten point lower for the bruised location than for the non – bruise location immediately after the experiment. The bruised tomatoes are therefore darker at some locations than the control tomatoes. This pattern does not continue for the entire analysis. Within a couple of days the control tomatoes have similar 'L' reading to the bruised tomatoes.

It is not only the 'L' factor that differs slightly for the bruised and non – bruise locations. For the 6000 sec and 7.5 mm amplitude analysis the 'a' value, which represent the green to red colour change, is on average 10 to 20 points higher for bruised tomatoes in comparison to the control tomatoes. Similar to the 'L' factor bruised and control tomatoes have ballpark values after a couple of days.

Figure 5-32 to Figure 5-37 show the data for the 60 second and 2.5 mm amplitude analysis. Only the 'a' value showed a significant difference between the bruised and the control tomatoes. For all of the other analyses concerning green tomatoes no other differences were noted. No duration seem to have a trend that relates to stress cycles.

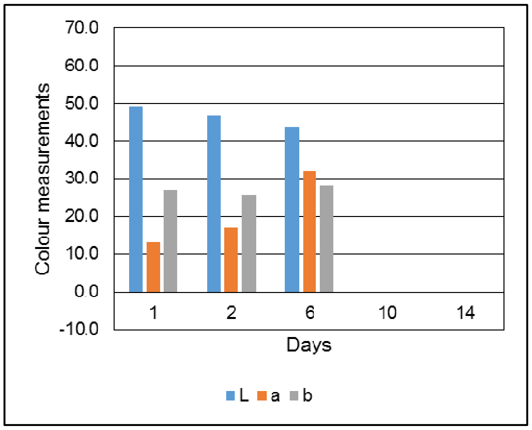


Figure 5-26: Colour measurement on 2 layers, 6000 seconds, 7.5 mm amplitude, bruised location.

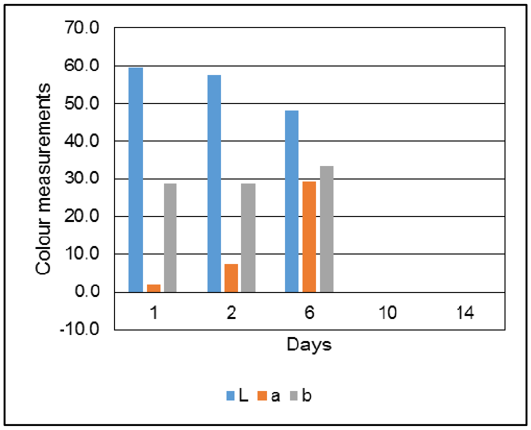


Figure 5-27: Colour measurement on 2 layers, 6000 seconds, 7.5 mm amplitude, non- bruise location.

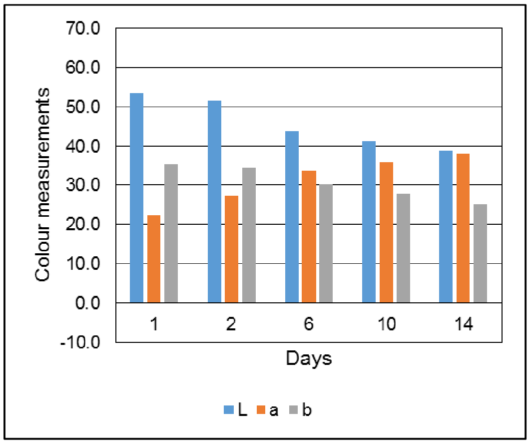


Figure 5-28: Colour measurement on 4 layers, 6000 seconds, 7.5 mm amplitude, bruised location.

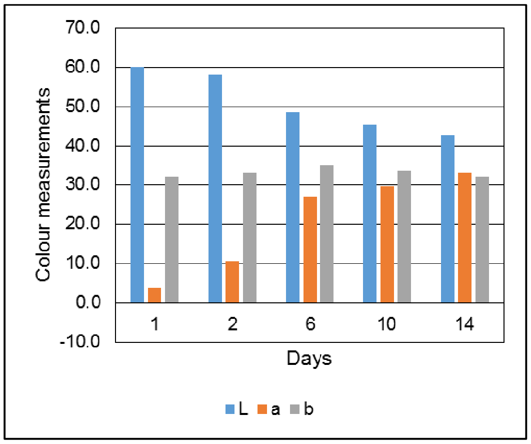


Figure 5-29: Colour measurement on 4 layers, 6000 seconds, 7.5 mm amplitude, non- bruise location.

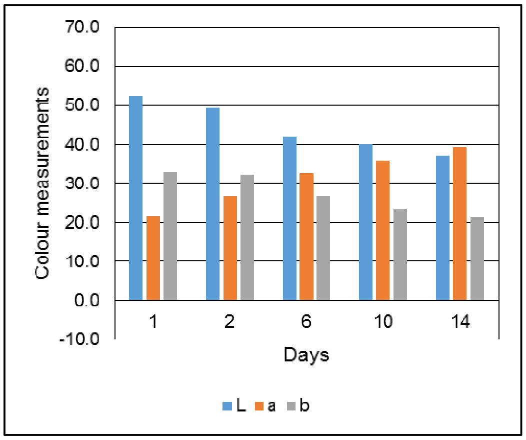


Figure 5-30: Colour measurement on 6 layers, 6000 seconds, 7.5 mm amplitude, bruised location.

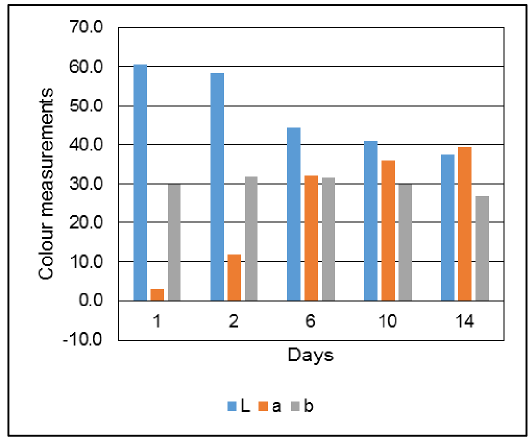


Figure 5-31: Colour measurement on 6 layers, 6000 seconds, 7.5 mm amplitude, non- bruise location.

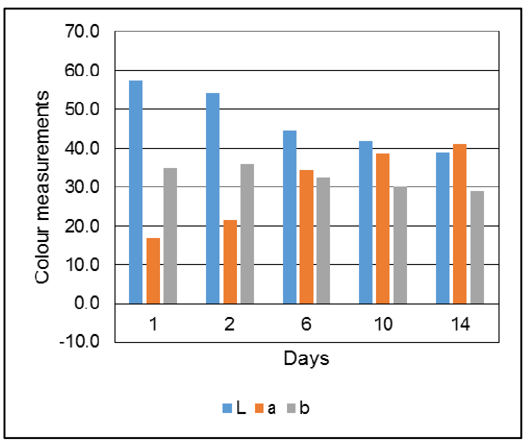


Figure 5-32: Colour measurement on 2 layers, 60 seconds, 2.5 mm amplitude, bruised location.

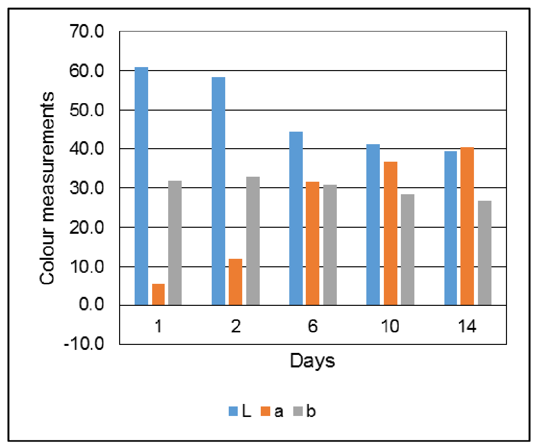


Figure 5-33: Colour measurement on 2 layers, 60 seconds, 2.5 mm amplitude, non - bruise location.

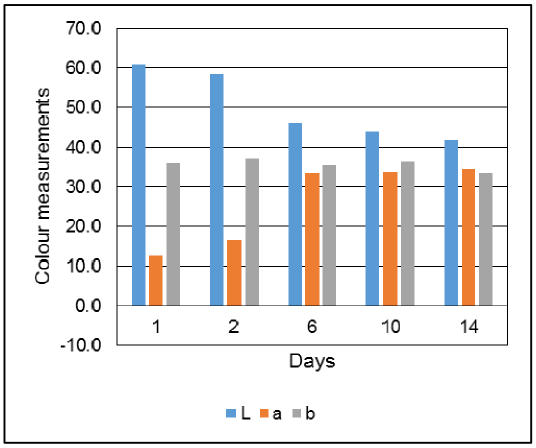


Figure 5-34: Colour measurement on 4 layers, 60 seconds, 2.5 mm amplitude, bruised location.

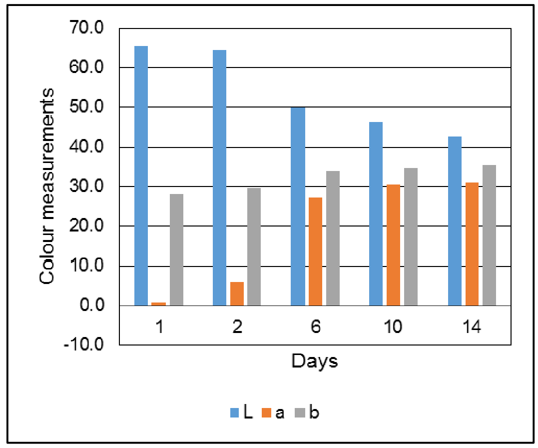


Figure 5-35: Colour measurement on 4 layers, 60 seconds, 2.5 mm amplitude, non - bruise location.

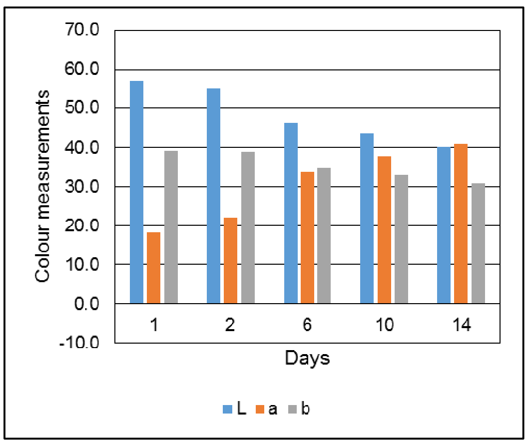


Figure 5-36: Colour measurement on 6 layers, 60 seconds, 2.5 mm amplitude, bruised location.

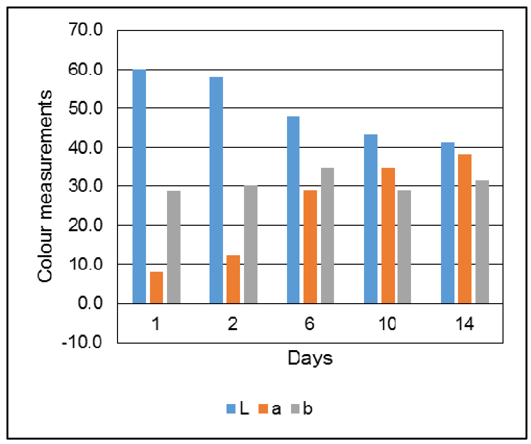


Figure 5-37: Colour measurement on 6 layers, 60 seconds, 2.5 mm amplitude, non - bruise location.

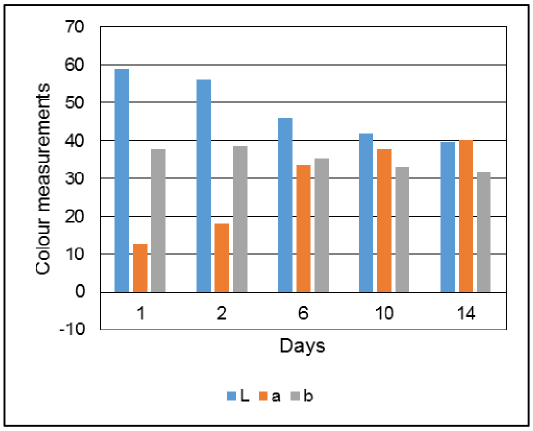


Figure 5-38: Colour measurements on control tomatoes, position one.

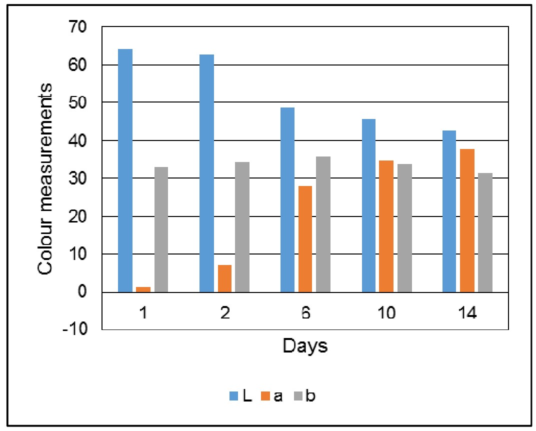


Figure 5-39: Colour measurements on control tomatoes, position two.

The rate of colour change was calculated and are presented in Appendix C. There are small differences in the rate of colour change between bruised and control tomatoes but no clear trend was visible. Colour changes in bruised tomatoes are similar to the normal rate of non-bruised tomatoes.

The colour measurements do not address the soft spots that appear on the tomatoes due to bruising. Figure 5-40 is an example of tomatoes with soft spots. Tomatoes such as these are less likely to be purchased by consumers and has lost economic value.

Figure 5-40: Identification of soft spots on tomatoes.

Although it is difficult to quantify ‘consumer perspective’ because it varies from one observer to the next, the marketability matrix attempts to bridge the gap between damage and shelf life.

5.5 CONSUMER PERSPECTIVE

A binary marketability matrix was constructed asking the question: "Would you purchase this tomato if it was on the retail shelf?" For a 'yes' answer the number '0' was allocated to the reading. If the answer is 'no' the number '1' was allocated. At least three people were asked their opinion regarding the marketability of the tomatoes.

The purpose of the marketability matrix was to address visual and firmness imperfections that goes unnoticed in the colour measurements. Table 5-4 shows the marketability matrix for the green and red tomatoes. The data from the marketability matrices were used to develop the experimental models as presented in Section 5.6.

Figure 5-41 and Figure 5-42 shows two of the issues that cannot be addressed during colour measurements.

Figure 5-41: Damaged pink tomato after 7.5 mm amplitude, 6000 second analysis.

Figure 5-42: Damaged pink tomato after 7 day: 5.0 mm amplitude, 6000 second analysis.

Figure 5-41 has a similar colour measurement to a pink tomato in perfect condition yet the firmness would hinder a consumer to make a purchase. The damaged tomato in Figure 5-42 is slightly darker in colour but the texture and firmness decreases its value to the consumer.

Table 5-4: Marketability matrix for green and red tomatoes (0 – 'Yes', 1 – 'No').

7.5_6000_R

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	1	1	1	0	0	0	0	0	0
5	1	1	1	1	0	0	0	0	0
9	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1

7.5_6000_G

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	1	1	1	0	0	0	0	0	0
2	1	1	1	0	1	0	0	0	0
6	1	1	1	1	1	0	1	0	1
10	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1

2.5_6000_R

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0	0	0	0	0	0	0	0	0
5	1	0	0	0	0	0	0	0	0
9	1	1	0	0	0	0	0	1	1
13	1	1	1	0	1	1	1	1	1

2.5_6000_G

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	1	0	0
10	1	1	1	0	0	1	1	0	1
14	1	1	1	1	1	1	1	1	1

7.5_600_R

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0	0	0	0	0	0	0	0	0
5	1	0	1	0	0	0	0	0	0
9	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1

7.5_600_G

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
6	0	1	1	0	0	0	0	0	1
10	1	1	1	1	0	0	1	1	1
14	1	1	1	1	1	0	1	1	1

2.5_600_R

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	1	0	0
9	1	1	0	0	0	1	1	1	0
13	1	1	1	1	1	1	1	1	1

2.5_600_G

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
6	0	0	1	0	0	0	0	0	0
10	0	0	1	0	0	0	0	0	1
14	1	0	1	1	0	0	0	1	1

7.5_60_R

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
9	1	1	1	0	1	0	0	0	0
13	1	1	1	1	1	1	1	1	1

7.5_60_G

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
14	1	0	0	1	0	0	0	1	1

2.5_60_R

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
9	1	1	0	0	0	0	0	1	0
13	1	1	1	1	1	1	1	1	1

2.5_60_G

Day	2 Layers			4 Layers			6 Layers		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0	0	0
14	1	0	1	0	0	0	0	0	0

5.6 EXPERIMENTAL MODEL

The purpose of the experiment was to estimate the loss in shelf-life due to the roughness of the road. In Figure 5-43 to Figure 5-45 the shelf life (or loss thereof) is shown on the Y-axis and the roughness is shown on the X-axis. The red, blue and green lines represent the duration of travel in seconds.

5.6.1 Red tomatoes

Figure 5-43 to Figure 5-45 shows the results of the marketability matrix analysis for the red tomatoes. The tomatoes in the two layer analysis has lost significant shelf life especially when tested at high amplitudes and over longer time periods. The tomatoes in the six layer analysis has the highest remaining shelf life after the analysis.

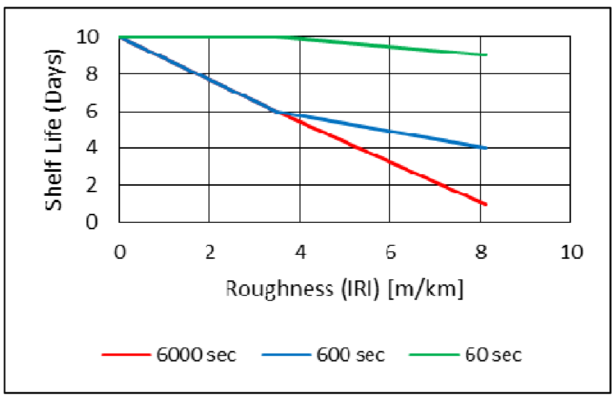


Figure 5-43: Shelf life prediction for Red tomatoes in the 1st and 2nd layers.

6000 seconds:

y = - 1.11 x + 9.95

600 seconds:

y = - 1.14 x + 10.0 for x ≤ 3.5

y = - 0.43 x + 7.52 for x > 3.5

60 seconds:

y = 10.0 for x ≤ 3.5

y = - 0.22 x + 10.76 for x > 3.5

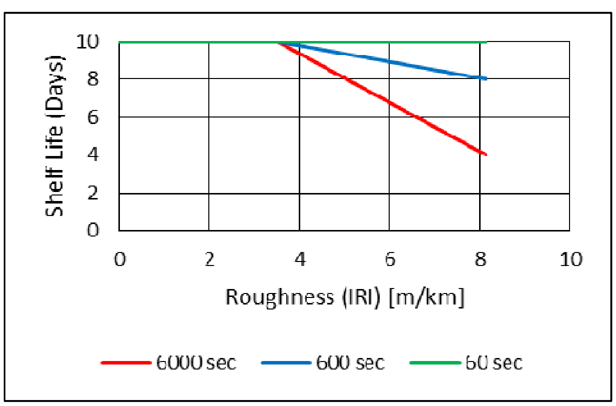


Figure 5-44: Shelf life predicted for Red tomatoes in the 3rd and 4th layers.

6000 seconds:

y = 10.0 for x ≤ 3.5

y = - 1.30 x + 14.55 for x > 3.5

600 seconds:

y = 10.0 for x ≤ 3.5

y = - 0.43 x + 11.52 for x > 3.5

60 seconds:

y = 10.0

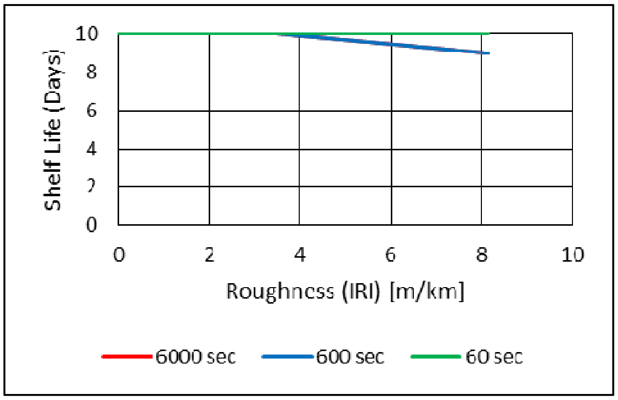


Figure 5-45: Shelf life prediction for Red tomatoes in the 5th and 6th layers.

6000 seconds:

y = 10.0 for x ≤ 3.5

y = - 0.22 x + 10.76 for x > 3.5

600 seconds:

y = 10.0 for x ≤ 3.5

y = - 0.22 x + 10.76 for x > 3.5

60 seconds:

y = 10.0

It is possible that tomatoes in halfbins that are positioned deeper than six layers could suffer more or equal amounts of damage than tomatoes positioned in the upper layers (first to fifth). A study by Van Linden et al. (2006) compared the probability of bruise development with the contact time for various levels of impact energy. Longer contact times and higher impact energies are more likely to develop into a bruise.

Contact time is influenced by the maturity of the fruit where red-ripe tomatoes had longer contact times than green tomatoes.

Tomatoes in the lower layers could acquire damage due to the loading of the tomatoes above and the lack of cell wall firmness.

5.6.2 Pink tomatoes

Figure 5-46 to Figure 5-48 shows the results of the marketability matrix analysis for the pink tomatoes. The tomatoes in the two layer analysis has lost significant shelf life especially when tested at high amplitudes and over longer time periods.

The tomatoes in the four and six layer analysis has the highest remaining shelf life after the analysis. The pink tomatoes behave similarly to the green tomatoes.

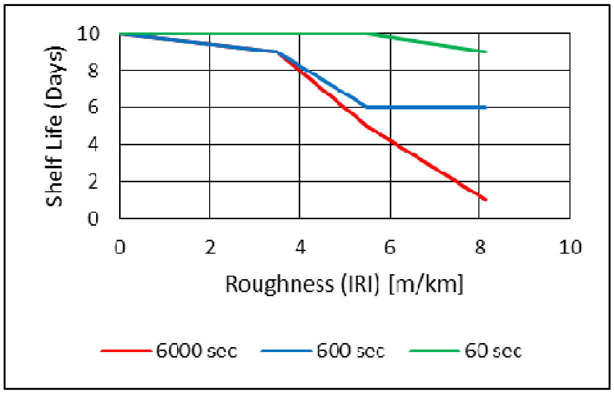


Figure 5-46: Shelf life prediction for Pink tomatoes in the 1st and 2nd layers.

6000 seconds:

y = - 0.29 x + 10.0 for x ≤ 3.5

y = - 1.73 x + 15.06 for x > 3.5

600 seconds:

y = -0.29 x +10.0 for x ≤ 3.5

y = - 1.51 x + 14.28 for 3.5 > x ≥ 5.49

y = 6 for x > 5.49

60 seconds:

y = 10.0 for x ≤ 5.49

y = -0.38 x +12.09 for x > 549

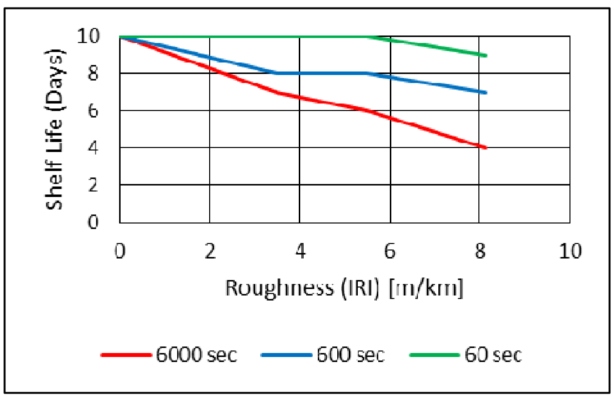


Figure 5-47: Shelf life predicted for Pink tomatoes in the 3rd and 4th layers.

6000 seconds:

y = - 0.73 x + 9.86

600 seconds:

y = - 0.57 x + 10.0 for x ≤ 3.5

y = 8 for 3.5 > x ≥ 5.49

y = - 0.38 x + 10.09 for x > 5.49

60 seconds:

y = 10.0 for x ≤ 5.49

y = - 0.38 x + 12.09 for x > 5.49

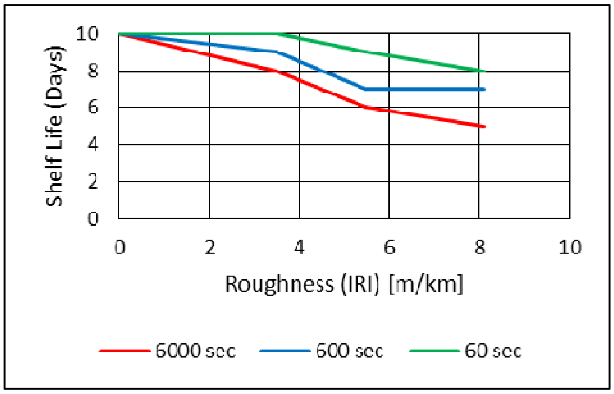


Figure 5-48: Shelf life prediction for Pink tomatoes in the 5th and 6th layers.

6000 seconds:

y = - 0.73 x + 10 for x ≤ 5.49

y = - 0.38 x + 10.33 for x > 5.49

600 seconds:

y = - 0.29 x + 10.0 for x ≤ 3.5

y = - 1.01 x + 12.52 for 3.5 > x ≥ 5.49

y = 7 for x > 5.49

60 seconds:

y = 10.0 for x ≤ 3.5

y = - 0.43 x + 11.52 for x > 3.5

5.6.3 Green tomatoes

Figure 5-49 to Figure 5-51 shows the results of the marketability matrix analysis for the green tomatoes. The tomatoes in the two layer analysis has lost significant shelf life especially when tested at high amplitudes and over longer time periods. The tomatoes in the four and six layer analysis has the highest remaining shelf life after the analysis.

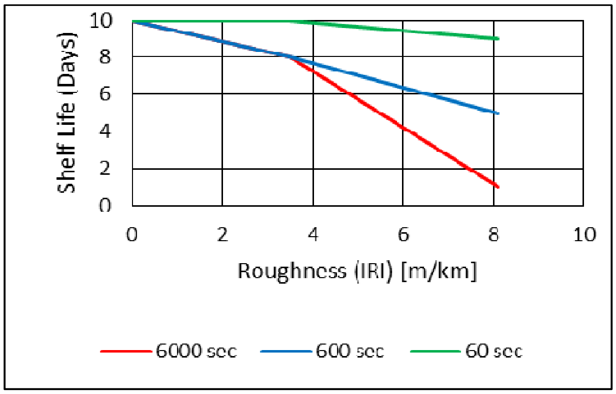


Figure 5-49: Shelf life prediction for Green tomatoes in the 1st and 2nd layers.

6000 seconds:

y = - 0.57 x + 10.0 for x ≤ 3.5

y = - 1.52 x + 13.3 for x > 5.49

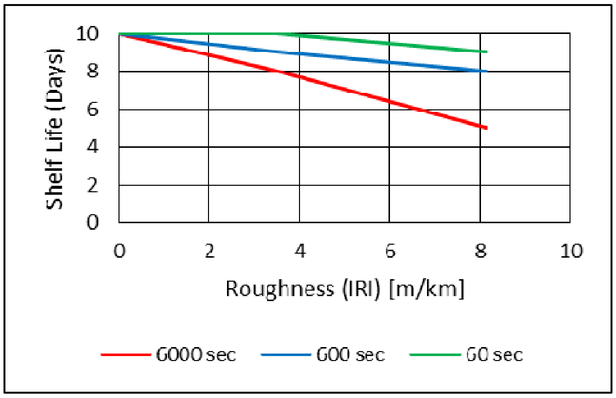
600 seconds:

y = - 0.62 x + 10.06

60 seconds:

y = 10.0 for x ≤ 3.5

y = - 0.22 x + 11.73 for x > 3.5



6000 seconds:

y = - 0.62 + 10.06

600 seconds:

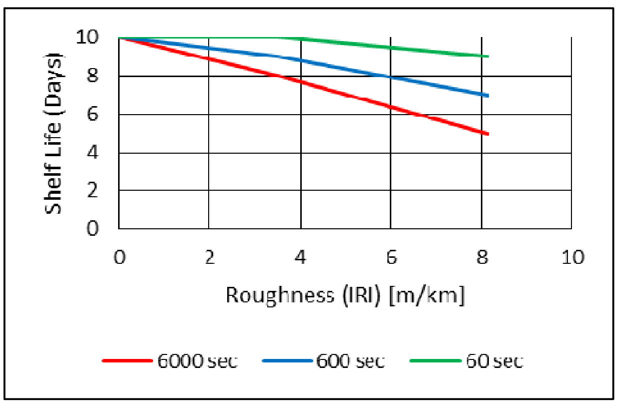
y = - 0.24 x + 9.95

60 seconds:

y = 10.0 for x ≤ 3.5

y = - 0.22 x + 10.76 for x > 3.5

Figure 5-50: Shelf life prediction for Green tomatoes in the 2nd and 3rd layers.



6000 seconds:

y = - 0.62 + 10.06

600 seconds:

y = - 0.37 x + 10.11

60 seconds:

y = 10.0 for x ≤ 3.5

y = - 0.22 x + 10.76 for x > 3.5

Figure 5-51: Shelf life prediction for Green tomatoes in the 5th and 6th layers.

5.6.4 Conclusion

When the green and the red tomatoes are compared it is clear that the green tomatoes are more likely to be damaged in the lower layers than the red tomatoes. If red tomatoes are placed in the lower layers the lack of firmness allows the fruit to absorb more energy before damage becomes visible.

The red tomatoes show more damage in the two layer analysis than the green tomatoes. In Section 2.6.2 it was highlighted that Van Linden et al. (2006) and Van Zeebroeck et al. (2007) concluded that physical damage increase with ripeness. Van Zeebroeck et al. (2007) reported that the bruising of tomatoes are affected by the contact time.

Contact time is influenced by the maturity of the fruit. When the 2 layer analysis was completed, the red tomatoes had significant freedom of motion in the upper layers. The freedom of motion combined with the increase in contact time would result in more bruise damage.

The pink tomatoes behaved in a similar manner than the green tomatoes. Both the Green and pink tomatoes has stiff sell wall structure and the contact time during collisions is less than for red tomatoes.

It is important to be aware of the limitations as mentioned throughout this study and caution should be used when interpreting these models. Further research and refinement of the models is required.

5.7 SUMMARY

Several data sets were collected as part of this study to find a connection between the damage to tomatoes and the roughness of the road. Although the study had various limitations that should be addressed the results proofed that there is a connection between road roughness and potential damage to tomatoes.

For roads with high roughness values (IRI > 8 m/km), which mostly consist of farm roads that are poorly maintained, all tomatoes in the first and second layers would acquire significant damaged irrespective of the maturity of the fruit.

A method to address this issue would be to reduce the travelling speed. This would result in smaller amplitudes, decreasing the energy input to the tomatoes. For the best results it is however advisable to maintain gravel roads. This would lead to a decrease in produce damage as well a decrease in vehicle maintenance and operating costs. A cost benefit analysis can also be done to weigh the maintenance cost against loss of income.

On well-maintained roads with roughness values less than 3.5 m/km Red tomatoes in the top layers tend to damage more with an increase in time as compared to tomatoes in the lower layers. Green and Pink tomatoes are more resistant to damage in the top layers than the Red tomatoes. It is therefore advisable when using halfbins to transport Red tomatoes in the lower layers and Green and Pink tomatoes in the upper layers.

From the damage models it is apparent that as the roughness of the road increases the damage to tomatoes increase as well. With this information in hand logistic planners can make informed decisions during route planning in weighing transportation costs to the cost of losses to produce during transportation.

5.8 REFERENCES

Berardinelli, Donati, V; Giunchi, A; Guarnieri, A; Ragni, L., 2005. Damage to pears caused by simulated transport. *Journal of food engineering,* Volume 66, pp. 219-266.

Jarimopas, B., Singh, S. P. & Saengnil, W., 2005. Measurement and analysis of truck transport vibration levels and damage to packaged tangerines during transit. *Packaging technology and science,* 18(4), p. 179.

O'Brien, M., Centry, P. J. & Gibson , R. C., 1965. Vibrating characteristics of fruit as related to in-transit injury. *Transactions of ASAE,* Volume 8, pp. 241-243.

Pretorius, C. J. & Steyn, WJvdM., 2012. *The influence of road roughness on the transportation of fresh produce.* Pretoria, Southern African transport Conference .

Van Linden, V., Scheerlinck, N., Desmet, M. & De Baerdemaeker, J., 2006. Factors that affect tomato bruise development as a result of mechanical impact. *Postharvest Biology and Technology,* Volume 42, pp. 260-270.

Van Zeebroeck, M; Van Linden, V; Darius, P; De Ketelaere, B; Ramon, H; Tijskens, E., 2007. The effect of fruit properties in the bruise susceptibility of tomatoes. *Postharvest Biology and Technology,* Volume 45, pp. 168-175.

6 CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

Income maximisation is the core practise of all commercial businesses. Due to the fragile nature of fresh produce, especially tomatoes, it is important to control the factors that influence the premature deterioration of the product.

Trucks are one of the best methods for transporting perishable products because of shorter transport times and the ability to reach more inland destinations than any other mode of transport (Chonhenchob et al., 2009; Jarimopas et al., 2005).

The relationship between economic growth and infrastructure investment became a well-studied topic in the late 1980s and early 1990s. Transportation infrastructure can be viewed as one of the most valuable assets.

Various authors investigated the effects of deteriorating road conditions. Chonhenchob et al. (2009) and Jarimopas et al (2005) showed that roads in a poor condition increase damage to fresh produce. Steyn & Bean (2009) indicated the effect of bad roads on vehicle operating and maintenance costs. Viljoen (2009) highlighted the contribution of poor road condition to fatal road accidents. Heggie (1995) highlighted the capital cost involved in replacing poorly maintained roads and the importance of a managing structure to ensure timely maintenance and rehabilitation of roads. These are some of the direct and indirect costs of deteriorating roads to consider not to mention that if road maintenance is delayed for longer than five years the cost to repair the pavement increase from six to eighteen times (SAICE, 2011).

The focus of this study was on the influence of road roughness on the quality and shelf life of tomatoes. This study has proven that the amount of stress cycles that tomatoes are exposed to on the road from grower to fresh produce market increases as the roughness of the road increase.

The distribution of the magnitude of the applied force becomes wider as the roughness of the road increase. The end result of this study is a subjectively developed model that links the consumer choice to purchase a tomato from a retail shelf to the condition of the road. This model can be refined as discussed in the text, however it can be used to support basic logistic decisions and operations.

6.2 CONCLUSION

The objective of this study as formulated in the general introduction included the investigation of the relationship between riding quality and tomato damage, the effect that the maturity of tomatoes has on the amount of damage and the role that two different packaging types played as method to contain produce during shipment between two points.

6.2.1 Relationship between roughness and damage

Three different amplitudes correlating to roughness values of 3.5 m/km, 5.49 m/km and 8.12 m/km were used to evaluate the effect of road roughness during a laboratory analysis.

This study indicated that as the roughness of the road increased so did the damage to the transported tomatoes, irrespective of the maturity of the fruit and its position within the package.

These finding are supported by several other studies by authors including Jarimopas et al. (2005) and Chonhenchob et al. (2009).

6.2.2 Relationship between maturity and damage

Three different stages of tomato maturity were investigated during the analysis. Tomato maturity was based on the skin colour which was defined as red, pink and green. It was not clear that a certain maturity would acquire damage on all accounts. The effect of maturity should be considered jointly with the position in the package.

On well-maintained roads with roughness values less than 3.5 m/km red tomatoes in the top layers tend to damage more with an increase in time as compared to tomatoes in the lower layers.

Green and pink tomatoes are more resistant to damage in the top layers than the red tomatoes.

6.2.3 Relationship between layer depth and damage

On all accounts, irrespective of the maturity of the fruit, the highest loss in shelf life was visible in the upper layers. This in in line with the findings by Jarimopas et al. (2005) and O'Brien et al. (1965).

For different combinations of frequencies and amplitudes, fruit can experience vibrations approaching 1.0 g. This can cause rotation, rubbing, skin discolouration and breakdown of surface tissue (O'Brien et al. 1965).

6.2.4 Summary

In conclusion, the consumer perspective on the marketability of tomatoes are difficult to measure however it is possible to give an indication of the magnitude and the amount of forces applied to tomatoes during transportation.

A subjective model was developed to determine how the shelf life of tomatoes are affected by road condition. This information is vital during logistic operations.

It is important to be aware of the limitations mentioned throughout this study.

Further research and refinement of the models is possible.

6.3 RECOMMENDATIONS

The following recommendations should be considered when continuing this research:

- The travel speed influences the measured accelerations and frequencies. This influence should be studied by varying the speed.
- To supplement the laboratory results, sections with known roughness values could be used and in-transit damaged tomatoes could be monitored to develop the damage prediction models.
- The effect of other frequencies should be investigated.
- For the laboratory analysis individual tomatoes should be used instead of the sand bags for the higher number of levels of tomatoes.
- A firmness test along with colour measurements should be considered to refine the damage prediction model

6.4 LIMITATIONS

Limitations were identified during this study. These limitations include but are not limited to the following:

- The frequency distribution of the laboratory experiment gives rise to predictable 'events'. The field data include a variety of frequencies which makes the 'events' unpredictable and the exact modelling thereof impossible.
- The use of sand bags to represent the weight of tomatoes could jeopardise the accuracy of the pressure data because it behaves as a single unit whereas the behaviour of stacked tomatoes could differ. This was however done to limit the amount of tomatoes required for each experiment.
- The use of small containers during the laboratory experiment could be limiting as it behaves similar to small boxes. As seen in the field experiment the small boxes and halfbins respond differently to the energy input from vehicle- pavement interaction.

- The frequency that was used to collect pressure data was set at 2 Hz. This differs to the frequency outputs from the laboratory and field experiment. Due to this difference it is possible that some 'events' were not recorded.
- Colour measurements are limited in its ability to predict damage to tomatoes although differences were noted between damaged tomatoes and the control tomatoes.
- The marketability matrix and the experimental models are subjective rating and could differ from one consumer to the next.

6.5 REFERENCES

Chonhenchob, V. & Singh, S. P., 2005. Packaging performance comparison for distribution and export of papaya fruit. *PackagingTechnology and Science,* Volume 18, pp. 125-131.

Heggie, I. G., 1995. *Managing and Financing of Roads, an Agenda for Reform,* Washington D. C.: World Bank Technical Paper number 275.

Jarimopas, B., Singh, S. P. & Saengnil, W., 2005. Measurement and analysis of truck transport vibration levels and damage to packaged tangerines during transit. *Packaging technology and science,* 18(4), p. 179.

O'Brien, M., Centry, P. J. & Gibson , R. C., 1965. Vibrating characteristics of fruit as related to in-transit injury. *Transactions of ASAE,* Volume 8, pp. 241-243.

SAICE, 2011. *SAICE Infrastructure Report Card*. [Online]
Available at: www.saice.co.za
[Accessed 21 July 2016].

Steyn, WJvdM. & Bean, W. L., 2009. Cost of bad roads to the economy. *6th State of Logistics Survey*, p. 24. CSIR, Pretoria.

Viljoen, N., 2009. Logistics Costs. *9th State of Logistics Survey*, pp. II-IV.

7 REFERENCES

ASCE, 2013. *Infrastructure Report Card.* [Online]
Available at: http://www.infrastructurereportcard.org/a/#p/roads/conditions-and-capacity
[Accessed 10 October 2016].

Aschauer, D. A., 1989. Is Public Expenditure Productive?. *Journal of Monetary Economics,* 23(2), pp. 177-200.

Bennet, A. B., 2002. Biochemical and genetic determinantsof cell wall disassembly in ripening fruit: a general model. *Hortscience,* Volume 37, pp. 3-6.

Berardinelli, Donati, V; Giunchi, A; Guarnieri, A; Ragni, L., 2005. Damage to pears caused by simulated transport. *Journal of food engineering,* Volume 66, pp. 219-266.

Bourne, M. C., 1977. Post harvest food losses - the neglected dimension in increasing the world food supply. *Cornell International Agricalture Mimeograph,* Volume 53, pp. 20-27.

Boyer, R. & McKinney, J., 2013. *Food Storage Guidelines for Consumers,* Virginia: Virginia Polytechnic Institute and State University.

Boyette, M. D., Sanders, D. C. & Rutledge, G. A., 1996. *North Carolina Department of Commerce.* [Online]
Available at: http://www.bae.ncsu.edu/programs/extension/publicat/postharv/ag-414-8/index.html
[Accessed 6 January 2011].

Canada Infrastructure, 2016. *CSCE.* [Online]
Available at: https://csce.ca/wp-content/uploads/2016/01/CIRP-2016-full-report.pdf
[Accessed 10 October 2016].

Cervantes-Godoy, D. & Dewbre, J., 2010. *Economic importance of agriculture for poverty reduction,* France: OECD Publishing.

Chonhenchob, V. & Singh, S. P., 2003. A comparison of corrugated boxes and re-usable plastic containers for mango distribution. *PackagingTechnology and Science,* Volume 16, pp. 231-237.

Chonhenchob, V. & Singh, S. P., 2005. Packaging performance comparison for distribution and export of papaya fruit. *PackagingTechnology and Science,* Volume 18, pp. 125-131.

Chonhenchob, V; Sittipod, S; Swasdee, D; Rachtanapun, p; Singh, S P; Sing, J., 2009. Effect of truck vibrations during transport on damage to fresh produce shipment in Thailand. *Journal of Applied Packaging Research,* 3(1), pp. 27-38.

COTO, 2007. *Guidelines for Network Level Measurement of Road Roughness,* South Africa: Committee of Transport Officials.

Dhar, R. & Seidel, K., 2012. *Packaging for Organic Foods.* [Online]
Available at: http://www.intracen.org/projects/tccep/publications/
[Accessed 5 August 2016].

Directorate Statistics and Economic Development, 2013. *Economic Review of the South African Agriculture,* Pretoria: Department of Agriculture, Forestry and Fisheries.

Fernald, J., 1999. Assessing the link between Public Capital and Productivity. *American Economic Review,* 89(3), pp. 619-638.

FHO, 1979. *Recommended practices for the prevention of mycotoxins in food, feed, and their products,* Rome: Food and Agricultural Organisation of the United Nations.

FSAI, 2014. *Guidance Note No. 18 Validation of Product shelf-life.* 2 ed. Dublin: Food Safety Authority of Ireland.

Gast, K. L. B., 1991. *Containers and Packaging Fruits & Vegetables,* Kansas: Kansas State University.

GCDC, 2016. *GC data concepts.* [Online]
Available at: www.gcdataconcepts.com
[Accessed 23 August 2016].

Gillespie, T. D., 1992. *Fundamentals of vehicle dynamics,* Warrendale: Society for Automotive Engineers.

Gramlich, E. M., 1994. Infrastructure Investment: A Review Essay. *Journal of Economic Literature,* Volume 32, pp. 1176-1196.

Harris, S. R., 1988. *Food and Agriculture Organisation.* [Online]
Available at: http://www.fao.org/wairdocs
[Accessed 6 January 2011].

Havenga, J H; Simpson, Z P; King, D; de Bod, A; Braun, M,., 2016. *Logistics Barometer South Africa,* Stellenbosch: Stellenbosch University.

Heggie, I. G., 1995. *Managing and Financing of Roads, an Agenda for Reform,* Washington D. C.: World Bank Technical Paper number 275.

Hinsch, R. T., Slaughter, D. C., Craig, W. L. & Thompson, J. F., 1993. Vibration of fresh fruits and vegetables durung refrierated truck transport. *American Society of Agricultural Engineers,* 36(4), pp. 1039-1042.

Holt, J. E., Schoorl, D. & Lucas, C., 1981. Prediction of bruising in impacted multilayered apple packs. *Transactions of the American Society of Agricultural Engineers,* 24(1), pp. 242-247.

HunterLab, 2008. *HunterLab.* [Online]
Available at: www.hunterlab.com
[Accessed 24 October 2016].

HunterLab, 2016. *HunterLab.* [Online]
Available at: http://www.hunterlab.com/miniscan-ez-user-manual.pdf
[Accessed 05 September 2016].

International Monetary Fund, 2016. *International Monetary Fund.* [Online]
Available at: http://www.imf.org/external/pubs/ft/weo/2016/01/weodata
[Accessed 12 July 2016].

Ittmann, H., 2013. Logistics Infrastructure Capacity. *10th State of Logistics Survey*, pp. 27-57.

Jarimopas, B., Singh, S. P. & Saengnil, W., 2005. Measurement and analysis of truck transport vibration levels and damage to packaged tangerines during transit. *Packaging technology and science,* 18(4), p. 179.

Joubert, U., 2013. The logistics piece in the economic puzzle. *10th State of Logistics survey*, pp. 2-12.

Kader, A. A., Morris, L. L., Stevens, M. A. & Albright-Holton, M., 1978. Composition and Flavor Quality of Fresh Market Tomatoes as Influenced by Some Postharvest Handling Procedures. *Journal of American Society for Horticultural Science,* 103(1), pp. 6-13.

Kannemeyer, L., 2014. *CSIR.* [Online]
Available at: www.csir.co.za/Built environment/Transport infrastructure/
[Accessed 04 September 2016].

Kasmire, R. F. & Kader, A. A., 1978. Handling tomatoes at wholesale and retail: a guide for better quality and greater profits. *Outlook,* 5(3), pp. 5-12.

Ligon, E. & Sadoulet, E., 2008. *Estimating the effects of aggregate agricultural growth on the distribution of expenditured,* s.l.: World Bank.

Limpert, R., 1982. *Vehicle system components. Design and safety..* New York: Wiley.

Litman, T., 2010. *Evaluating Transportation Economic Development Impacts,* Victoria: Victoria Transport Policy Institute.

Li, Z., 2013. The effect of compressibility, loading position and probe shape on the rupture probability of tomato fruits. *Journal of food engineering,* Volume 119, pp. 417-476.

Martin, W. & Warr, P. G., 1990. *The Declining Economic Importance of Agriculture,* Australia: Research School of Pacific Studies.

Media Club South Africa, 2016. *Media Club South Africa.* [Online]
Available at: http://www.mediaclubsouthafrica.com/africa/37-economy/economy-bg/111-sa-economy-key-sectors#agriculture
[Accessed 13 July 2016].

Mizrach, A., 2007. Nondestructive ultrasonic monitoring of tomato quality during shelf-life storage. *Postharvest Biology and Technology,* Volume 46, pp. 271-274.

Mohsenin, N. N., 1986. *Physical Properties of Plant and Animal Material. Structure, Physical Characteristics and Mechanical Properties..* New York: Gordon and Breach Science Publishers Inc.

Nasrin, T A A; Molla, M M; Hossaen, A; Alam, M S; Yasmin, L., 2008. Effect of Postharvest Treatments on the Shelf-life and quality of tomato. *Bangladesh Journal of Agricultural Research,* 33(3), pp. 579-585.

Nation Master, 2016. *Nation Master.* [Online]
Available at: http://www.nationmaster.com/country-info/stats/Transport/Highways/Total/Per-capita
[Accessed 12 July 2016].

National Economic Council, 2014. *An Economic Analysis of Transportation Infrastructure Investment,* Washington: The White House.

O'Brien, M., Centry, P. J. & Gibson , R. C., 1965. Vibrating characteristics of fruit as related to in-transit injury. *Transactions of ASAE,* Volume 8, pp. 241-243.

O'Brien, M; Claypool, L L; Leonard, L L; York, G K; MacGillivray, J H., 1963. Causes of fruit bruising on transport trucks. *Hilgardia,* 35(6), pp. 113-124.

Papagiannakis, A. T. & Gujarathi, M. S., 1995. Roughness Model Describing Heavy Vehicle-Pavement Interaction. *Transportation Research Record*, Volume 1501, pp. 50-59.

Pavement Interactive, 2007. *Pavement Interactive.* [Online]
Available at: http://www.pavementinteractive.org/
[Accessed 25 07 2016].

PaveTesting, 2016. *PaveTesting.* [Online]
Available at: http://www.pavetesting.com/high-speed-profilometer
[Accessed 13 August 2016].

Pereira, A. M. & Andraz, J. M., 2012. On the Regional Incidence of Highway Investment in the USA. *Annual of Regional Science,* Volume 48, pp. 819-838.

Poonyth, D., Hassan, R., Kirsten, F. J. & Calcaterra, M., 2001. *Is agriculture sector growth a precondition for economic growth? The case of South Africa,* Pretoria: University of Pretoria.

Pretorius, C. J., 2011. *The influence of road roughness on the transportation of fresh produce. BEng Dissertation,* Pretoria: University of Pretoria.

Pretorius, C. J. & Steyn, WJvdM., 2012. *The influence of road roughness on the transportation of fresh produce.* Pretoria, Southern African transport Conference .

Pretorius, F. J., 1990. *The dynamic effects of vehicles on flecible pavements, MEng Dissertation,* Stellenbosch: University of Stellenbosch.

RAL, 2015. *Annual Report 2014/15,* s.l.: Roads Agency Limpopo.

SAICE, 2011. *SAICE Infrastructure Report Card.* [Online]
Available at: www.saice.co.za
[Accessed 21 July 2016].

SANRAL, 2016. *The South African National Roads Agency.* [Online]
Available at: http://www.nra.co.za/live
[Accessed 21 July 2016].

Sayers, M. W., Gillespie, T. D. & Paterson, W. D. O., 1986. *Guidelines for Conducting and Calibrating Road Roughness Measurements,* Washington D C: World Bank.

Sayers, M. W. & Karamihas, S. M., 1998. *The little book of profiling,* s.l.: The Regent of the University of Michigan.

Schoorl, D. & Holt, J. E., 1982. Road-vehicle-load interactions for transport of fruit and vegetables. *Agricultural Systems,* Volume 8, pp. 143-155.

Schuur, C. M. M., 1998. *Agricultural Organisation of the United Nations.* [Online]
Available at: http://www.fao.org/docrep/x5016e/x5016e00.html
[Accessed 6 January 2011].

Spectral Dynamics, 2010. *Spectral Dynamics.* [Online]
Available at: http://www.spectraldynamics.com
[Accessed 22 September 2016].

Steyn, WJvdM., 2010. *Some effects of inadequate road maintenance on traffic loads.* Somerset West, SARF/IRF Regional Conference for Africa.

Steyn, WJvdM., 2011. *Evaluation of Effects of Road Maintenance Actions on Applied Tyre-Loads.* Kwa-Zulu Natal, 10th Conference on Asphalt Pavements for Southern Africa.

Steyn, WJvdM. & Bean, W., 2012. The potential effects of deteriorating road conditions in South Africa. *9th State of Logistics survey*, pp. 30-38. CSIR, Pretoria.

Steyn, WJvdM., Bean, W., King, D. & Komba, J., 2011. *Evaluation of Selected Effects of Pavement Riding Quality in Logistics Costs in South Africa. .* Transportation Research Board Volume 2227, pp. 138-145. Washington, Transportation Research Board.

Steyn, WJvdM. & Bean, W. L., 2009. Cost of bad roads to the economy. *6th State of Logistics Survey*, p. 24. CSIR, Pretoria.

Steyn, WJvdM., Bean, W. L., Pretorius, C. J. & Van der Walt, G., 2011. The Potential Effects of Bad Roads on Transported Cargo. *8th Logistics Survey*, pp. 11-12. CSIR, Pretoria.

Steyn, WJvdM. & Coetzer, S., 2014. *ZZ2 Evaluation and Produce Damage - Final Report,* Pretoria: University of Pretoria.

Steyn, WJvdM. & Monismith, C. L., 2010. *Analysis of Vehicle-Pavement Interaction Effects on Vehicular Loads and Transported Cargo, Prepared for University of California Pavement Research Centre. UC Davis & Berkley.* California: California Department of Transportation.

Studman, C., 1997. *Factors affecting the bruise susceptibility of fruit..* Reading, University of Reading, pp. 273-281.

Tatom, J. A., 1991. Public Capital and Private sector Performance. *Federal Reserve Bank of St. Louis Review,* Volume 73, pp. 3-15.

TCGF, 2010. *A Global Language for Packaging and Sustainability. A framework and a measurement system for our industry.,* France: Lssy-les-Moulineaux.

Tekscan, 2016. *Tekscan.* [Online]
Available at: www.tekscan.com
[Accessed 23 August 2016].

The Heritage Foundation, 2016. *2016 Index of Economic Freedom.* [Online]
Available at: http://www.heritage.org/index/country/southafrica
[Accessed 12 July 2016].

The World Factbook, 2016. *The World Factbook.* [Online]
Available at: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2085rank.html
[Accessed 12 July 2016].

Tigist, M., Workneh, T. S. & Woldetsadik, K., 2013. Effect of variety on the quality of tomato stored under ambient conditions. *Journal of Food Science and Technology,* 50(3), pp. 447-486.

Twede, D. & Harte, B., 2003. Logistical packagig for food marketing systems. In: R. Coles, D. McDowell & M. J. Kirwan, eds. *Food Packaging Technology.* Oxford: Blackwell Publishing Ltd, pp. 95-119.

Van Linden, V., De Ketelaere, B., Desmet, M. & De Baerdemaeker, J., 2006. Determination of bruise susceptibility of tomato fruit by means of an instrumented pendulum. *Postharvest Biology and Technology,* Volume 40, pp. 7-14.

Van Linden, V., Scheerlinck, N., Desmet, M. & De Baerdemaeker, J., 2006. Factors that affect tomato bruise development as a result of mechanical impact. *Postharvest Biology and Technology,* Volume 42, pp. 260-270.

Van Zeebroeck, M; Tijskens, E; Dintwa, E; Kafashan, J; Loodts, J; De Baerdemaeker, J; Ramon, H., 2006. The discrete element method (DEM) to simulate fruit impact damage during transport and handling: Case study of vibration damage during apple bulk transport.. *Postharvest Biology and Technology,* Volume 41, pp. 92-1.

Van Zeebroeck, M; Van Linden, V; Darius, P; De Ketelaere, B; Ramon, H; Tijskens, E., 2007. The effect of fruit properties in the bruise susceptibility of tomatoes. *Postharvest Biology and Technology,* Volume 45, pp. 168-175.

Verghese, K., Lewis, H., Lockrey, S. & Williams, H., 2013. *The role of packaging in minimising food waste in the supply chain of the future,* Melbourne: RMIT University.

Viljoen, N., 2009. Logistics Costs. *9th State of Logistics Survey*, pp. II-IV.

Willcox, J. K., Catignani, G. L. & Lazarus, S., 2003. Tomatoes and cardiovascular health. *Critical Reviews in Food Science and Nutrition,* Volume 43, pp. 1-18.

World Bank, 1994. *Annual Report,* Washington: World Bank.

Wright, C. R., Pentzer, R. C., Whiteman, T. M. & Rose, D. H., 1931. *Effect of various temperatures on the storage and ripening of tomatoes,* Washingon D C: United States Department of Agriculture.

8 APPENDIX A

Red tomatoes colour measurement graphs.

9 APPENDIX B

Pink tomatoes colour measurement graphs.

10 APPENDIX C

Green tomatoes colour measurement graphs.