QUANTIFYING THE TRANSPORTATION RELATED RISKS IN THE TRANSPORTATION OF AVOCADOS FROM FARM TO PACKHOUSE USING BAYESIAN NETWORKS

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THESIS ABSTRACT

QUANTIFYING THE TRANSPORTATION RELATED RISKS IN THE TRANSPORTATION OF AVOCADOS FROM FARM TO PACKHOUSE USING BAYESIAN NETWORKS

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Title:	Quantifying the transportation related risks in the transportation of avocados from farm to packhouse using Bayesian Networks
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The focus of this study is to gain a better understanding of the hazards affecting the transportation of avocados from farm to packhouse by developing an effective risk assessment tool farmers can use. The transport related factors considered in this study encompass all hazards which may affect the avocado, from the point the fruit is picked to the point the avocado is packed at the packhouse.

The study has been undertaken in five stages, namely:

- A literature study split into four main stages, including an investigation into avocado specific hazards, transportation related hazards, market influencers and investigating analysis tools.
- Data collection (including environmental indicators, accelerations and GPS measurements) stemming from field tests conducted with a smart avocado device (smAvo);
- Data analysis of the smAvos, including assessing the kinetic energy the avocado experiences;
- Risk analysis and Bayesian Network Development including those hazards identified in the literature study as well as from the smAvo, and
- Bayesian Network analysis, using Delphi Fuzzy methodology and smAvo data to determine the influence of the combination of risk factors identified.

The risk assessment tool was developed through the use of Bayesian Networks. This tool eliminates the guesswork of what causes the largest reduction in shelf life/waste and therefore profit. The Network considers the joint probability of these hazards, and posterior probabilities of any subset of variables when evidence is introduced.

The Bayesian Network is analysed and optimised by means of finding factors that will cause the greatest improvement of shelf life and decreased damage. A converse analysis is done by determining the effect of, for example poor road conditions or truck type. The result of this analysis provides the farmer with a decision-making tool which will optimise processes, increase profits (by reducing waste) and eliminate any guesswork. The Network can be used by the farmer and updated as new evidence is discovered.

The analysis concludes with the most damaging areas within the network is at harvest, followed by truck transportation effects, packhouse conditions and lastly farm transportation effects. In order to optimise the network, emphasis is put on the plant condition, followed by any delay in transportation and the picking technique used during harvest. A "what-if" analysis was done which concluded poor road conditions can increase overall damage by 0.44 per cent, whereas poor harvest conditions can increase this to 12.57 per cent.

DECLARATION

I, the undersigned hereby declare that:

I understand what plagiarism is and I am aware of the University's policy in this regard;

The work contained in this thesis is my own original work;

I did not refer to work of current or previous students, lecture notes, handbooks or any other study material without proper referencing;

Where other people's work has been used this has been properly acknowledged and referenced;

I have not allowed anyone to copy any part of my thesis;

I have not previously in its entirety or in part submitted this thesis at any university for a degree.

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LIST OF SYMBOLS AND ABBREVIATIONS

AE	Average Agreement Degree in terms of Fuzzy Logic
AM	Agreement Matrix in terms of Fuzzy Logic
Arc	Representing relationships between nodes in Bayesian Networks
Bayesian Network	Based on Bayes theorem, a Bayesian Network illustrates the causal relationships between the cause and final event in a system
BW	Bandwidth
CDC	Consensus Degree Coefficient
Civiltronics	A term used to incorporate the development of sensors and platforms into civil engineering to enhance the understanding of engineering principals and systems
DF_{ij}	Defuzzification in terms of Fuzzy Logic
f_{ij}	Fuzzy Number corresponding to an expert in terms of Fuzzy Logic
$FPS(Z_i)$	Fuzzy Probability Score in terms of Fuzzy Logic
FTA	Fault Tree Analysis
Fuzzy Logic	Mathematical method used to deal with the degree of uncertainty of human judgement
GPS	Global Positioning System

Hazard	A situation which can result in the physical injury of the target in a situation
HAZOP	Hazard and Operability Analysis
IRI	International Roughness Index
Node	Representing a variable in the Bayesian Network
P	Bayes factor or likelihood ratio
P(A)	Probability of event A
P(A|B)	Conditional probability of A given B
P(B)	Probability of event B
PD	Power Density
R	Overall Fuzzy Number
r	Number of years
RAD	Relative Agreement Degree in terms of Fuzzy Logic
Risk	The likelihood of an event happening
$S(\tilde{R}_i, \tilde{R}_j)$	Similarity Measure Function
SAAGA	South African Avocado Growers' Association
smAvo	Artificial smart avocado
t	Time interval
T	Return period
U	Probability of Occurrence
w_{ij}	Weighting applied to a fuzzy number
Z_i	Fuzzy number for a basic event
λ	Failure rate

1 INTRODUCTION

1.1 Background

The Neolithic Revolution is a significant point in history (Weisdorf, 2005). It marks the point in time in which many different regions around the world, between 10 000 and 5 000 years ago, humans transitioned to farming. This allowed for further development in civilisation and material wealth. As a result, over time populations have become dependent on agriculture (National Geographic, 2011). Farmers were able to produce surplus food which could be used to trade for other goods, or as we know it today, money.

Moving forward to the present-day South Africa, subtropical fruit, for example avocados and mangos, comprise of a large portion of the export industry (Sanders, et al., 2000). The fruit therefore carry large economic value that results in a need for the assurance of a good quality product and therefore financial reward. This study focusses on the avocado, due to its sensitive nature and susceptibility to bruising (Van Zeebroeck, et al., 2007), however the findings are transferable to other similar produce.

Produce, such as avocados, is transported along road networks to get from farm to packhouses. The produce is transported along gravel (unpaved) farm roads, provincial roads, national highways through the distribution network, and in some instances to harbour where they will be exported. The transportation is mainly in heavy vehicles, where the vibrations due to vehicle pavement interactions can cause damage to the transported produce (Steyn, et al., 2015). The damage to avocados will affect the shelf life of the produce. Due to financial implication to the producers, research has been done to better understand how the produce is damaged from when the avocado is picked, to how it is stored and transported. Mitigation measures could be identified to better understand the hazards during transportation, and therefore reduce waste.

To keep damage, and therefore waste, to a minimum, there is a need to better understand the risks involved in this process and where in this process these risks can be mitigated.

1.2 Problem Definition

Previous research investigated the effects of temperature, humidity and vehicle-pavement interaction, to name a few, on the shelf life (and therefore waste) of an avocado or similar produce (Pretorius and Steyn, 2019; Steyn, 2015; Perez et al., 2004). A problem that arises lies in determining the risk level associated with the combination of these aspects.

Transportation is a fundamental aspect in the agricultural industry. A more comprehensive study is required of the potential hazards within the process, the probability of these occurring, and hence quantifying these risks. The interaction between risk factors will be investigated by using Bayesian Networks with the use of BayesiaLab software (Bayesia, 2020).

There is a need to gain a better understanding of the transportation of avocados from farm to packhouse and prevent unnecessary loss of produce and profit during this portion of the avocado journey.

The problem definition is to identify and quantify the key risks, their interrelationship and effect in transporting avocados from farm to packhouse.

1.3 Objectives

The objectives of the study are:

- To gain a better understanding of transportation related risks affecting avocados in order to identify areas causing damage to the fruit, that through mitigation, can reduce waste and increase the shelf life of the fruit;
- To quantify the impacts and risk factors involved in the transportation of avocados from farm to packhouse using data from an artificial smart avocado (smAvo);
- To develop a Bayesian Network model which will provide a holistic assessment of the risks affecting the early stages of the avocado supply chain, and
- To quantify and rank the risks within a sequence of events along the avocado journey from farm to packhouse through developing a Bayesian Network with data collected.

For the purpose of this study, the term “transportation related risks” will refer to all risks which may result in a reduced quality product (relating to shelf life/waste) which may include, but is not limited to, environmental factors as well as vehicle-pavement interaction.

1.4 Scope

The scope of the research is defined by the battery limits as follows:

- The study is limited to avocados, from picking to delivery at the packhouse;

- The study is limited to ZZ2 farms and a currently utilised standard route to the packhouse;

- The study focuses on transportation related risks which affect the condition of the avocado i.e. those variables along the initial stages of the supply chain (from tree to packhouse) which may contribute to a reduced quality product,

- The study is limited to identifying the hazards along the network and does not provide solutions to those hazards, and

- The study is relevant to South Africa.

1.5 Methodology

The methodology of this study consisted of conducting a number of tests in the field and analysing the data by means of a desk study. The field tests consists of an artificial smart avocado (smAvo) following the same transportation route as the avocados on the ZZ2 avocado farm from the point of picking to processing at the packhouse.

The following influencing factors were measured:

- Environmental indicators;
- Acceleration;
- Barometric Pressure;
- Angular Velocity;
- Light Intensity, and
- GPS measurements were taken.

The methodology consists of the following phases:

- Data collection from a smart avocado device (smAvo);
- Data analysis of the smAvos;
- Risk Analysis including those hazards identified in the literature study as well as from the smAvo, and
- Bayesian Network Analysis, using Delphi Fuzzy methodology and smAvo data to determine the influence of the combination of risk factors identified.

1.6 Structure of the document

The research project is structured into the following chapters:

- Chapter 1: Introduction
- Chapter 2: Literature Review
- Chapter 3: Methodology
- Chapter 4: Data collection and processing
- Chapter 5: Bayesian Network Development
- Chapter 6: Bayesian Network Interpretation and Discussion
- Chapter 7: Conclusions and Recommendations
- Chapter 8: References
- Appendices

2 LITERATURE REVIEW

2.1 Introduction

The literature study is split into four sections, namely investigating:

- The hazards affecting the avocado fruit predominantly independent of transport related factors. These include effects of disease, environmental effects, as well as storage conditions to name a few.
- Transport related hazards end effects, such as Vehicle-Pavement interactions, road network and maintenance, as well as driving ability.
- Market price influences, and
- Analysis tools and techniques, such as Fuzzy Logic and Bayesian Networks considered for this study.

2.2 Avocado Influencing factors

The following section discusses factors predominantly affecting the avocado condition and factors which can lead to damage during the transportation network. These include, but are not limited to:

- Avocado strength properties (Baryeh, 2000);
- Avocado disease such as black spot (Korsten et al., 1997);
- Ways in which fruit can experience damage (Van Zeebroeck, et al., 2007);
- Packaging design and their influence (Boelema, 1987);
- Storage conditions which affect the shelf life of an avocado (Perez et al., 2004);
- Packhouse procedures (Milne, 1997), and
- An overview of the farm used in experimentation (ZZ2, 2020).

2.2.1 Avocado properties

A large portion of avocados cultivated in South Africa are dark-skinned Hass-type avocados (Donkin, 2020). These avocados include species such as Carman, Gem, Lamb-Hass and Maluma. The remaining portion of the avocados produced consist of greenskinned-type avocados, such as Fuerte, Pinkerton, Ryan and Reed. According to the South African Avocado Growers' Association (SAAGA), the greenskinned avocados make up less than 20 per cent of production in nurseries.

The avocado pear (*Persea americana*) has been documented as originating from tropical America. The plant is capable of growing in soil types with good drainage which are not too saline in nature (Baryeh, 2000). Avocados are harvested for consumption, at which point the fruit begins its ripening process. The ripening occurs due to the natural rise in ethylene, a fruit hormone (Khan, 2006). In South Africa, the harvest season extends from March to September. The avocado shelf life is dependent on the respiration rate and ethylene production (Perez, et al., 2004).

Baryeh (2000) investigated the strength properties of an avocado pear. It was found that an avocado had better strength properties between harvest and 7 days after harvest, followed by a rapid decline in strength. Table 2-1 gives an indication of the reduction in strength of an avocado after harvest. At harvest, the fruit could be packaged in layers of 35, thereafter at 15 days the fruit would need to be packaged in 2 layers.

Table 2-1: The modulus of elasticity, yield stress and rupture stress of an avocado after harvest (Baryeh, 2000)

Time after harvest (days)	Modulus of elasticity (kN/m^2)	Apparent modulus of elasticity (kN/m^2)	Yield stress (kN/m^2)	Rupture stress (kN/m^2)
0	480 024	555 018	1 020	858
5	325 110	408 127	752	592
10	115 007	127 036	244	184
15	73 550	81 725	165	105
20	48 116	54 675	103	76

The fruit experiences a wide variety of forces during harvest, transportation and storage. This may cause internal or external cellular damage to the avocado fruit. This damage allows organisms to enter the fruit and subsequently decay. The strength of the avocado is a good indication of the maturity of the fruit, degree of ripeness, predicted shelf life and tissue composition of the fruit.

2.2.2 Avocado diseases

Subtropical fruit, for example avocados and mangos, comprise of a large portion of the export industry in South Africa (Sanders et al., 2000). The fruit therefore carry large economic value which results in a need for the assurance of a good quality product.

A threat to these plants is disease such as anthracnose caused by *Colletotrichum gloeosporioides*. Disease such as this can be prevented by a pre-harvest spray which prevents post-harvest latent infections.

However, in the event the fruit is damaged, there is a potential entry point for pathogens to enter the fruit during transportation (Bill et al., 2014). The damage may also cause skin discolouration and localised softening which will not be desirable to the consumer. In addition to mechanical damage, it is not recommended to harvest avocados during wet weather as this increases the chances of disease during distribution and storage. Possible effects can be vascular browning which is associated with stem end rot (Whiley et al., 2002).

In South Africa, some fungicide programmes in the past included a monthly pre-harvest application of benomyl, cupric hydroxide or copper oxychloride, which was recommended during periods of high rainfall. This however has been known to cause resistant pathogen genotypes and even after discontinued use in some areas, these genotypes have remained for several years. It has since been recommended to reduce spraying to once per season.

Black spot caused by *Pseudocercospora purpurea* and sooty blotch caused by Akaropeltopsis are a common pre-harvest fruit disease (Korsten et al., 1997). Scooty blotch causes discolouration of the avocado skin which affects market price. Black spots can become severe in avocado plants if left untreated. In some orchids, avocado losses up to 69 per cent have been recorded due to black spot. As previously noted, fungicides used to control some of these diseases can have several detrimental effects, including possible affects on human health and additional cost of removing spray residues on the produce at the packhouse. Korsten et al. (1997) noted that the use of the field spray *Bacillus subtilis* has the ability to produce antibiotics in laboratory conditions.

Once avocados are picked they should be kept in the shade as excess heating may cause dehydration, sunburn and reduce the quality of the fruit (Whiley et al., 2002). Covering the bins with leaves was found to be beneficial at reducing skin discolouration.

2.2.3 Fruit damage

Van Zeebroeck, et al. (2007) measured mechanical damage on fruit. The mechanical damage extends from harvesting, to pack house operations, handline and transport of the produce. Due to consumers wanting a consistent and high standard of goods, this issue requires greater understanding. The effect of mechanical damage is not only limited to the visual appearance of produce, but also the risk of bacterial and fungal contamination which would affect the shelf life of the fruit. The study indicated that for apples, the most common type of postharvest mechanical injury is bruising. The bruising could cause dead or wounded tissue in the fruit which would provide a point for the disease to manifest and accelerate.

There are multiple possible causes of impact damage in the handling chain. An apple could be injured in multiple ways, for example:

- The fruit could come into contact with other fruit when growing;
- The fruit could come into contact with branches causing abrasion, puncture and bruising;
- Herbivorous animals such as insects or birds for example can puncture the skin, and
- Weather, such as wind or hail, can cause damage.

The damage caused by pre-harvest can be difficult to predict or control and the fruit is often discarded if damaged before packaging. Picking is an area which causes damage, as Baryeh (2000) indicated. There are a few ways one can harvest avocados, for example knocking them off with a long pole. In these cases, the fruit falls to the ground and is then picked up by hand and placed into baskets, jute bags, carts or cartons traditionally made of wood or cardboard. Some fruit hit hard surfaces, such as stumps, and have sections sheared or chipped off. Other methods include picking them by hand. It was noted that if the fruit does not detach easily and only two or three fingers were used to detach the fruit, damage may occur. A better way to detach the fruit is by using the full hand.

Additional damage, such as impact damage, can be done when fruit is emptied out of their containers. Other influencing factors include fruit impact against each other during transport, dropping from containers and the impact of transport vibrations from vehicle-pavement interaction. There is also an argument that if one harvested avocados is wet, there is an increased chance of fungal stem end rot (Milne, 1997).

The damage a fruit experiences, as described previously, may have different effects, for example:

- Scratch or scuffing damage, which is visible on the outer skin of the fruit due to relative motion between fruits and other surfaces, and may cause fruit rot;
- Bruising or chipping damage, which is damage to the outer skin in addition to the underlying flesh due to shear, and may cause cell rupture or membrane disruption causing fruit rot;
- Crushing damage, this appears through the skin to the flesh due to an impact or static load, which may cause the cells to rupture, and
- Cracking damage, which appears due to a thin discontinuity of the skin and flesh due to normal stress, which allows for microbial infections causing accelerated fruit rot.

A measure which can be taken to lessen the impact of the above-mentioned influences is the cushioning and dampening properties of the packaging material used, the dynamic response of the packaging box and the friction between the fruit and the container. The fruit susceptibility to damage was noted to depend on the fruit properties, as well as the maturity, temperature, size and cultivar to name a few.

2.2.4 Packaging of Avocados

International guidelines indicate tolerances and quality definitions regarding levels of mechanical damage, sunburn, disease, insect damage, fruit size and packaging requirements (Whiley et al., 2002). Therefore, packaging of fruit plays a vital role in agricultural transportation. It is usually recommended that the avocado reach the packhouse within 2 hours of picking (Bill et al., 2014).

A study was done looking at the packing height and shape of packing containers (Baryeh, 2000). A square and triangular packing arrangement was investigated and the height at which damage occurred was observed relative to the time after harvest. The critical packaging level decreased for both packaging styles. Square packaging, on average, allowed for a higher stacking height as opposed to triangular packing.

Pallet design is a compromise between transport requirements, the stability of the pallet and the need for efficient air-flow (Whiley et al., 2002). Boelema (1987) looked at the cooling of avocados in pallets. The lack of contact between fruit and air was a main factor under consideration. Pallets were designed to maximise the air and fruit contact in order for the fruit to receive the maximum amount of cooling. The packaging had to allow for maximum ventilation openings, provide adequate strength and be sized so that a forklift could pick the package up, whilst keeping cost low. The cartons had to allow for three basic air patterns, namely horizontal flow when in a cold room, down flow when transported along the road and up flow in the container.

The produce is susceptible to damage from the weight of other fruit when packing (Baryeh, 2000). Fruit can undergo cracking or crushing damage. Damage is very low when transported in single layers, when more layers are introduced, the avocados may experience scuffing, crushing, cracking or bruising damage.

Almost all plants produce ethylene, which is one of five organic basic plant hormones (Khan, 2006). Ethylene is known to cause a great agricultural and horticultural loss to post-harvest ripening. Ethylene is also produced when a fruit is damaged, which results in an accelerated ripening of the fruit. Meyer and Terry (2010) wrote a journal article describing ethylene removers, 1-Methylcyclopropene (1-MCP) and e + ® Ethylene Remover and the effects on physical attributes such as colour and firmness, as well as the change in fatty acid composition and C7 sugars content in the ripened fruit. An experiment was conducted whereby avocados were transported from Spain to the UK, with one batch receiving no chemical treatment, another treated with 1-MCP and the other was transported with e + ® Ethylene Remover in a petri dish. The result of the study was that e + ® Ethylene Remover and 1-MCP were effective in delaying the ripening of the fruit at low temperatures. The study indicated that upon removing the fruit from cold storage and transferring them to shelf life conditions, the 1-MCP demonstrated uneven ripening, whereas e + ® Ethylene Remover resumed natural ripening. The delayed ripening did not affect the fatty acid composition during this experiment, and it was identified that the effect of C7 sugars required further analysis.

2.2.5 Storage Conditions of an Avocado

During the ripening process, the avocado will visually progress from a green flesh colour to a black colour as it ripens (Perez et al., 2004). The avocado's respiration behaviour consists of three stages, namely:

- The pre-climacteric minimum, where low amounts of respiration occur;
- The climacteric maximum, where the maximum amount of respiration occurs, and
- The post-climacteric stage, where a decline in respiration occurs.

The ripening of the avocado occurs at the sudden rise in respiration between the first two stages. Once the fruit is harvested the avocados start to ripen. Depending on the storage conditions, the process can take 7 to 13 days. It was noted during a study that if the avocado is harvested before the "physiological maturity", the avocado does not soften regularly and is susceptible to decay.

Shelf life was defined as the "period in which a product should maintain a predetermined level of quality under specified storage conditions (Perez et al., 2004)". The shelf life is said to be dependent on the storage temperature, the exposition time, the cultivar and harvesting conditions. It was noted that the shelf life of the fruit can be prolonged if it is kept at low temperatures and relative humidity conditions. This is due to the metabolism of the fruit being slowed down by the reduction of the respiration rate, ethylene production, the colour change and the softening of the fruit. The fruit is also susceptible to chilling injury. According to literature, the optimum temperature for an unripe avocado is 5 to 13 °C, which would allow for approximately 2 to 4 weeks of shelf life. If the avocado was stored in an uncontrolled environment it would store anywhere between 2 to 6 weeks. Once the avocado is matured, the optimum temperature drops to 2 to 4 °C. An experiment found that a mature avocado stored at 5 °C, at a relative humidity of 85 per cent to 90 per cent, reached a shelf life of 2 to 3 weeks. In an environment with temperatures of 27 °C, mature fruits would ripen within 10 days. In addition to decreased ripening time, if an avocado is exposed to temperatures above 25 °C the fruit may experience uneven ripening, skin discoloration, flesh darkening and even off flavours (Kader, 2002).

Huysamer and Maré (2003) looked at the effect of storing Fuerte and Hass avocados at chilling (3 °C and 5 °C) and no chilling temperatures (5.5 °C and 7 °C) both in high (100 per cent) and low (75 per cent) relative humidity. The fruit were then ripened at 20 °C to evaluate the effect of the storage conditions. The fruit showed signs of internal disorders, grey pulp and vascular browning, some Hass avocados showed signs of decay. It is thought that when the relative humidity conditions reach 100 per cent the fruit may start to decay. Relative humidity can influence the water loss in plants and plant organs.

The experiment found that for Hass avocados, only 26.7 per cent of the fruit was sound. Grey pulp was significantly higher in fruit stored at chilling temperatures (33.3 per cent) than at slightly higher temperatures (13.3 per cent). Fruit stored at higher temperatures and low relative humidity has higher levels of external anthracnose (30 per cent). Ripening rates were slower at lower temperatures and higher relative humidity.

Woolf et al. (2000) did research on the influence of direct sunlight on postharvest temperature responses and ripening of avocados. It was concluded that the postharvest behaviour of the avocado fruit was heavily affected by the pre-harvest exposure to sun. It noted that fruit exposed to sunlight were more tolerant of temperature extremes and had a longer postharvest shelf life.

2.2.6 Packhouse procedures

One of the first steps taken at a packhouse is a representative sample is collected, which is evaluated for damage and then any damaged fruit is disposed of (Milne, 1997). An important factor is the packhouse hygiene, this is inclusive of staff, equipment used, sterilising cold rooms and any fruit that experiences severe impact damage such as falling on the floor must be disposed of.

The Perishable Products Export Control Board (PPECB) in South Africa assures that the minimum food safety and quality requirements of respective importing countries are met, partly by proper cold chain management (The Perishable Products Export Control Board, 2019). If these standards are not met, the produce cannot go out for export. Fruit undergo waxing so that the fruit to maintains an improved appearance and increased shelf life. In addition to this the produce undergo grading analysis to determine the size and shape according to international standards. All cartons should receive markings including cut-off dates, once packaged the fruit must be reduced to final storage temperatures.

2.2.7 ZZ2 farm

ZZ2 farm had faced challenging times in the past where part of their crop was destroyed by hail and needed to bring in a new plantings to make up for the damage (ZZ2, 2020). The harvest is now being cultivated and the farm is able to get fresh produce from picking to ripening facilities within a week. The farm is able to produce avocados year-round due to the trees producing fruit at lower-altitudes in early March and then from trees at higher altitudes through to December.

The farm produces a variety of avocados including Fuerte, Maluma Hass, Pinkerton, Ryan, Lamb Hass, Reed, Queen and other varies Hass varieties. The Fuerte, which is a green-skinned avocado variety is available to harvest from mid to late February and from mid-May the Hass variety is available for harvest.

ZZ2 preserves approximately 20 per cent of their crops for the local market. The rest of the produce is sorted by mechanical means and packed ready for export to Europe, the Far East and the UK. Once the produce is packed, the avocados are cooled in high-humidity coolers to approximately 5.5 °C. The produce is then ripened as needed.

2.3 Transportation influencing factors

The following section discusses transport specific factors which can affect the condition of the transported produce. Literature including the investigations into other produce, such as tomatoes and figs have been included as the transportation related factors are transferrable. The following factors have been discussed in this section:

- Vehicle pavement interaction and their resulting effects and influencing factors (Steyn et al., 2015);
- Damage done to produce due to transportation (Cakmak et al., 2010);
- The relationship between shelf life and International Roughness Index (Pretorius and Steyn, 2019);
- Road networks and maintenance effects (SANRAL, 2014);
- Driving ability (Cockram et al., 2004), and
- Labour influences (Nielson et al., 1993; Sundstrom, 1986).

2.3.1 Vehicle – Pavement Interaction

To better understand vehicle pavement interaction, one must first understand the pavement engineering methods one can use to measure the pavement effects. International Roughness Index (IRI) is a measure of the vehicles response to the pavement when driving over it (Sayers and Karamihas, 1998). This method is detailed in the following subsection. Once this is discussed the factors affecting riding quality and their effects are discussed.

2.3.1.1 International Roughness Index

Over time, there have been multiple methods of road profiling which measure road roughness (Sayers and Karamihas, 1998). A road profiler is a device that measures the surface unevenness of a road, providing an indication of the profile of a road section. Some devices that can be used to determine the profile is a Dipstick, which is "walked" along a section and uses an inclinometer to measure the difference in height between two supports. Another device, an Inertial Profiler (GM Design), obtains its values from an accelerometer sensor, which makes high speed profiling possible. The profilers can be used to monitor the condition of a road network for pavement management systems. It can be used to evaluate the quality of newly constructed pavements or repaired sections and aid in rehabilitation design. Due to the multiple methods of measuring roughness, a need existed to relate the results from various methods to a universal value. Therefore, the International Roughness Index (IRI) was developed.

The IRI provides an indication of the vehicle's response to the pavement as it passes over. The IRI summarises the roughness qualities of the pavement and relates this to the overall vehicle operating cost, riding quality, dynamic wheel loads and the surface condition of the pavement. As seen in Figure 2-1, depending on the class of a road section, the required IRI may vary.

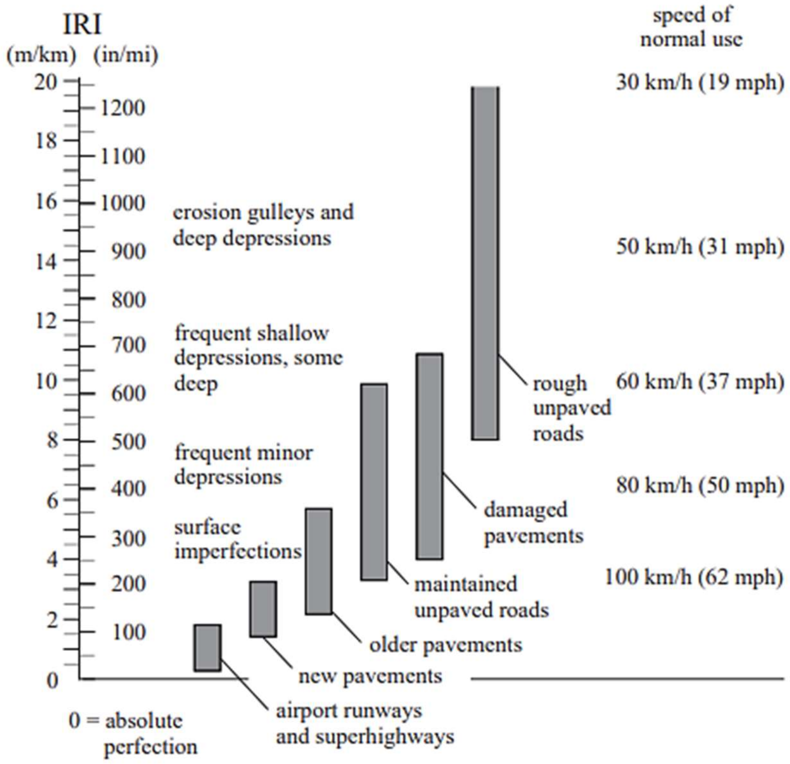

Figure 2-1: IRI requirements for various pavement classes (Sayers and Karamihas, 1998)

The IRI is based on an algorithm that incorporates a quarter-car model. This model indicates that the riding quality experienced by the user is not solely based on the road roughness, but that the suspension that supports the vehicle is able to reduce the effects of road roughness at higher vehicle speeds.

2.3.1.2 Factors affecting riding quality

A study done in 1993 indicated that air-ride suspension trailers traveling on similar highways experienced less vertical acceleration than from a steel-spring suspension (Hirsch et al., 1993). It was noted that for both suspension types the horizontal acceleration was much less.

Produce is transported along road networks, which may result in the vehicle being negatively affected by the pavement condition (Steyn et al., 2015). The riding quality and pavement structure are directly related. If the structure is compromised, more defects are evident and therefore the quality of the pavement decreases. This in turn negatively affects the vehicle, as vibrations would increase causing possible structural damage to the vehicle. An increase in vibrations would result in an increase in transportation costs. This is due to a risk of loss of cargo and increased wear and tear on the vehicle, resulting in increased maintenance costs. Comparisons have been made which suggest operational vehicle savings can be made when the roads are maintained at a higher standard.

In addition to the pavement condition, the tyre pressure can influence the vibrations felt in the vehicle (Jefferson, 2014). If the tyre is under or overinflated, the vehicle may not perform at its optimum and therefore result in vibration in the vehicle. If a tyre is overinflated there will be less traction, and if the tyre is underinflated the vehicle response will decrease, as well as the performance and safety (Tirebuyer, 2020). There is an exception to the rule, if one were to go off-roading, a decreased tyre pressure will aid in grip assuming that vehicle speeds are kept low.

2.3.1.3 Riding Quality effects

Steyn et al. (2015) compared the acceleration inside trucks to the resulting damage on transported produce, as seen in Figure 2-2. A vehicle transporting goods was fitted with an accelerometer that measures the vertical, horizontal and longitudinal accelerations. The trucks had dual tyres on all axles except for the steering axle and had an air suspension on the trailers. The tomatoes were loosely transported and taken to a processing plant. The route followed in the United States consisted of interstate highways, state highways, country roads and farm roads.

Results were observed and noted that the rougher roads exhibited higher accelerations, than smoother roads. More specifically, the higher up a tomato was relative to the base of the trucks, the more acceleration was measured, compared to the load closer to the base of the truck.

Figure 2-2: Location of sensors used in the study (Steyn et al., 2015)

Figure 2-3 (Steyn et al, 2015) indicates the potential effects riding quality has on the greater transportation economy. Poorer riding quality can influence fuel consumption, leading to increased vehicle operating and environmental costs. The same is valid for increased damage to vehicles and to transported cargo, which can cause an increase in freight transportation costs.

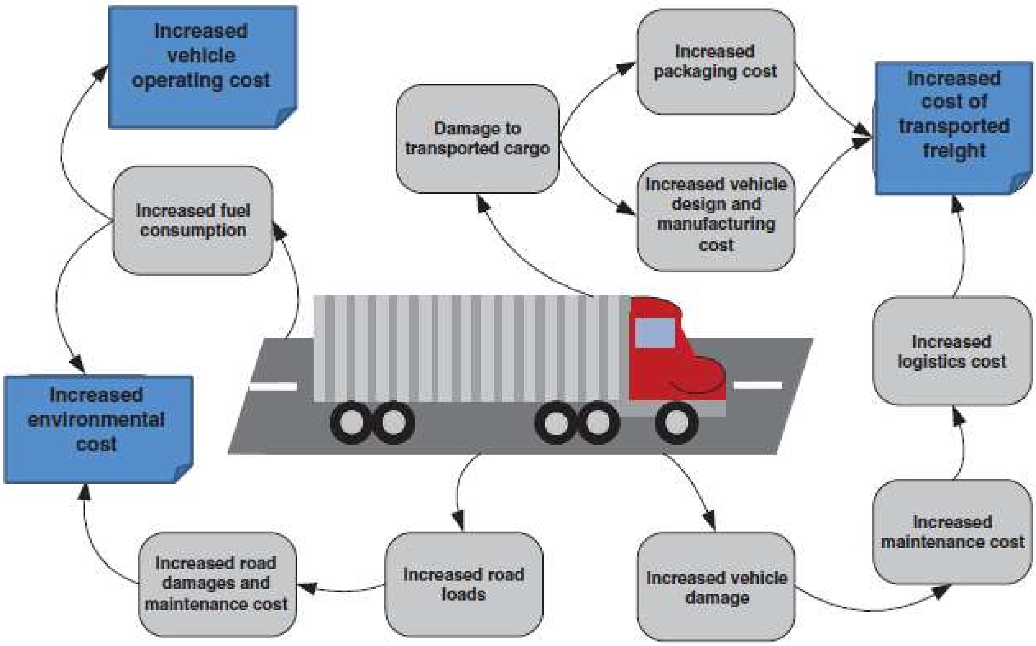

Figure 2-3: Potential effects of road quality on the broader economy (Steyn et al., 2015)

2.3.2 Damage during agricultural transportation

A comparison between fresh fig transportation and avocado transportation can be drawn. Both produce types are susceptible to damage in similar ways and is therefore taken into consideration in this study.

Cakmak et al. (2010) evaluated the quality losses of fresh fig fruits during their transportation. The vibrational aspects relating to the transportation of the fruits, as well as the packaging and condition of the roads were analysed. Fruits were assessed by measuring the acceleration of the truck, as well as by simulating the experiment considering different packaging types. In the study done on figs, it was concluded that cardboard packaging did not aid in the preservation of figs, whereas polystyrene offset some of the negative effects of transportation.

A few years prior to Cakmak's study, Jarimopas et al. (2005) measured and analysed the effects vibration levels agricultural produce experience in commercial truck shipments and what effect the vibrations have on the produce. Measurements were taken at the rear of the truck on the trailer bed, and at the top and bottom of packaging containing the produce. The vibration levels were monitored at speeds of 20, 40 and 80 km/h and road surfaces including gravel, concrete and asphalt surfacings. Jarimopas analysed the data by means of developing a power density plot (PSD).

As noted by Sayers and Karamihas (1998), the term power in PSD comes from the early application to electronics where the PSD illustrated the distribution of electrical power over frequency. When the philosophy is applied to vibrational data obtained from roads with the intent of analysing vibrations, the relation to power is lost. Following Jarimopas analysis method, the unit for power density becomes g^2/Hz.

Jarimopas analysed the data over a frequency range of 1 to 127.75 Hz. The power density over a band of frequencies is calculated by Equation 1, with $RMS\ gi^2$ as the root mean square acceleration measured in g at any point within a bandwidth (BW) of frequencies. N indicates the number of instants sampled for a segment of vibration history. The PD are then plotted against frequency in order to obtain the power density spectrum.

$$\boldsymbol{PD = \left(\frac{1}{BW}\right)\sum\frac{(RMS\ gi^2)}{N}}$$

Equation 1: Power Density equation

When analysing the road conditions and truck transportation, there are three (3) major ranges of frequencies, these being:

- 0.1 to 5 Hz indicating the truck suspension;
- 5 to 20 Hz indicating the type response, and
- Greater than 20 Hz indicating the high-frequency response from the structure, the road roughness and the drive train.

Power densities vary depending on the type of road surface, the velocity and the truck type. Jarimopas indicated that for lower frequency ranges, the power densities for gravel surfaces where much larger than that for concrete and asphalt surfacings. The findings were also that the higher the truck velocity, the more damage was observed to the fruit, in this case tangerines. The highest damage to the produce was observed at the top basket for every combination of truck type, surfacing and velocity.

2.3.3 Shelf life and International Roughness Index

Pretorius and Steyn (2019) investigated a model relating tomato damage and loss of shelf life due to the road condition, fruit ripeness and position of the fruit in a container. The focus of the model was the extent the road condition contributed to the quality deterioration of the fresh produce.

The assumption was the roads with higher roughness values could cause premature deterioration in the quality of the produce. The research was split into two phases, the first phase consisted of measuring the road roughness, the vertical acceleration that the produce is exposed to and the measurement of the in-transit pressures applied to the produce. The second phase consisted of an experimental simulation of the produce in transit so that the pressures experienced by the produce could be measured.

Roughness measurements were taken using a PaveProf profilometer at 10 m interval using standard interlink fleet trucks (Pretorius and Steyn, 2019). Accelerometers were installed in two different packaging types, namely a half bin, which can take approximately 80 kg of tomatoes and a standard box which can carry approximately 5 kg. As a control an accelerometer was installed to the body of the truck.

Eighteen road sections were selected for the experiment which ranged between surfaced and gravel and IRI sections ranging between 0.74 to 7.09 m/km. The frequency recorded from the accelerometer was analysed, with two dominant frequencies due to vehicle body bounce and axle hop were identified. The frequencies were 2.5 Hz and 13 Hz respectively.

A fast Fourier transform (FFT) analysis was run in order to create a PSD plot. The PSD plot indicated the frequency rangers measured by the accelerometers and the energy input at that frequency. No relationship between frequency and roughness was identified, therefore the power values from the PSD graphs were plotted and a linear relationship between road roughness and the power values were observed. Energy was related to amplitude by the assumption that the mass of the tomato is at its maximum displacement when velocity is zero, therefore the potential energy and displacement would be equal to the amplitude. From the results obtained, the amplitudes were correlated to the IRI, therefore amplitudes 2.5 mm, 5.0 mm and 7.5 mm are equivalent to 3.5 m/km, 5.49 m/km and 8.12 m/km.

Pressure sensors were installed in the in-transit test, as well as in the laboratory simulation. The laboratory simulation was subjected to the same amplitudes previously determined.

In conclusion, there was a correlation between road roughness and the damage done to the produce. When considering an IRI of 3.5 m/km, red tomatoes at the top layers during transport tend to damage more with an increase in transport time than when compared to the tomatoes at the lower layers. Green and pink tomatoes tended to be more resistant to damage at the top layers. Overall, the top layers experienced the highest gravitational force and therefore experienced the highest damage. The high gravitational force caused rubbing, rotation, skin discolouration and the breakdown of surface tissue.

A graph relating shelf life of tomatoes to IRI are illustrated in Figure 2-4. The coloured lines indicate the duration of travel.

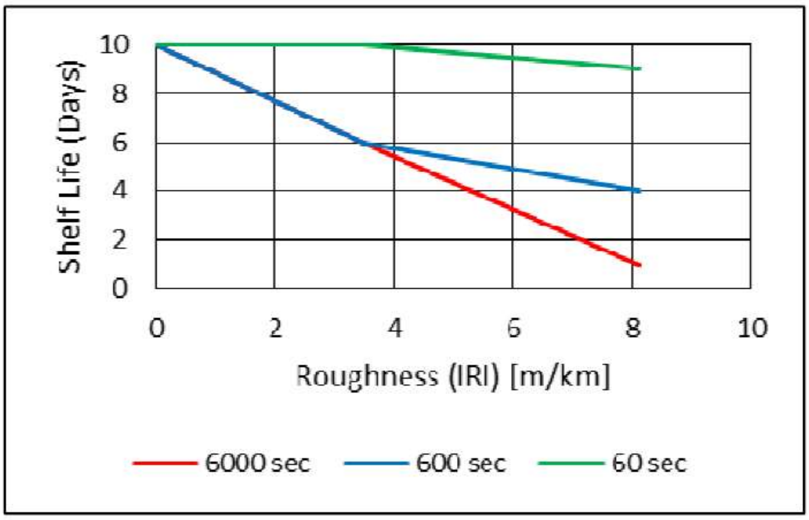

Figure 2-4: Shelf life prediction for red tomatoes in the first and second layers (Pretorius, 2017)

2.3.4 Road network and maintenance

A roads main function is to provide the user with mobility and accessibility (SANRAL, 2014). Mobility allows for a "quick, safe and economical movement of people, goods and services", whereas accessibility "facilitates access for people, goods and services to the higher order mobility network". The higher-class roads function is mainly to provide mobility, with low accessibility, and have a significant economic and commercial importance and therefore have a higher design reliability. Whereas the lower-class roads are intended to provide access rather than mobility as seen in Figure 2-5.

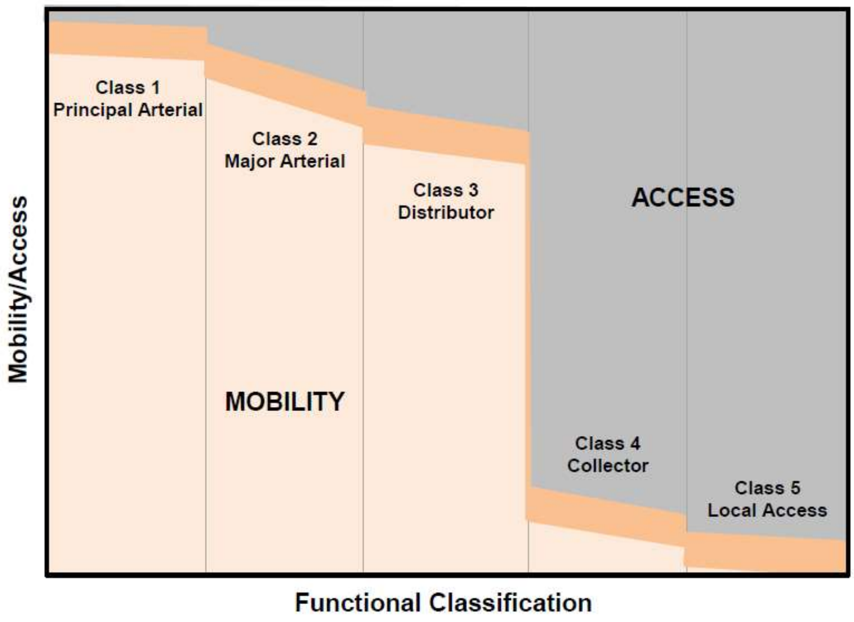

Figure 2-5: Functional Classification of Roads (SANRAL, 2014)

South African roads are split into three levels of government, namely national, provincial and municipal. The respective governing body is responsible for the maintenance of the road. There are two different maintenance strategies which can be followed when maintaining a road, namely conducting heavy rehabilitation less frequently, or frequent maintenance actions such as resurfacing (SANRAL, 2014). Due to a road following a nonlinear deterioration as seen in Figure 2-6, it is advisable to monitor and frequently conduct routine and preventative maintenance.

In South Africa, pavements are categorized in terms of the level of service required (SANRAL, 2013). A category *A* road would have a higher design reliability, compared to a category *D*, i.e. a road of category *D* has a design reliability of 50 per cent meaning that the road will abide by the criteria 50 per cent of the time, as seen in Figure 2-7.

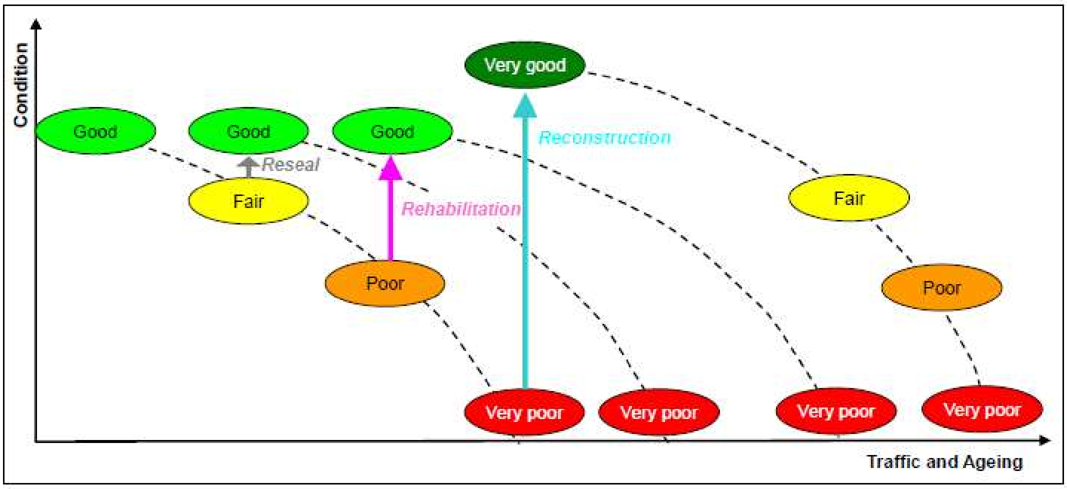

Figure 2-6: Impact of Timeous Pavement Maintenance on Life Cycle Costs (SANRAL, 2014)

	Road Category			
	A	B	C	D
Description	Major inter-urban freeways and major rural roads	Inter-urban collectors and rural roads	Lightly trafficked rural roads, strategic roads	Rural access roads
Importance	Very important	Important	Less important	Less important
Level of service	Very high	High	Moderate	Moderate
Typical Pavement Characteristics				
Approximate design reliability (%)	95	90	80	50
Length of road exceeding terminal distress condition at end of structural design life	5	10	20	50
Total equivalent traffic loading (E80/lane)	3 - 100 million over 20 years	0.3 - 10 million Depending on design strategy	< 3 million Depending on design strategy	<1 million Depending on design strategy
Typical pavement class	ES10 - ES100	ES1 - ES10	< ES0.03 - ES3	ES0.003 - ES1
Daily traffic (evu)	> 4000	600 - 10 000	< 600	< 500
Riding quality				
Constructed IRI	2.4-1.6	2.9-1.6	3.5-2.4	4.2-2.4
Terminal IRI	3.5	4.2	4.5	5.1
Rut level for flexible pavements (mm)				
Warning	10	10	10	10
Terminal	20	20	20	20
Area of shattered concrete for rigid pavements (%)				
CRCP and UTCRCP				
Warning	0.2	0.3	0.4	0.5
Terminal	0.5	0.7	0.8	1.0
JCP and DJCP				
Warning	2	3	4	5
Terminal	5	6	8	10

Figure 2-7: Road Category variables (SANRAL, 2013)

Road roughness, particularly considering unpaved roads, is a significant factor in influencing the market value of farm produce. Swanepoel et al. (2020) looked at the deterioration of unpaved roads and how to best maintain them.

Regression models were fit to real road roughness data and correlated with a class 3 profilometer and supplemented with maintenance history and historical rainfall data

(Swanepoel et al., 2020). The roads under investigation were under the management of a farming conglomerate in Limpopo, South Africa.

The most accurate model for predicting the deterioration in road roughness was found to be an exponential function specifically for sections with high and low traffic with a low slope. The rainfall season did not have an influence on the model, however greater deterioration occurred during the wet seasons. The study noted that whilst frequent maintenance is highly effective, it is not a cost-effective solution. The road should rather be monitored and maintained based on an “optimised grading trigger”.

2.3.5 Driving ability

Various factors affect the driving ability of long-distance truck drivers, one being falling asleep at the wheel (McCart et al., 2000). A survey was done among truck drivers, where it was determined that almost half of the truck drivers (47.1 per cent) sampled had fallen asleep at the wheel, with approximately 25.4 per cent in the last year. Factors contributing to this include a busy work schedule, symptoms of sleeping disorders, not sleeping well when on the road and night-time drowsiness.

Studies were also done which highlight the risk of driving in adverse weather conditions (Chakrabartya and Guptab, 2013). A study observed a driver’s speed variation to determine the response to certain stimuli, as well as psychophysical tests such as visual fatigue test, visual acuity test and driving simulation tests. This was done by fitting three (3) video cameras, one by the drivers face, one at the feet to observe the breaks, clutch and accelerator and one to observe the traffic. The reaction times were observed during different weather conditions. The reaction times were better when the weather conditions were clear, and worse when rainy or cloudy. It was found that the driver fared better when they obtained information about the roadway, traffic conditions and if there was better traffic management along the route.

Cockram et al. (2004) examined the relationship between driver behaviour and driving events during the transportation of sheep. The study noted that the driving style can have a major influence on the welfare of the transported cargo and the sheep’s ability to rest. There are two main components of driver behaviour, namely style and skill (West and French, 1993). The skill reflects the ability of the driver to control a vehicle, which is reflected in steering control. The style of the driver describes the manner in which the vehicle is driven and is characterised by lateral and longitudinal acceleration and speed.

The experiment was done with different drivers and different groups of sheep (Cockram et al., 2004). The speed of the vehicle was put into three categories low (<25 km/h), medium (25-50 km/h) and high (>50 km/h). The roads types were identified were minor roads (farm roads, unclassified roads or UK B roads) and main single carriageway roads (UK A roads) or motorways. The intensity of acceleration and braking was categorised as a change in speed of 5 km/h over 5 s (low), 3 s (medium) and 1 s (high) period. G forces were also measured into categories low, medium and high, relating to <0.1 g, 0.1 to 0.2 g and >0.2 g. In the study, 82 per cent of the loss of balance was caused by driving events. However, 22 per cent of driving events were followed by a loss of balance. High intensity driving events were more likely to cause loss of balance than medium or low intensity events. There was a strong relationship between road type and the sheep response to transport. The motorway resulted in fewer driving events compared to single carriageway roads. Therefore, if the vehicle is driven in a careful manner, keeping accelerations, braking and cornering to a minimum, the sheep would not have made frequent postural adjustments to maintain balance. This would reduce the risk of harm, such as bruising, coming to the animal.

2.3.6 Labour influence

Tzaneen experiences relatively hot temperatures with an average of 24 °C in February, peaking at 30 °C (Climate-data.org, 2020). These temperature conditions may have an influence on the productivity and therefore care workers take in their work (Li et al., 2016; Sundstrom, 1986). It is known that climate change can cause an increase in global temperature, which can accentuate seasonal temperature extremes (Lindsey and Dahlman, 2020) and therefore impacting workers picking the avocados.

There is a correlation between high-temperature outdoor working and productivity in China (Li et al., 2016). Workers installing rebar were observed and their productivity measured. It was noted in the study that the least hazardous time was 7:00 to 9:00 and that idle time increased when temperatures increased. The most hazardous time was between 14:00 and 15:00. The study indicated that high temperatures cause heat stress in the body and therefore decreases labour productivity.

A similar study was done in Qatar that looked at the influence of temperature, humidity and wind on the productivity of construction workers (Senouci et al., 2018). The study highlights that the temperature affects not only the daily work life, but also the transportation of personnel to site, as well as that of the equipment and materials. The study concluded that the productivity levels of labourers increased in winter and decreased in summer. A correlation was done on the effect of temperature on productivity, from which it was concluded that the correlation was strong. The effect of humidity and wind had a lower impact on productivity.

During high temperatures, the human body tries to maintain its constant body temperature of 37 °C (Sundstrom, 1986). It does this by dilating peripheral blood vessels to radiate heat at the skin, sweating for evaporative cooling, as well as faster breathing. A study found that uncomfortable heat is associated with poor performances in an office. A study was done where temperatures were set to 20 °C and 24 °C, and it was concluded that a better performance was achieved at a temperature of 20 °C. Sundstrom noted that studies have been done associating accidents with high temperature, indicating that higher temperatures are related to poor performance. The ability of an individual performing mental tasks in heat is related to the individuals tolerance to heat and the time exposed to that heat.

For the purpose of this study, it can be postulated that a decrease in mental performance due to heat can result in avocado pickers dropping the avocados when picking or emptying the avocado jute bags into crates, causing impact damage.

Nielson et al. (1993) looked at individuals exercising in dry, hot environments and the influence of heat acclimation. Individuals exercised daily at high temperatures for 9 to 12 days, and it was noted that their endurance time almost doubled within that period at high temperatures when compared to the controls who exercised in heat after 6 to 9 days exercising at cooler temperature. The levels of exhaustion for those in the acclimation experiment was at approximately 39 °C. This study indicates that with acclimation, the effect of temperature can be reduced. Considering this study, this theory could translate to the workers with experience working in the heat may be less susceptible to the environmental temperatures when working.

2.4 Market influencers

The agricultural economy and market price factors are discussed in this subsection. To better understand the scale of profit losses or gain it is important to understand the magnitude of the economy, as well as market price indicators.

2.4.1 Agricultural economy

According to the Economic Review of the South African Agriculture for 2017/2018, the value of agricultural production has increased by 4.7 per cent, and was estimated at R 281 370 million (Department for Agriculture, 2018). The contribution to the GDP was estimated at R 90 458 million at nominal prices in 2017. In 2008 a kilogram of avocados could sell for R9.64 and in 2017 they could fetch approximately R22.10 per kilogram (Reuters, 2018). Since 1994, the primary agricultural sector grew by 7.5 per cent, comparing this to the total economy which grew by 10.7 per cent per annum. The agricultural industry showed a decline from 3.9 per cent in 1994 to 2.2 per cent in 2017.

South Africa exports about 55 000 t/year, of which 95 per cent of that goes to Europe and the UK, ZZ2 is one of South Africa's largest Avocado producers (ZZ2, 2016). Recently there has been a growing demand in avocados due to the increase in popularity. This combined with Mexico's 20 per cent slump in production, which is responsible for producing 45 per cent of the worlds avocado supply, has caused more than a 150 per cent increase in avocado price in 2016, a record high. With countries like the United States of America consuming about 90 000 t/year, which is equivalent to 75 per cent of South Africa's annual production, there is a large market for the product.

Fruits are occasionally taken to market or consumers directly after harvest, however in most cases they are transported to storage and then to the consumer, as seen in Figure 2-8.

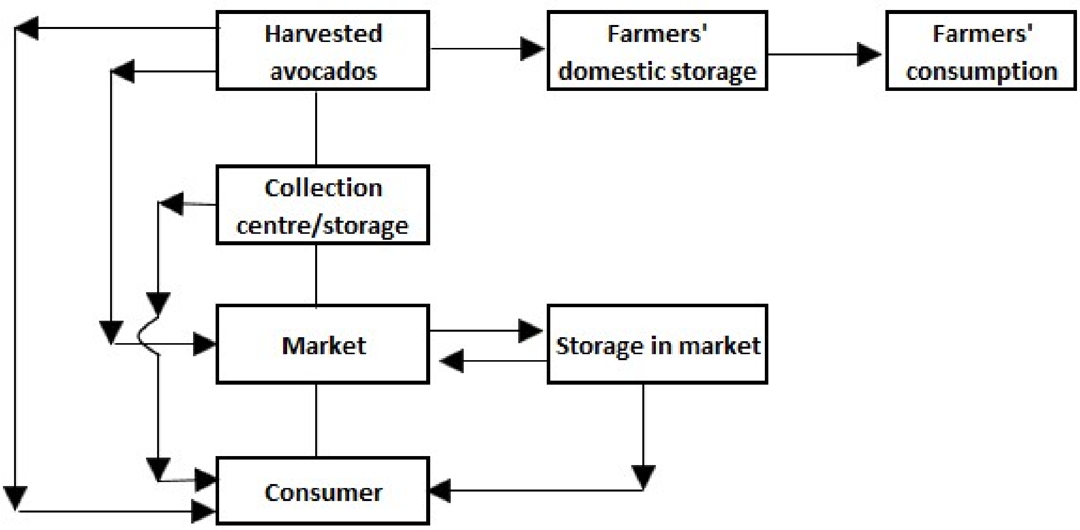

Figure 2-8: Avocado Post-harvest handling system (Baryeh, 2000)

2.4.2 Market price influences

Agricultural produce is sensitive to climatic conditions, such as extreme precipitation or drought, as well as climate change (Tucker et al., 2010). Coffee farmers in Guatemala, Honduras and Mexico experienced a period of extreme weather conditions that caused volatility in the price of coffee. The study by Tucker et al. (2010) looked at what farmers' perceptions and adaptations were when considering risks such as extreme weather events. In general, farmers did not have an adaptive response to extreme events, which was unexpected. The market price however experienced price fluctuations that was seen as normal variability to local farmers. The lack of adaptation could also be attributed to the difficulty that comes with loss of labour and initial investment, as well as the cultural link the local farmers feel. Geotz et al. (2016) looked at the effect extreme weather and export controls had on the regional price of wheat. The region experienced severe droughts between 2010 and 2013 which can have dramatic consequences on agricultural production. Production was 30 per cent and 20 per cent below the annual production in Russia and Ukraine respectively. Export controls were implemented to prevent dramatic increases in world prices from being transmitted to domestic markets, therefore keeping domestic prices low. The study indicated that weather shocks have a strong short-run influence on local prices.

2.5 Analysis Tools and techniques

The analysis tools and techniques considered have been summarised in this subsection. These include:

- A HAZOP and Fault Tree Analysis (Yazdi and Kabir, 2017);
- Fuzzy Logic (Hsu and Chen, 1996), and
- Bayesian Networks (Conrady and Jouffe, 2015).

2.5.1 Risk Analysis

There are multiple methods available for hazard analysis, including Hazard and Operability Analysis (HAZOP) and Fault Tree Analysis (FTA). The analysis technique is intended to address issues in probabilistic risk assessments, namely the challenges of unavailable data, dependency of failure events and uncertainty (Yazdi and Kabir, 2017).

The difference between a HAZOP and FTA is that the fault tree focusses on the top event and works down, whereas the HAZOP approach focusses on an intermediate step, elements such as valves or heat exchangers, and works down determining possible reason for malfunction, and once this is understood, uses an upward approach which looks at what might happen in the event of these malfunctions. An FTA focusses on the top event and follows a downward approach identifying what may have caused the top event, for example what caused an explosion. Another method, known as the failure-mode and effect analysis, works from the bottom up and looks at each element in a plant to determine what could happen if that element failed.

2.5.1.1 Fault Tree Analysis

FTA is used to determine all possible ways an undesirable state /failure of a system can occur, known as the top event (Vesely et al., 2002). The fault trees only contain those events that can cause the failure, not surrounding factors that do not contribute to this top event. The fault tree is binary and therefore only allow for a success or failure event. The tree shows the user which combination of events are necessary for the higher event to occur by setting up a series of gates as seen in Figure 2-9.

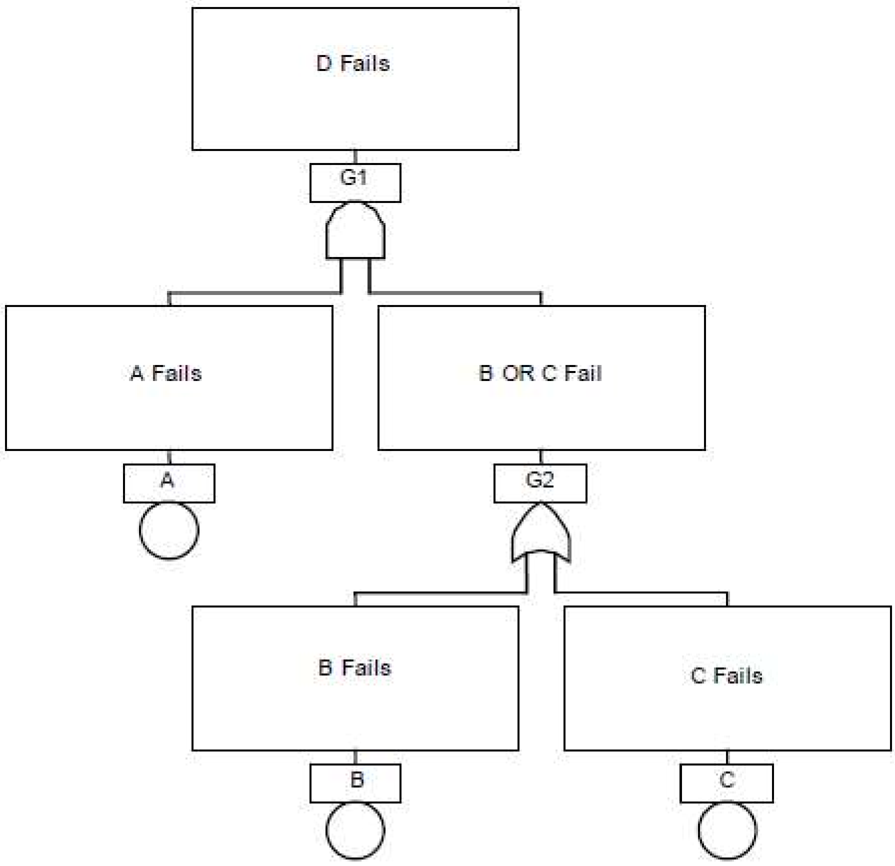

Figure 2-9: Simplified Fault tree (Vesely et al., 2002)

A qualitative or quantitative approach can be taken in FTA. A qualitative analysis reduces the fault tree to a set of minimal cut sets (MCSs). The MCS represent the smallest possible combination of events that could lead to the cause of a hazardous event or top event. This demonstrates the relation from the basic events to the top event, with the basic events being at the bottom of the fault tree. This is important information as it identifies weak links in the process that could lead to failure. For example, if there is one case of human error in the system, the top event could occur. A quantitative approach would calculate the top event probability using the probability of failure of an event occurring. It is necessary to have failure data available if one were to use this approach. The minimal cut set probability can be calculated following this process. The approach follows the assumption that the events are statistically independent, which is not a true representation of real-life applications, particularly in terms of process analysis.

The benefits FTA has to decision making are extensive. FTA analysis can:

- be used to understand the logic leading to a top event, and incorporate a number of systems and system interactions;
- prioritise contributors leading to the top event;
- be used as a proactive tool to prevent the top event from occurring by identifying vulnerable scenarios;
- monitor the performance of a system;
- minimise and optimise resources;
- assist in designing a system, and
- be used as a diagnostic tool to identify causes of top events by enabling one to identify the chain of events which occurred and prevent a recurrence.

Due to the lack of data in many instances, fuzzy set theory has been used, resulting in a fuzzy fault tree approach.

Therefore, Bayesian Networks (BN) can be used to illustrate the causal relationships between the cause and final event in a given system. The network can forward calculate the probability of an unknown variable, as well as backward analyse and update a probability of a known variable based on some evidence.

2.5.1.2 Fuzzy Logic and the Delphi method

There are a few ways one can accumulate data. One of these is the Delphi method, which is used to obtain a reliable consensus, regarding any topic, from a group of experts (Habibi et al., 2015). This is done by a series of questionnaires and controlled feedback. The technique can provide insight into problems and can be done anonymously to avoid "groupthink".

As Hsu and Chen (1996) noted in their Journal Article titled "Aggregation of fuzzy opinions under group decision making", when a group of experts come together to give a group consensus of a problem, there are generally moments of disagreement as the experts have their own opinions on matters. This is where fuzzy set theory can be extremely helpful as it assists in dealing with the "fuzziness of human judgement". When dealing with human judgement there may be a level of uncertainty which is taken into account by having a fuzzy number with an upper, middle and lower bound value. There are many ways one can implement the fuzzy set theory.

Hsu and Chen (1996) proposed an approach using a Similarity Aggregation Method (SAM), which combines the experts subjective estimates by representing them as a trapezoidal fuzzy numbers. The fuzzy numbers from each expert is obtained by means of the Delphi method, and it is assumed that there is a common intersection at some alpha level, as seen in Figure 2-10. The purpose of the alpha cut is seen in Figure 2-11, as the two experts in this case do not have a common intersection. In this instance, an aggregation result would be unreasonable and without continued discussion between experts, a result cannot be achieved.

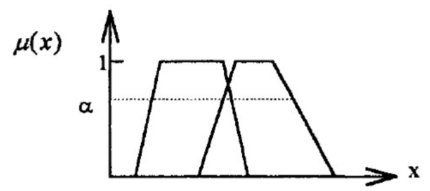

Figure 2-10: Fuzzy logic alpha cut (Hsu and Chen, 1996)

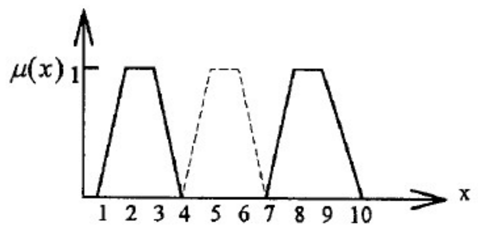

Figure 2-11: Fuzzy logic with no common intersection (Hsu and Chen, 1996)

The method proposed consists of the following steps:

1. A fuzzy number relating to each expert is achieved and if no intersection between experts is achieved then the Delphi method is used to adjust the values to get a common intersection at a fixed alpha level cut;
2. The agreement degree of the opinion between each pair of expert is calculated;
3. The agreement matrix is constructed;
4. Calculate the average agreement degree;
5. Calculate the relative agreement degree;
6. Define the degree of importance of each expert;
7. Calculate the consensus degree coefficient of each expert, and
8. Aggregate the fuzzy number opinions by means of the consensus degree coefficient.

A similarity measure function, as seen in Equation 2, is applied to measure the degree of agreement between the experts' opinions. The reference *i* and *j* refer to the two experts under consideration.

$$S(\tilde{R}_i, \tilde{R}_j) = \frac{\int_x \left(\min\left\{\mu_{\tilde{R}_i}(x), \mu_{\tilde{R}_j}(x)\right\}\right) dx}{\int_x \left(\max\left\{\mu_{\tilde{R}_i}(x), \mu_{\tilde{R}_j}(x)\right\}\right) dx}$$

Equation 2: Similarity measure function

The ratio is essentially the difference between the consistent area between the two experts and the total area, as illustrated in Figure 2-12. Therefore, if the two experts have the same opinion, then $S(\tilde{R}_i, \tilde{R}_j)$ = 1 i.e. they are in agreement. If they have completely different sets of opinions $S(\tilde{R}_i, \tilde{R}_j)$=0.

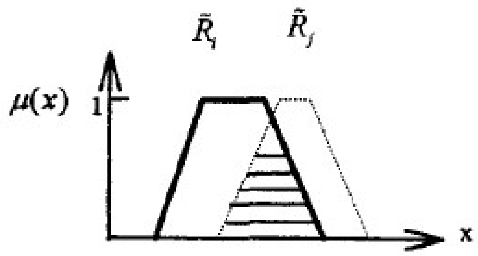

Figure 2-12: Consistent are between the two experts R*i* and R*j* (Hsu and Chen, 1996)

Once this is done, an agreement matrix can be set up to evaluate the agreement degree between the experts (Equation 3). A degree of importance can then be set up between the experts that can be used as a weighting factor to the fuzzy numbers, as indicated in Equation 4 and Equation 5, with *n* representing the total number of experts.

$$AM = \begin{bmatrix} 1 & \cdots & S_{1j} \\ \vdots & \ddots & \vdots \\ S_{i1} & \cdots & 1 \end{bmatrix}$$

Equation 3: Agreement matrix

$$A(E_i) = \frac{1}{n-1} \sum_{\substack{j=1 \\ j \neq i}}^{n} S_{ij}$$

Equation 4: Average Agreement Degree

$$RAD_i = \frac{A(E_i)}{\sum_{i=1}^{n} A(E_i)}$$

Equation 5: Relative Agreement Degree

In some instances, the importance of experts vary and so the weighting can be adjust by manually selecting the importance of an expert. If the importance of each expert is equal then the importance rating is equal such that $w_1 = w_2 \ldots w_n = 1/n$.

The consensus degree coefficient of each expert can be calculated (Equation 6 where $0 \leq \beta \leq 1$) and the overall fuzzy number combining the experts opinions can be determined (Equation 7 where $(\cdot)$ is the fuzzy multiplication operator). The β factor allows the use user to ignore the importance of an expert and to consider the importance factor of the expert.

$$CDC_i = \beta \cdot w_i + (1 - \beta) \cdot RAD_i$$

Equation 6: Consensus degree coefficient

$$\tilde{R} = \sum_{i=1}^{n} (CDC_i (\cdot) \tilde{R}_i)$$

Equation 7: Overall fuzzy number

As Habibi et al. (2015) also noted useful steps followed to achieve a conclusion from expert opinions using linguistic expressions. The first is to collect and fuzzify expert opinions based on linguistic expressions, as seen in Table 2-2 as an example.

Table 2-2: Triangular fuzzy number for a five-point scale (Habibi et al., 2015)

Linguistic Expressions	Fuzzy number
Very Important	(0.75, 1, 1)
Important	(0.5, 0.75, 1)
Moderately Important	(0.25, 0.5, 0.75)
Unimportant	(0, 0.25, 0.5)
Very Unimportant	(0, 0, 0.5)

The second step is to aggregate the fuzzy numbers, which can be done in a variety of ways. One method is done by averaging the lower, middle and upper values and obtaining a fuzzy average.

The third step consists of defuzzification, this can be done by a variety of methods, for example averaging the lower, middle and upper values or by using the centre of area method as seen in Equation 8.

$$\boldsymbol{DF_{ij}} = \frac{[(\boldsymbol{u_{ij}} - \boldsymbol{l_{ij}}) + (\boldsymbol{m_{ij}} - \boldsymbol{l_{ij}})]}{\boldsymbol{3}} + \boldsymbol{l_{ij}}$$

Equation 8: Defuzzification using the centre of area method

2.5.1.3 Risk Analysis Application

Yazdi and Kabir (2017) propose a new risk analysis approach, consisting of four main stages. The stages consist of hazard analysis, fault tree construction, data collection and Bayesian modelling.

Hazard analysis consists of brainstorming factors that may cause harm to equipment, people or the environment. Various methods can be used for hazard analysis. The method chosen in this particular study is hazard and operability analysis (HAZOP). A HAZOP analysis is a disciplined procedure that is meant to identify how a process may deviate from its intended path (Dunjó et al., 2010). It uses a formal, systematic critical examination of a process and its engineering systems to assess the potential for malfunction. The methodology lies in following the process flow diagrams and piping and instrumentation diagrams and break up the design into manageable sections with distinct boundaries called nodes. The HAZOP studies were originally used for processes that use hazardous materials, however the analysis technique is now used for a wider range of applications such as for medical procedures and road safety measures.

As discussed in Chapter 2.5.1.1, the fault tree construction begins with the specified top event at the top of the tree and the rest of the tree branching out in a downward direction. The top event is typically an asset loss or safety hazard. The basic events of the tree should be known before the tree can be constructed. The basic events are typically statistically independent and can be described as two binary states, failed or not failed. The probability of failure can then be calculated using the formula described in Equation 9, where P denotes the probability of failure, λ the failure rate (failures per year) and t the time interval. An expert judgement method can be used by method of a scientific consensus approach for unknown basic event probabilities.

$$\boldsymbol{P(t) = 1 - e^{-\lambda t}}$$

Equation 9: Exponentially distributed failure rate

The expert judgements can be combined by means of averaging and considering criteria such as personal experience and education as a weighting. To keep an objective approach, a fuzzy analytical hierarchy process can be adopted. The combination of expert judgements can be divided into three stages, namely Stage 1 is obtaining linguistic terms of the unknown basic events, Stage 2 is converting the terms into fuzzy numbers and then Stage 3 is converting the fuzzy numbers into fuzzy possibility scores. Stage 1 provides seven options of an event occurring, the guideline is that there should be between 5 and 9 options (split between very high, high, fairly high, medium, fairly low, low and very low).

Once the linguistic terms have been collected, they are converted into fuzzy numbers. Trapezoidal and triangular fuzzy numbers are used to map the function. The sum-production algorithm is used to combine all the expert's opinion, as seen in Equation 10. Z_i denotes the combined fuzzy number for the Basic Event, w_j represents the weighting applied to the expert j and f_{ij} is the fuzzy number corresponding to that expert. n and m correspond to the number of experts and relevant Basic Event.

$$\boldsymbol{Z_i = \sum_{j=1}^{n} w_j \cdot f_{ij} \qquad i = 1, 2 \ldots m \quad j = 1, 2 \ldots n}$$

Equation 10: Sum-production algorithm

Once the combined or aggregated fuzzy number has been calculated, the fuzzy number is converted into a fuzzy probability score.

Thereafter the fuzzy possibility score of fuzzy number Z can be calculated with Equation 11 and a failure probability score can be calculated.

$$FPS(Z_i) = \frac{[FPS_{Right}(Z_i) + 1 - FPS_{Left}(Z_i)]}{2}$$

Equation 11: Fuzzy possibility score

Bayesian Networks are described in the following subsection. When mapping fault trees as a Bayesian Network, the top, intermediate and basic events can be converted into leaf, intermediate and root nodes.

The approach defined in this study is illustrated in Figure 2-13.

The effectiveness of this approach was demonstrated by applying the method to the risk assessment of an ethylene transportation line unit in an ethylene oxide plant by comparing the results from a more traditional analytical approach (Yazdi and Kabir, 2017). The proposed approach resulted in more accurate results as the introduction of event dependence was taken into account.

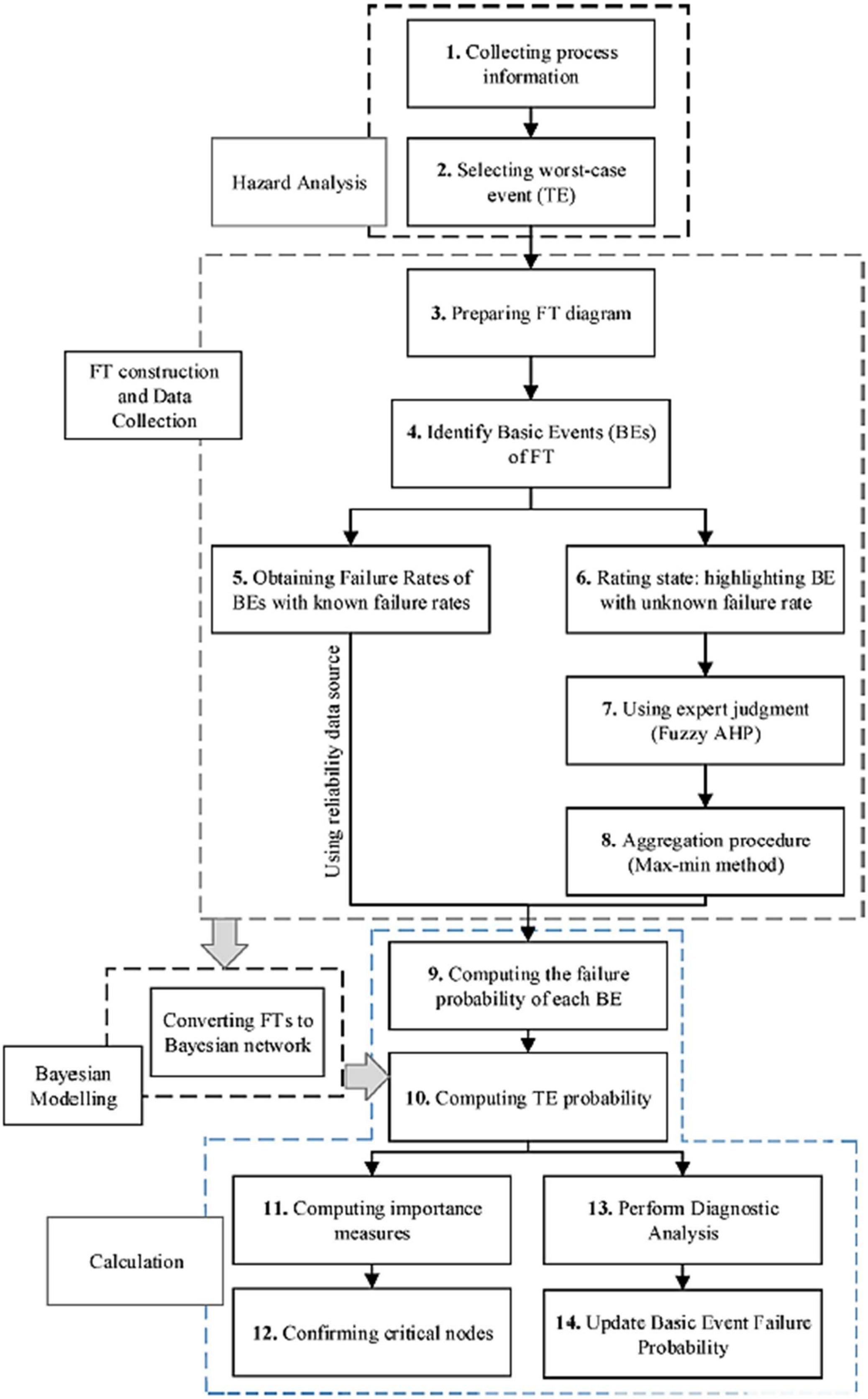

Figure 2-13: Method Framework (Yazdi and Kabir, 2017)

2.5.2 Bayesian Networks and Artificial Intelligence

2.5.2.1 Bayesian Networks

Bayesian Networks are based on Bayes theorem as described in Equation 12 (Conrady and Jouffe, 2015). Bayes' theorem describes conditional probability of an event A and B. Probability A (P(A)) is the "prior probability", also called the unconditional or marginal probability, of A. P(A) therefore does not take the probability of event B into account, however the event B does not have to occur after event A. The development of Bayesian Networks came about when bi-directional interpretations were analysed. This means that human learning and machine learning can be done in tandem. Bayesian Networks can be developed by a combination of human and artificial intelligence.

A Bayesian Network consists of interlinking nodes (or variables), in particular child nodes which are caused by parent nodes (Conrady and Jouffe, 2015).

$$\boldsymbol{P(A|B) = P(A) \times \frac{P(B|A)}{P(B)}}$$

Equation 12: Bayes theorem

P(B|A) divided by P(B), is known as the Bayes factor, or likelihood ratio. The Bayesian Networks looks at the top-down, as well as the bottom-up combinations, which later became a preferred method for uncertain reasoning in Artificial Intelligence (AI). Therefore, "a Bayesian Network compactly represents the Joint Probability Distribution (JPD) and this, can be used for computing the posterior probabilities of any subset of variables given evidence about any other subset (Conrady and Jouffe, 2015)".

Graphs are used in BayesiaLab, software that uses Bayesian Networks to illustrate calculated probabilities. Nodes represent variables of interest. The direct links between the nodes represent statistical or causal dependencies that exist between the variables. The direction of the link represent which node is the parent and which is the child node. A probability distribution can either be marginal if no parent node exists, known as the root node, or conditional if the parent nodes exist. Therefore, parent and child nodes would have conditional probabilities. Once complete, the Bayesian Network represents the joint probability distribution, which can be used to develop the posterior probabilities.

2.5.2.2 Application of Bayesian Networks

Bayesian networks were used to predict the probability of damage to roads and bridges due to extreme events in Iowa (Kulkarni and Shafei, 2018). The state identified its vulnerability in its transportation network not being able to meet the necessary requirements due to constantly evolving safety and efficiency requirements. The factors identified include extreme weather events, the loss associated with them and their increasing intensity. An additional concern was the aging effects of the infrastructure and the resulting reduced structural capacity. A Bayesian Network was set up to systematically capture the cause and resulting consequence of the various climatic scenarios, as well as the factors with the highest probability of causing damage. The network takes the factors as well as sequence of factors into account. The network can represent complex interactions between variables, as well as indicating their dependencies using conditional probability that can be updated when new information is introduced into the network. Causal relationships, in terms of bridges for example, can be the scouring or corrosion effects on the key components that make the bridge vulnerable to collapse. The corrosion or scouring could be the cause of collapse.

Figure 2-14 represents the model that was developed in the investigation of the impact of extreme weather events on infrastructure. The model follows the logic that, for example, extreme precipitation causes mudslides, landslides and flooding. The extreme precipitation is classified as the parent node, and the resulting effects as the child nodes.

As Kulkarni noted (Kulkarni and Shafei, 2018), there are two methods one can use to obtain information for networks. One can use a frequentist, which uses statistical measures such as means and coefficients of variation, or one can adopt a knowledge-based approach, which is achieved through “expert elicitation”. This is done through the study of papers and reports. In order to create a network, the steps required are as follows:

1. Gather information based on the frequency of occurrence;
2. Gather exposure scenarios, and
3. Evaluate the consequence.

The probability of occurrence used in the study is described in Equation 13. U describes the probability of occurrence, T the return period and r the number of years.

$U = 1 - (1 - \frac{1}{T})^r$

Equation 13: Probability of occurrence

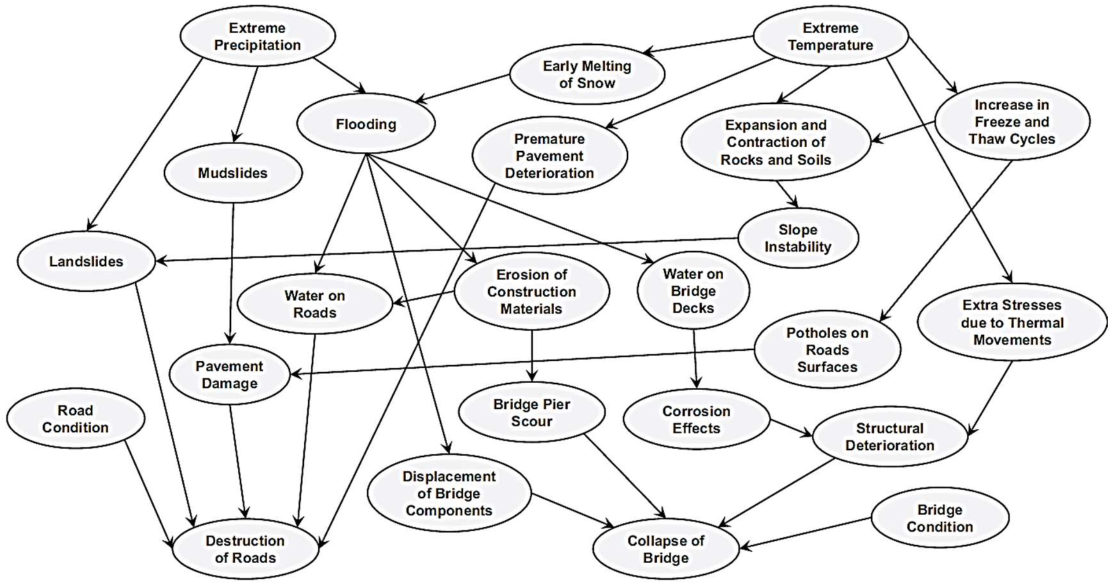

Figure 2-14: Bayesian Network developed in the study of the impact of extreme weather events on infrastructure (Kulkarni and Shafei, 2018)

Using the developed Bayesian Network, a sensitivity analysis of various scenarios was done in order to understand the sensitivity of a sequence of events, as seen in the tornado graph in Figure 2-15. The graph highlights the most influential scenarios.

The Bayesian Network approach enabled a holistic framework that allowed the user to evaluate the vulnerability of road networks subject to extreme events. The predictive and explanatory capabilities of the Bayesian Network were used to understand how extreme precipitation and temperature impact the transportation networks. The study indicated that the Bayesian Network is capable of identifying direct and indirect losses. The method proved to be valuable in the decision-making processes and resource allocation.

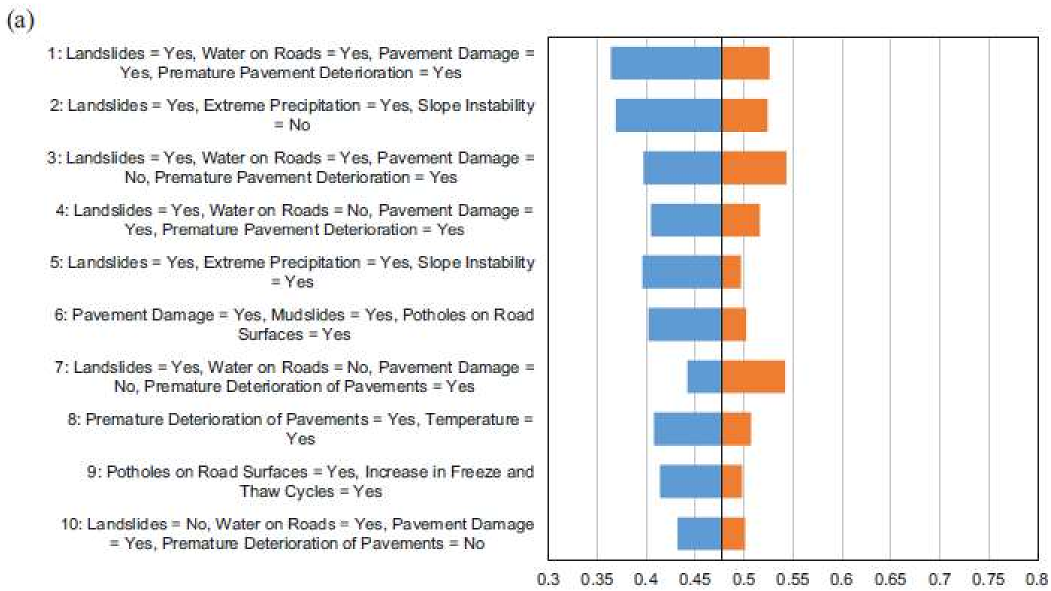

Figure 2-15: Sensitivity analysis for the probability of destruction of roads (Kulkarni and Shafei, 2018)

2.6 Summary

The agricultural industry has been experiencing an increase in production and was estimated at R 281 370 million in 2018. It was estimated that South Africa exports approximately 55 000 t/year of which 95 per cent goes to Europe and the UK, with ZZ2 being one of South Africa's largest avocado producers. The growing industry is therefore put under pressure to produce high quality products. This results in the desire to reduce produce loss in order to meet the demand and increase profits.

In order to reduce waste, it is required to understand the risk factors that could result in a substandard product. As discussed in this Chapter, there are multiple factors that affect the shelf life of an avocado during the transportation process. These ranging from vehicle-pavement interaction (Steyn et al., 2015) to the amount of air flow in between pallets (Boelema, 1987).

Various methods are available for risk analysis, such as HAZOP analysis, fault tree analysis, failure-mode and effect analysis and Bayesian Network modelling. The difference between techniques such as these is dependent on whether one wants to conduct a top down analysis, focus on intermediate steps or a bottom up analysis that focusses on the individual elements of a process.

Yazdi and Kabir (2017) conducted a study whereby the fault tree analysis and Bayesian Network techniques were combined in a risk analysis focused on process industries. The FTA is an analytical technique that can be used to determine all possible factors contributing to a top event, however it follows the assumption that the events are statistically independent. Bayesian Networks can therefore be used to illustrate causal relationships, whilst considering unknown variables and it can consider dependent variables. Yazdi and Kabir (2017) have proposed a risk analysis consisting of four main stages, namely hazard analysis, fault tree construction, data collection and Bayesian modelling. In the event not all failure criteria are known, a fuzzy set theory can be adopted.

Kulkarni and Shafei (2018) showed in their study, which looked at the impact of extreme events on the transportation infrastructure in Iowa, how the implementation of Bayesian Networks could aid in identifying vulnerabilities in a transportation network. The study incorporated frequentist (statistical measures from available data) and knowledge-based approaches (expert elicitation).

The literature study indicates that by identifying and understanding the influencing factors in the agricultural transportation network, it is possible to quantify these risk factors by using certain techniques. The techniques used to do this include fault trees, fuzzy logic and Bayesian Networks. In addition, by identifying these risk factors, there is the possibility of reducing produce loss and increasing profit is possible.

This literature study completes the first objective of this study, which is gaining a better understanding of the transport related factors affecting avocados and tools which can be used to effectively identify and mitigate these hazards.

3 METHODOLOGY

3.1 Introduction

The aim of this thesis is to identify and determine the risk and combination of risks affecting the shelf life of an avocado. Various researchers have documented the possible effects of transporting produce from farm to market. As an example, Cakmak et al. (2010) looked at the possible effect vibrations, caused by a truck, have on produce and the type of packaging which could counteract these vibrations. Van Zeebroeck, et al. (2007) looked at the mechanical damage a fruit may be subject to and identified bruising as one of the most common injuries during the transportation of avocados.

As noted in an article titled “Civiltronics: Fusing Civil and elecTronics Engineering the 4IR Era” (Steyn and Broekman, 2020), the Fourth Industrial Revolution (4IR) is transforming the civil engineering industry. Civiltronics, which has been newly termed at the University of Pretoria, aims to incorporate the development of sensors and platforms to enhance the understanding of civil engineering principals and systems.

This forward thinking outlook is carried on in this study and therefore instrumentation used to conduct this investigation is based on a wireless, inertial measurement unit (Kli-Pi) which was originally used for railway applications (Broekman and Gräbe, 2018). The intelligent railroad ballast was used to measure high frequency, three-dimensional accelerations, deflections and rotations along tracks subject to heavy-haul freight trains (Steyn and Broekman, 2020). The device proved invaluable in gaining insights in the dissipation of kinetic energy in granular material as well as the lateral and longitudinal forces at depth. The instrument has since evolved into an artificial smart avocado (smAvo) which has some enhancements including improved environmental sensory capabilities. The smAvo will be the instrument of choice for this study and is discussed in this Chapter.

This study focuses on quantifying the risks involved in the transportation of avocados from farm to packhouse, as well as the interdependence of these risk factors. The methodology is split into four sections, namely:

1. Data collected from the smAvo, which encompasses the point the smAvo is picked from the tree, transporting the fruit via tractor along farm roads to the truck, loading and transportation to the packhouse via the R36 as well as packhouse procedures;
2. Data analysis, whereby the smAvo data is processed and interpreted;

3. Risk analysis, where the process of transporting avocados from farm to packhouse is studied and risk factors are identified by means of a variation of a HAZOP analysis, and
4. Bayesian Network analysis, where the probabilities of the respective risk factors are calculated and expert knowledge is quantified based on the fuzzy Delphi method, and a Bayesian Network is set up and studied to determine the risk factors and their interdependence.

3.2 Instrumentation

As previously mentioned, the smAvo was used to measure the transportation and environmental effects an avocado experiences on its journey from farm to packhouse. smAVO is the only piece of equipment which was used in the field.

The smAvo predecessor, Kli-Pi, was developed at the University of Pretoria (Broekman and Gräbe, 2018; Broekman et al., 2020). The Kli-Pi consists of two main components, namely a stand-alone internal unit which contains all necessary electronics for the Inertial Measurement Unit (IMU) and a 3D printed exoskeleton which protects the IMU. The smAVO has since evolved to incorporate additional measurement capabilities, such as temperature and light measurement functions, as well as developments to the design to improve water resistance.

Two versions of the smAvo have been used in this study due to complications faced with water ingress at the packhouse. Therefore, for the packhouse procedures a revised, more water-resistant version of the smAvo has been used. The main difference between the two version is the latter, more water-resistant version, incorporates an IP68-rated enclosure encompassing the electronics, which protects components even when fully submerged in water. Other changes in the water resistant smAvo is the size of the battery, therefore affecting the overall mass of the smAvo. The first version has a mass of 0.267 kg and the water-resistant version has a mass of 0.198 kg. Swapping between the two versions will have no effect on the data collected as was verified through an evaluation of the collected parameters.

The smAvo makes use of a TinyDuino sensor platform, which is made up of multiple electronic printed circuit boards, also referred to as shields (TinyCircuits, 2020). smAvo comprises of the following components (Broekman, 2020; Broekman et al., 2020):

- TinyZero processor shield with an accelerometer incorporated into the same board;
- Telit JF2 GPS shield GPS receiver with an external antenna;

- microSD card memory shield with an 8 Gb microSD memory card;
- real time clock tiny shield, and
- Combo 13-Dof sensor shield that allows for the measurement of heading, pitch and roll instrument, a temperature and humidity sensor, barometric pressure sensor and an ambient light sensor.

The environmental readings the smAvo collects include:

- GPS readings;
- Light intensity;
- Barometric air pressure;
- Temperature and relative humidity readings, and
- Tri-axial accelerometer and rotational velocity readings.

The components, as shown in Figure 3-1, are enclosed in a 3D printed shell and the design is based on the characteristics of a Hass Maluma avocado. The device has undergone testing to achieve the same elastic modulus, elongation yield, yield stress and yield force an avocado would typically display. The device is recharged by means of a wireless recharging unit.

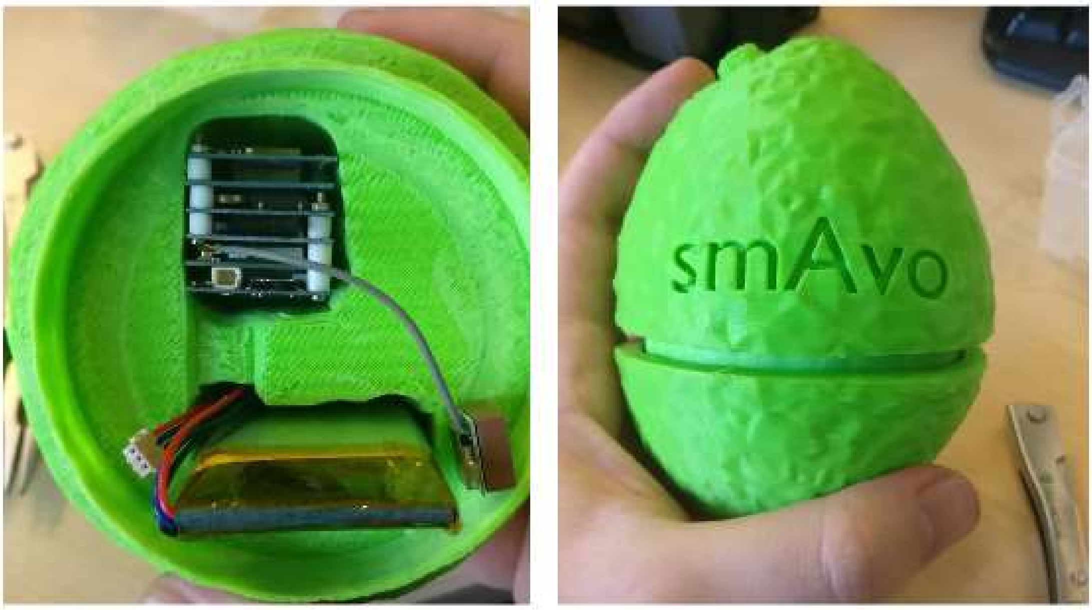

Figure 3-1: smAvo device (Broekman, 2020)

The unit of measurement and accuracy is indicated in Table 3-1.

Table 3-1: smAvo measurements, units and accuracy

Measurement	Accuracy
Temperature	±0.4 °C
Relative humidity	2 %
Light intensity	60 000 lux operating range
Barometric pressure	± 1 hPa
GPS positioning	2.5 m

The accelerometer measurements are done at a frequency of 100 Hz. The smAvo output consists of a log.csv and a cov.csv file. The environmental data are recorded in the log.csv file, and the coefficient of variance (CoV) data are recorded to the cov.csv file.

Before the measurements at ZZ2 were taken, the devices were tested over a 24-hour period to ensure the device was functioning correctly.

3.2.1 Field measurements

3.2.1.1 Survey Location

The field test was done between a ZZ2 avocado farm near Politsi in Limpopo Province, South Africa to the ZZ2 headquarters approximately 30 km away. The route taken between farm and packhouse is indicated in Figure 3-2.

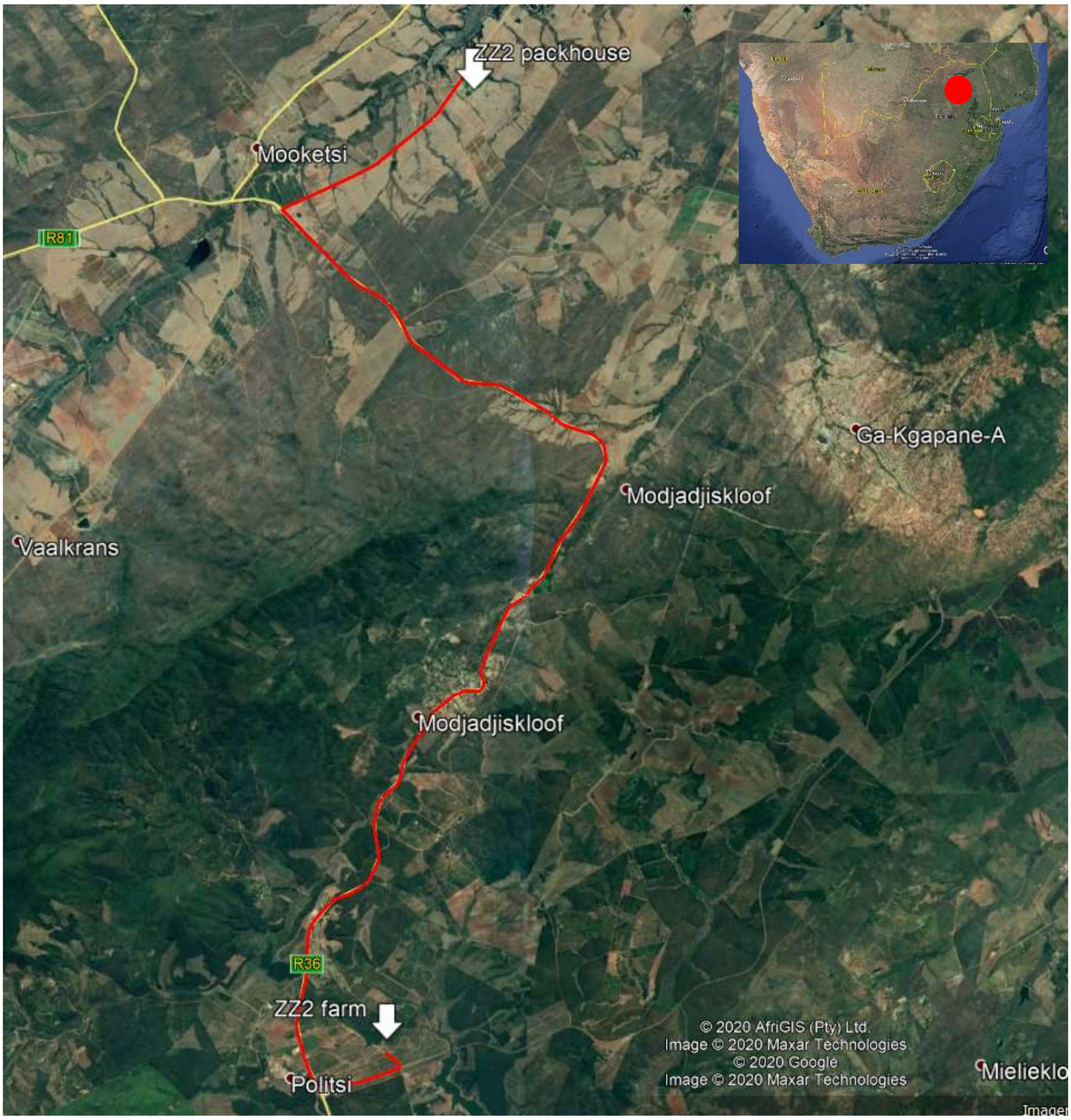

Figure 3-2: Project location

The goal of the experiment is to handle the smAVO in the same manner as the other avocados to understand the environmental factors the produce is subject to. The route the ZZ2 trucks take vary between surfaced and gravel sections. Figure 3-3 indicates the surfaced sections in green and the gravel section in blue.

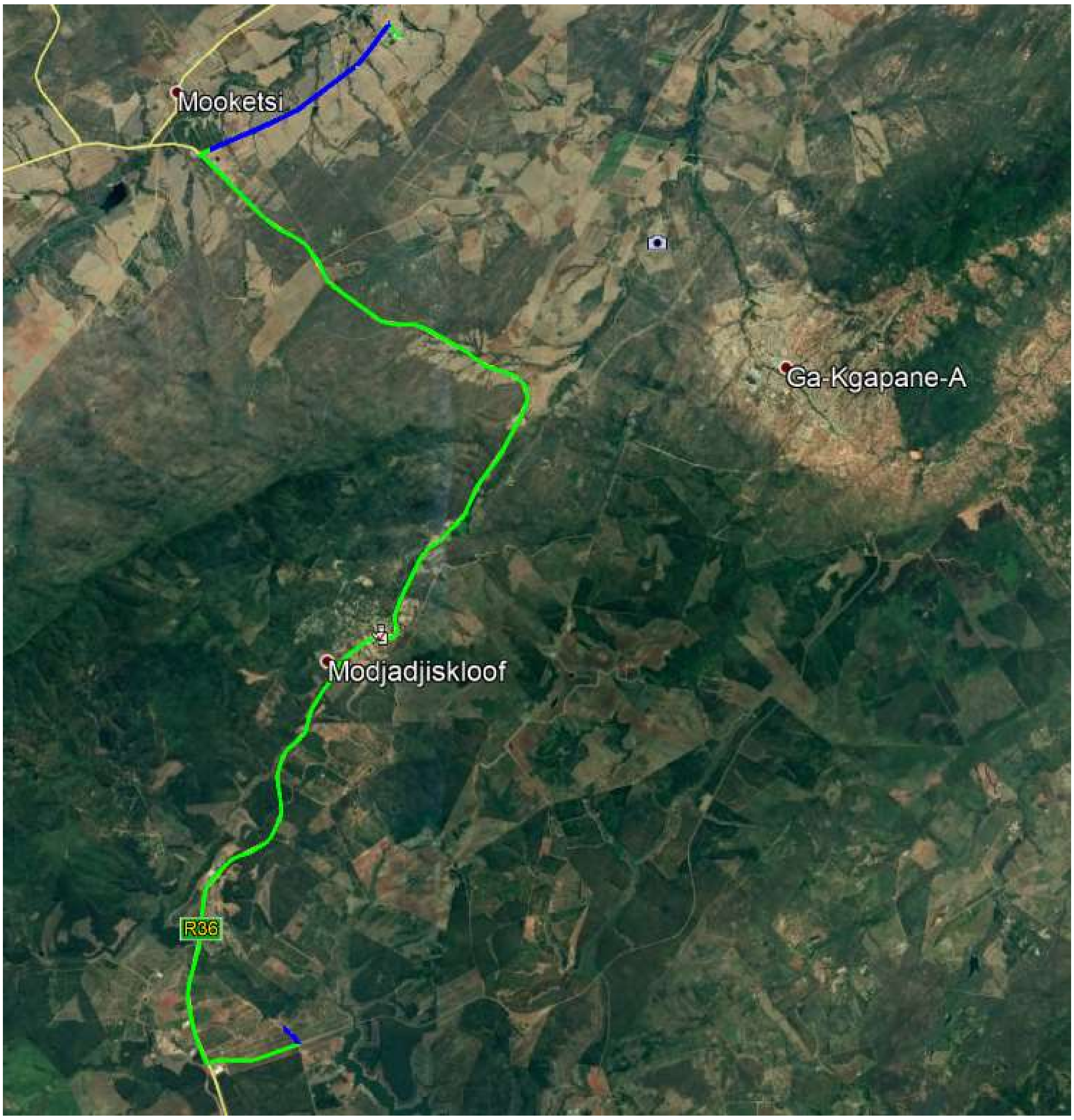

Figure 3-3: smAvo route with surfaced pavement sections indicated in green and gravel sections in blue

The avocado journey has been broken down into eight (8) sections for analysis. The sections have been separated by considering the variation in IRI between the road types. Referring to Figure 2-1, rough unpaved roads generally have a higher IRI than newer asphalt roads. The sections are as follows:

1. Picking the avocado to the point the avocado is transferred to the crate by the labourers;
2. The tractor journey to truck and forklift lifting the crate into the truck;

3. The journey along the farm gravel road;
4. The journey along the paved road at the exit of the farm to the R36 turnoff;
5. The R36 journey;
6. The turnoff onto Jachtpad gravel road;
7. The arrival of the truck at ZZ2 and unloading at packhouse, and
8. Packhouse procedures.

3.2.1.2 Data collection

Three (3) numbered, non-water resistant smAvo devices are put through five (5) runs between the tree and packhouse over a series of two (2) days. The packhouse procedures are then tested separately with the water resistant smAvo devices. Two (2) water resistant smAvos are put through the packhouse procedures three times.

The smAvos are turned on and hung in avocado trees with tape. This is done to simulate the picking technique of the pickers as seen in Figure 3-4.

Figure 3-4: smAvo placed ready for picking (Broekman, 2020)

Once the picker's bag is full, the avocados are emptied into crates as seen in Figure 3-5. It is vital to communicate to all workers involved that the smAvo should be treated in the same manner as the other produce. The smAvo's are placed in different locations in the crate. The locations varied between the centre and diagonal corner of the crate. It is imperative to take note of the location of each smAvo.

For this experiment smAvo1 is placed in the bottom corner of the crate, smAvo2 the top corner and smAvo3 in the centre for each run. On day 1 the crate is placed at the bottom front right of a Rigid truck. The following day the crate is placed at the centre of an Articulated truck.

The crates are transported by tractor on gravel farm roads to the truck collection point as seen in Figure 3-6. The crates are lifted by means of a forklift onto the truck. The crate containing the device is marked with an X using tape so that the devices could be easily located on arrival at the packhouse.

Figure 3-5: smAvo transported by tractor to the truck (Broekman, 2020)

Figure 3-6: smAvo loaded into the ZZ2 truck for transport to the packhouse (Broekman, 2020)

The truck's route starts at the farm, traveling at approximately 35 km/h to the paved R36. The truck travels towards Modjadjiskloof, of which part of the journey consists of traveling up a slow uphill at approximately 20 km/h. The truck turns onto Jachtpad road, which is gravel, and travels approximately 5 km to the packhouse. On arrival, the crates are unloaded from the truck, and the smAvo devices were switched off just before packhouse procedures commence.

The water resistant devices are switched on and put through the packhouse procedures, as shown in Figure 3-7 to Figure 3-9. It is communicated to the staff that the device should be treated in the same manner as the other avocados. It is important to talk to the staff once again at the packhouse as they are completely separate from the events at the farm and therefore do not have knowledge about the experiment yet.

The packhouse procedures entail the avocados being dropped from the transportation crate into a water tank for initial washing. The produce is loaded onto a moving bay where defective avocados are picked out. The moving bay vibrates the avocados dry and the process is repeated whereby the produce is washed in a secondary washing tank and vibrated dry. Once this is complete, the avocados are divided up according to size and packed into boxes ready for transportation. At this point, the devices are collected and switch off as this concludes the field measurements.

Figure 3-7: Avocados are put through the packhouse procedures (Broekman, 2020)

Figure 3-8: The avocados sorted for any defects (Broekman, 2020)

Figure 3-9: The avocados packed for shipment (Broekman, 2020)

3.2.2 Desk study

After each run the data are copied over and is stored on a computer. The data are analysed for areas of impact. The data are scrutinised to ensure the device took accurate measurements and any significant outliers are excluded from the study.

The avocado journey from tree to packhouse is analysed by means of a variation of a HAZOP analysis described in Chapter 2.5 which provides a methodical technique of analysing risk. The risk analysis is done by identifying different processes within the transportation network and methodically determining risks and hazards. For each risk or hazard identified a short description explaining the node is included, as well as possible variations of the relevant risk as well as the resulting effect is described. For example, the plant condition is a risk factor, which will affect the condition of the avocado produced. The states of this aspect include a healthy or unhealthy plant. The effect of this aspect is the overall produce as a disease-ridden plant cannot produce healthy and acceptable avocados. This technique enables the identification of problem areas within the transportation network which will aid in the development of the Bayesian Networks.

Failure probabilities are identified from the data. Probabilities that were unable to be calculated were estimated by means of the Fuzzy Delphi method. The method entails obtaining a reliable opinion consensus of a group of experts by subjecting them to a series of questionnaires.

Six experts were chosen for this study and are all working within the agricultural transportation field. Their expertise range between Civil, Mechanical and Industrial Engineering, as well as individuals with general experience working within the agricultural transportation field.

The experts were asked to estimate the effect by means of linguistic values as seen in Figure 3-11. The linguistic values were then taken and transformed into fuzzy numbers using a triangular distribution and following the methodology described in Chapter 2.5.1.2.

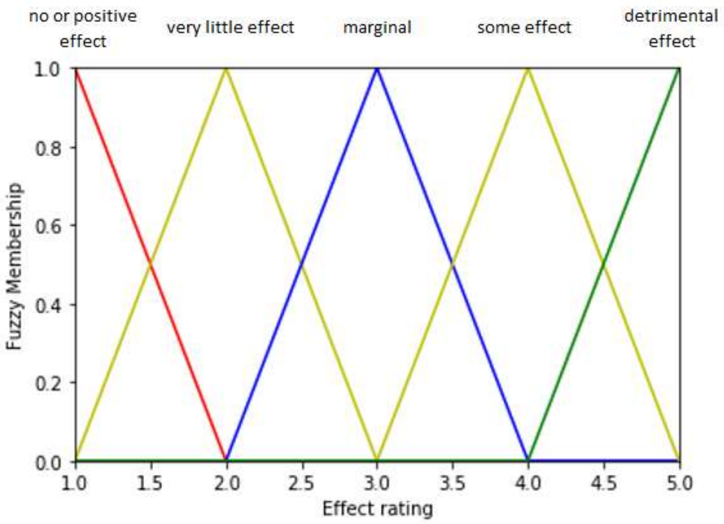

Figure 3-10: A geometric illustration of a triangular fuzzy number distribution

There was no additional weighting applied to the experts chosen. The relative agreement degree was used as a weighting between the experts, as discussed in Chapter 2.5.1.2. The results from the first series of questionnaires were adequate for this analysis. If in the event the experts do not agree (i.e. have polarising views), a second series of questionnaires, as well as additional facilitation between experts, should be run until a reliable/more consistent result can be achieved. The feedback would then be used as the probabilities and effects for the Bayesian Network.

3.3 Limitations

Various limitations were identified and encountered during this study, these being:

- The study is limited to the journey between the tree and packhouse and therefore does not take the journey to harbour into account due to logistics involved and time constraints the project is subject to;
- The study is limited to one avocado farm (ZZ2) and one packhouse (ZZ2) due to time constraints and logistics;
- The expert opinions are limited to those identified in this study and therefore if a greater sample set is taken the opinions may vary therefore varying the resulting analysis;
- The Fuzzy Dephi method used is limited to one round of questionnaires;
- Damage occurring to the avocados when on the tree cannot be taken into account, and
- Only two truck types regularly used by the farm are analysed.

3.4 Summary

The smAvo is used to understand the conditions an avocado is subjected to during postharvest procedures between the farm and the packhouse. Amongst others, environmental and rotational measurements are taken for analysis. A variation of a HAZOP study, Fuzzy Delphi methodology and Bayesian Network analysis techniques are used to gain a greater understanding of factors affecting the shelf life of an avocado.

The methodology is summarised in Figure 3-11.

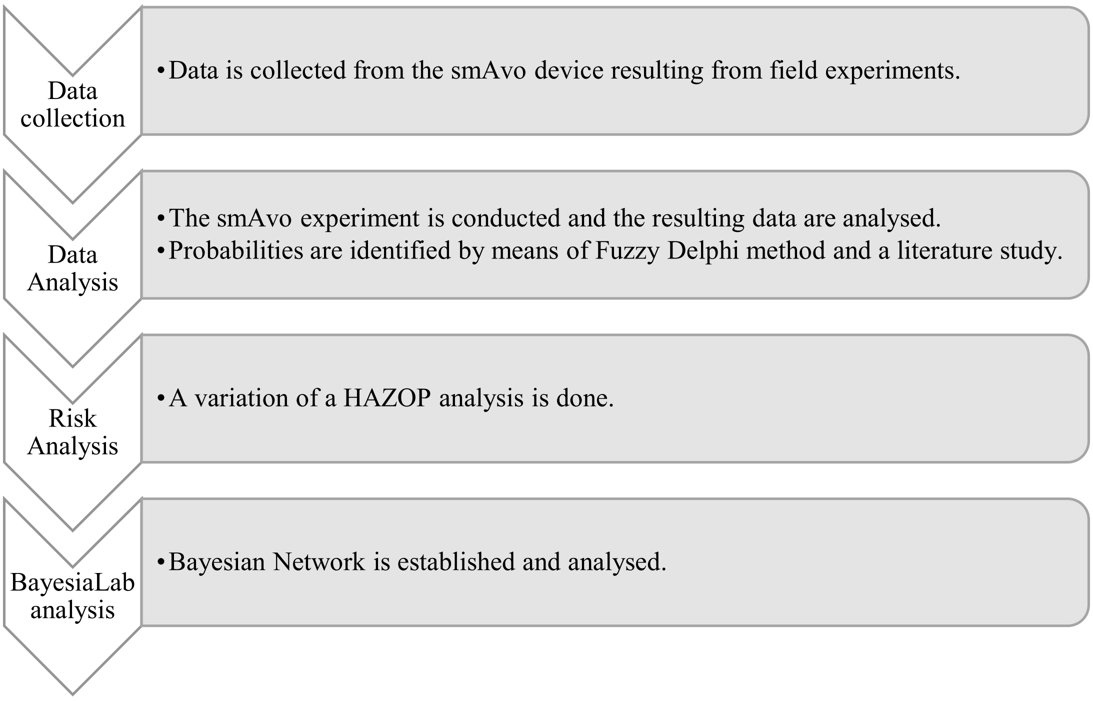

Figure 3-11: Methodology schematic

4 DATA COLLECTION AND PROCESSING

4.1 Introduction

Data collected from the smAvo devices were analysed and graphically summarised in the following sections. The readings were processed and summarised noting the most damaging position during transportation. The intent of the data analysis was to identify areas within the transportation network that may affect the shelf life of the produce.

4.2 Data processing

The data collected, as following the methodology described in Chapter 3, is summarised in the following subsections. It is important to note that smAvo1, smAvo2 and smAvo3 are placed in different locations in the crate during transfer. During processing, it was noted that smAvo3 produced faulty readings and therefore the results were not used in analysis.

The packhouse processes were analysed separately, as a different version of the smAvo device was used for wet conditions. There was a stop and start action upon arrival at the packhouse and the point the device went through the packhouse processes.

4.2.1 Sections

The average time a smAvo spends in each section, from picking to arrival at the packhouse has been broken down and illustrated in Figure 4-1. The smAvo tests were conducted over a span of a few days and it is worth noting that on day 1 run 2 (D1R2), the smAvo devices spent significantly more time in Section 2, when compared to the other test runs indicating a delay in the transportation process. The particular run in question resulted in the avocado taking over 2 hours to travel from the point of picking to the packhouse, which as noted by Bill et al. (2014) is over the recommended limit.

The sectional split was derived by analysing GPS and barometric data against Google Earth satellite imagery, as well as consulting notes taken during the testing procedure.

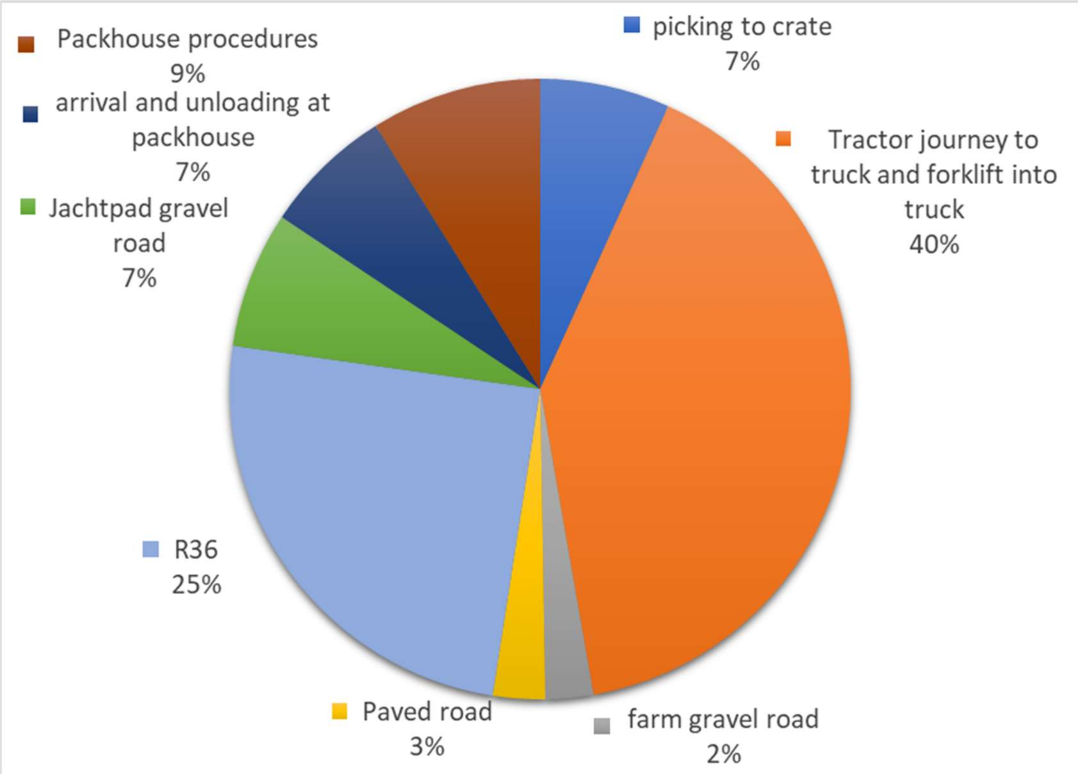

Figure 4-1: Percentage time smAvo spends in each section

The following subsections refer to post experiment numbered smAvo devices. The smAvos were renumbered (as smAvo1 to smAvo8) to aid in readability and avoid confusion as smAvo1 and smAvo2 were used multiple times in the consecutive runs. The smAvos were placed in varying positions in the crates and trucks, as summarised in Table 4-1. The packhouse procedure devices were omitted from the table.

Table 4-1: smAvo position variation during transit

smAvo number	Vertical crate placement	Horizontal crate placement	Truck type used for transport	Crate placement in the truck
1	Centre	Corner	Rigid 11	Bottom front right
2	Top	Corner		
3	Bottom	Corner		Top front right
4	Top	Corner		
5	Bottom	Centre	Articulated 122	Centre
6	Top	Centre		
7	Bottom	Centre		(placement recording error)
8	Bottom	Centre		

4.2.2 Temperature

Temperature measurements were taken by the smAvo devices from the point of picking to arrival at the packhouse. The average temperature measurements taken by each device per section is illustrated by the box and whisker plot in Figure 4-2. Appendix A contains a detailed summary of the dataset.

The data indicate that on average the avocados experience an increase in temperature from Section 1 (30.3 °C) to Section 7 (38.9 °C). Packhouse procedures, done indoors at the ZZ2 facility, are conducted at lower temperatures, at an average of 26.6 °C.

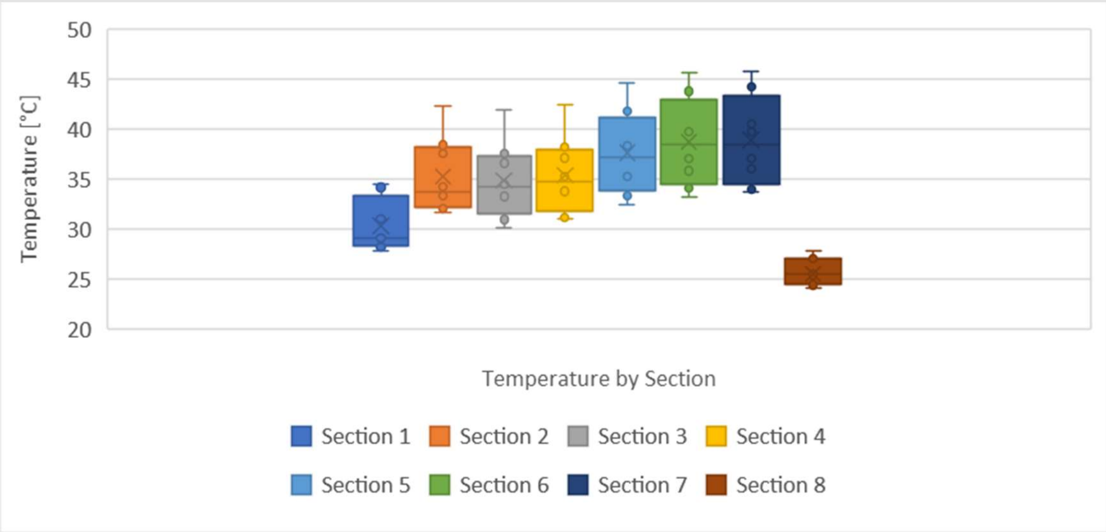

Figure 4-2: Box and Whisker plot for temperature measurements by Section

The temperature data were manipulated to obtain the relative increase or possible decrease in temperature between Sections based on the initial temperature at picking. A ratio was obtained by dividing the temperature by the respective initial picking temperature. This was done in an effort to remove the influence of difference in starting temperatures (due to time of day picked) and obtain a direct comparison as seen in Figure 4-3.

The Figure clearly indicates that smAvo1 and smAvo2 experiences a larger increase in temperature than the other test runs. smAvo1 and smAvo2 test were picked at 11:00 and therefore approaching the hottest time of the day, therefore experiencing a greater increase in temperature. The remaining avocados were picked at 14:00 (smAvo3, 4, 6 and 8) and at 9:00 (smAvo5 and 7).

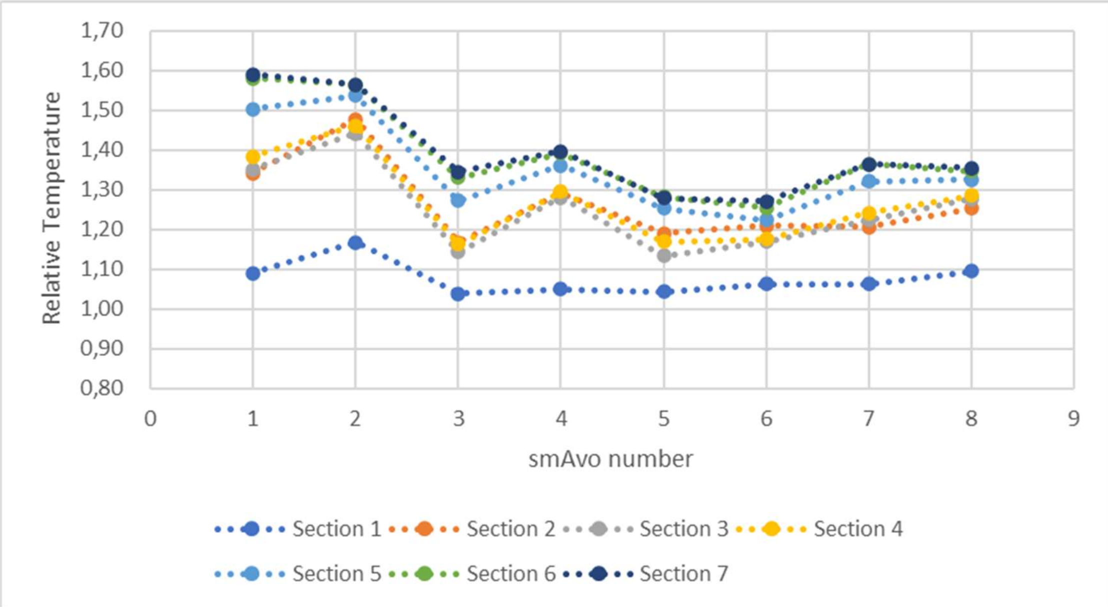

Figure 4-3: Relative Temperature per section

The relative temperatures were then averaged over all sections according to the aspect under consideration (e.g. truck type or position within the crate). There was a minor difference in temperature when considering truck type, as the Rigid truck had an average of 1.4 times the picking temperature and the Articulated truck experienced an average on 1.27 times the picking temperature. The difference can be attributed to the airflow in the truck. However, the devices used for testing on the day the Rigid vehicles were used were picked at 11:00 and therefore may be skewing the data. The vertical position in the crate (if the device was placed at the top, middle or bottom of the crate) played a role. The device at the top experienced an average higher temperature of 1.32 compared to the middle device at 1.41 and the bottom device at 1.23. This may be indicating that there is less airflow between the avocados within the crate.

The horizontal placement within the crate played a minor role as both device in the corner and centre of the crate recorded a temperature of 1.39 and 1.26 respectively. Therefore, if the smAvo is placed at the top of the crate the device will experience a 7 per cent increase in temperature when compared to the bottom placement, and a 14 per cent increase in the centre compared to the bottom of the crate.

The crate's position in the truck was compared and noted that the crate at the bottom front right of crate experienced an average temperature of 1.5, the top front right device recorded temperatures at 1.3 times the picking temperature and the crate located at the centre experienced a temperature of 1.22 times the picking temperature.

As indicated in Chapter 2.2.5 by Perez et al. (2004), the optimum storage temperature for an unripe avocado is between 5 and 13 °C. This will allow for a shelf life of between 2 and 4 weeks. If the temperature were to be at 27 °C the shelf life would decrease to approximately 10 days. The data collected from the smAvo indicate that temperatures were well above the optimum range (100 per cent above 27 °C), with the minimum temperature measured being approximately 24 °C in the packhouse.

Although this study indicates the temperatures are above the optimum level, the effect of season was not taken into account during data collection. It is advised that in subsequent studies the smAvo is run through the same process during different times of the year.

4.2.3 Humidity

Figure 4-4 indicates that the humidity, on average, decreases from picking to arrival at the packhouse. The data indicate that the humidity in the packhouse is significantly higher than experienced in Section 1 to 7, with a mean of 53.4 per cent, than that experienced when first picked (44.1 per cent) and upon arrival at the packhouse (35.2 per cent).

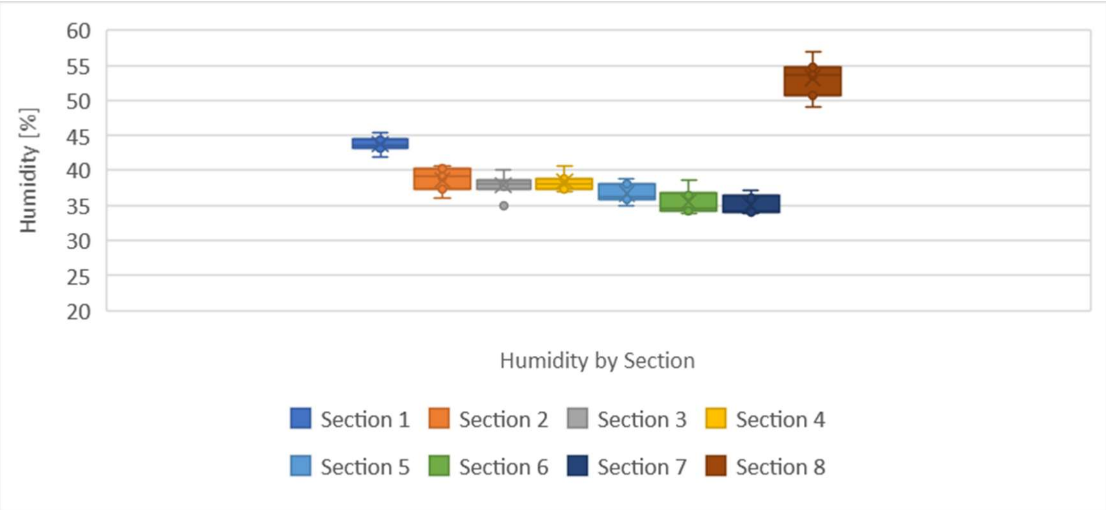

Figure 4-4: Box and Whisker plot for humidity measurements by section

Figure 4-5 indicates the average change in humidity experienced relative to the Section. The analysis indicates that in general there is a drop in humidity when the smAvo is underway in the tractor and the truck in comparison to the humidity at the point of picking. By the time the device reaches Section 7, there is almost a 3.0 per cent drop in humidity. Once the avocados enter the packhouse there is a slight increase in humidity.

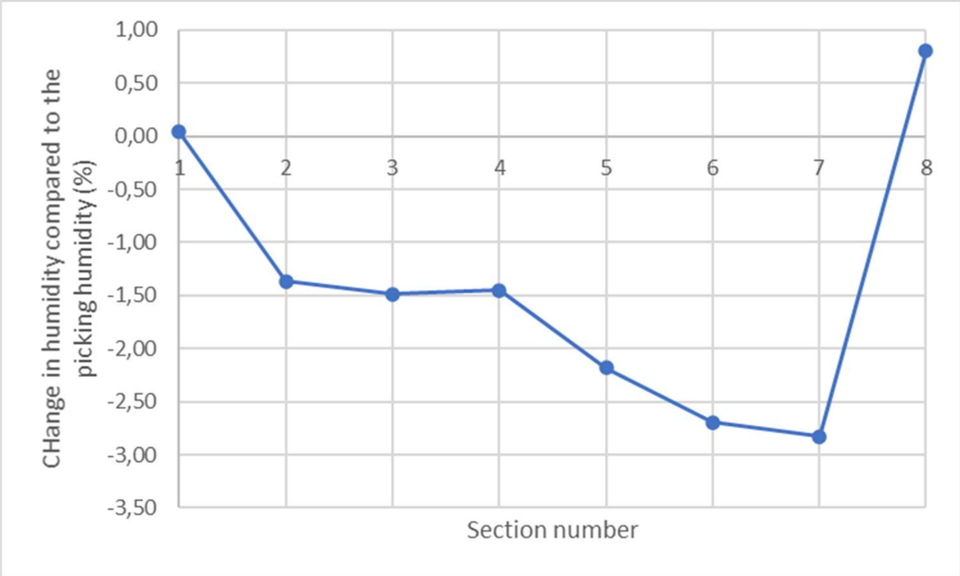

Figure 4-5: Humidity change relative to the point at picking

As noted in Chapter 2.2.5, relative humidity conditions should remain below 85 per cent. Over the course of the experiment humidity conditions did not reach high levels previously thought to cause a reduction in shelf life. The humidity over the duration of the experiment was below 85 per cent.

As noted in Chapter 4.2.2, the seasonal effects were not taken into account. It is advised that in subsequent studies the smAvo is run through the same process during different times of the year.

4.2.4 Acceleration

Acceleration measurements have been summarised and plotted in Figure 4-6 and Figure 4-7. The box and whisker plot in Figure 4-6 indicates that the higher accelerations experienced are in Section 1 and 8, i.e. by the pickers and by the packhouse procedures.

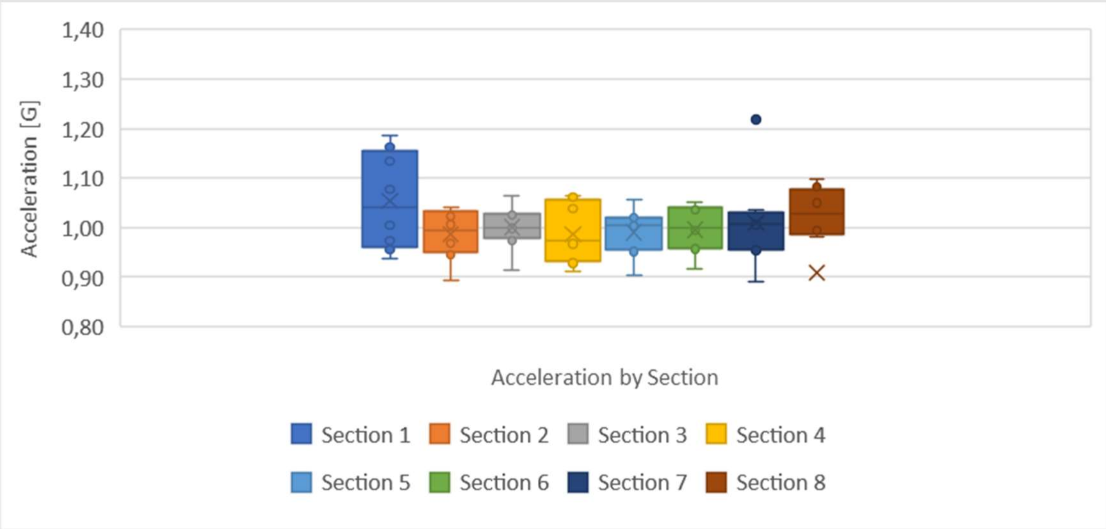

Figure 4-6: Box and Whisker plot for Acceleration measurements by section

Section 1 in Figure 4-7 is highly variable for acceleration experienced. This indicates that the manner in which the picker handles the avocado has a clear effect and is highly variable. The acceleration measured varied between 1.19 G and 0.94 G. The effect of position of the device in the crate had a smaller effect, as the devices in the corner experienced on average 0.96 G and the device in the centre 1.03 G. The truck type had minimal influence as well, as the device in the rigid truck measured on average 0.96 G and the articulated truck measured 1.03 G.

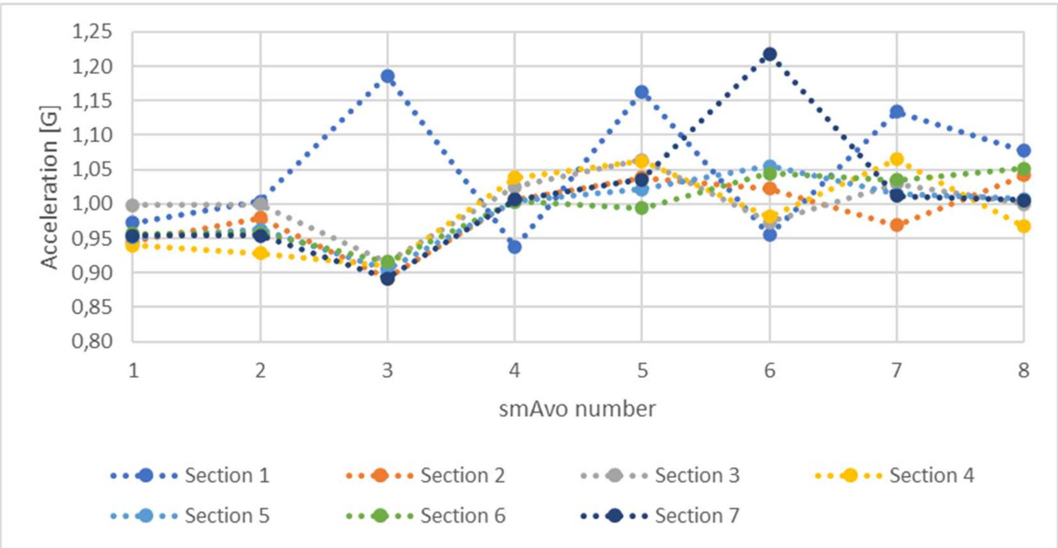

Figure 4-7: Acceleration measured for smAvo 1 to 8

4.2.5 Angular Velocity

The angular velocity measured indicates that there is high levels of movement experienced in Section 8 (the packhouse processes), as seen in Figure 4-8. Section 1 experiences higher velocities, presumably due to the picking action. Section 3 and 6 are portions of the route where the produce is transported over gravel roads. When comparing the two Sections, Section 6 (Jachtpad road), experiences higher velocities than the other road transport portions.

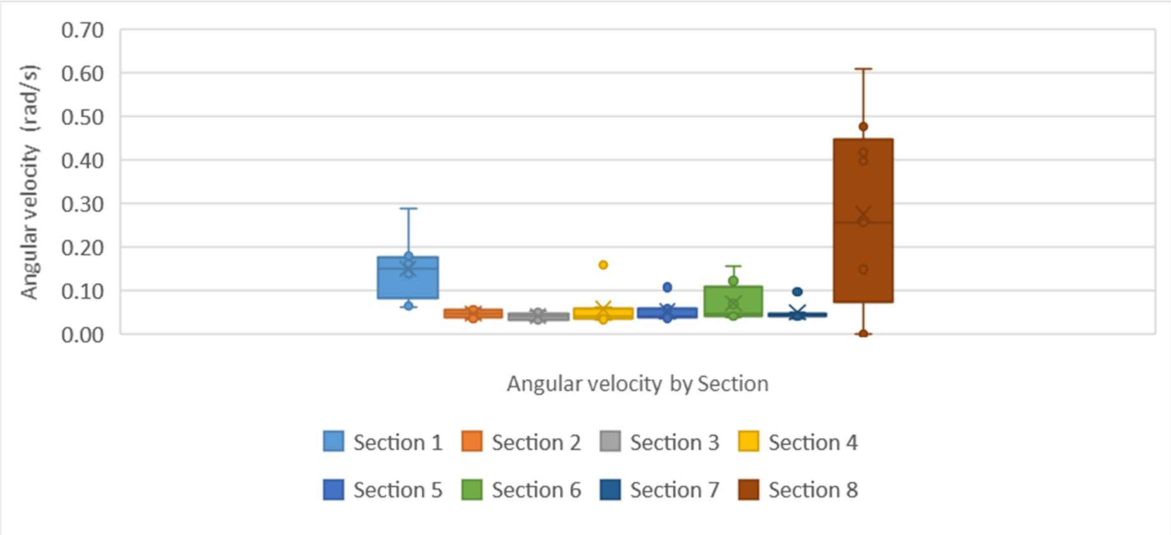

Figure 4-8: Box and Whisker plot for angular velocity measurements by section

Figure 4-9 indicates Section 1 experiences the highest angular velocity when excluding Section 8. The Articulated truck caused higher accelerations than the Rigid truck by a factor of 1.2. There was a substantial difference in the velocity when considering the vertical position in the crate. The device at the top of the crate, when compared to the bottom of the crate, experienced an angular velocity of 1.6 times, compared to the centre at 0.8 times The smAvos experienced a slightly higher acceleration in the centre of the crate than in the corner, by a factor of 1.1.

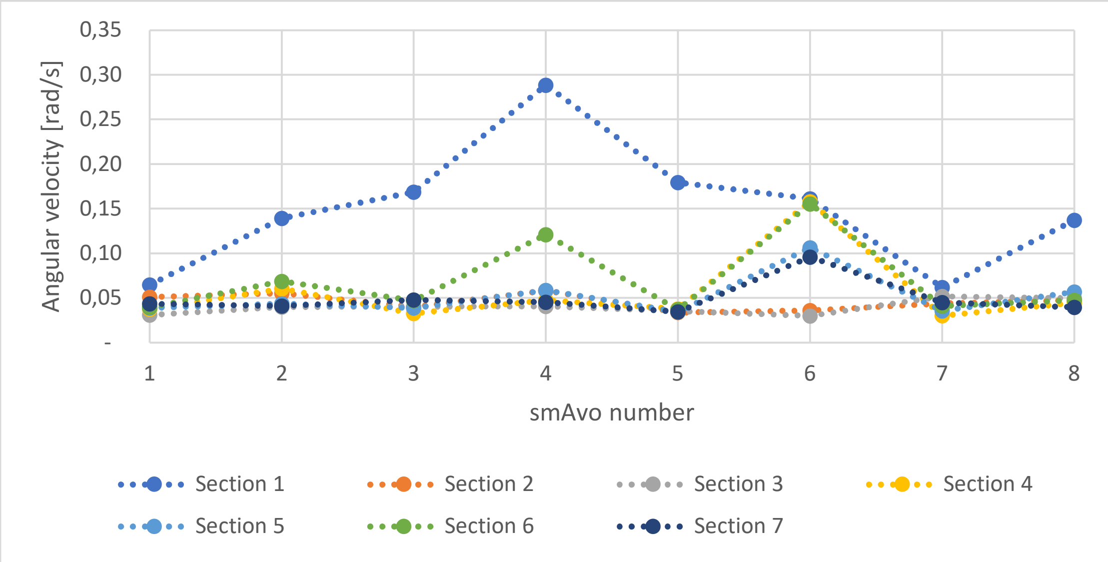

Figure 4-9: Angular velocity measured for smAvo 1 to 8

4.2.6 Light intensity

Light intensity was measured by the smAvo devices, and as seen in Figure 4-10, Section 1 experiences the most amount of sunlight. The following sections experience increasingly less amounts of light, with the exception of Section 8 in the packhouses receiving artificial light.

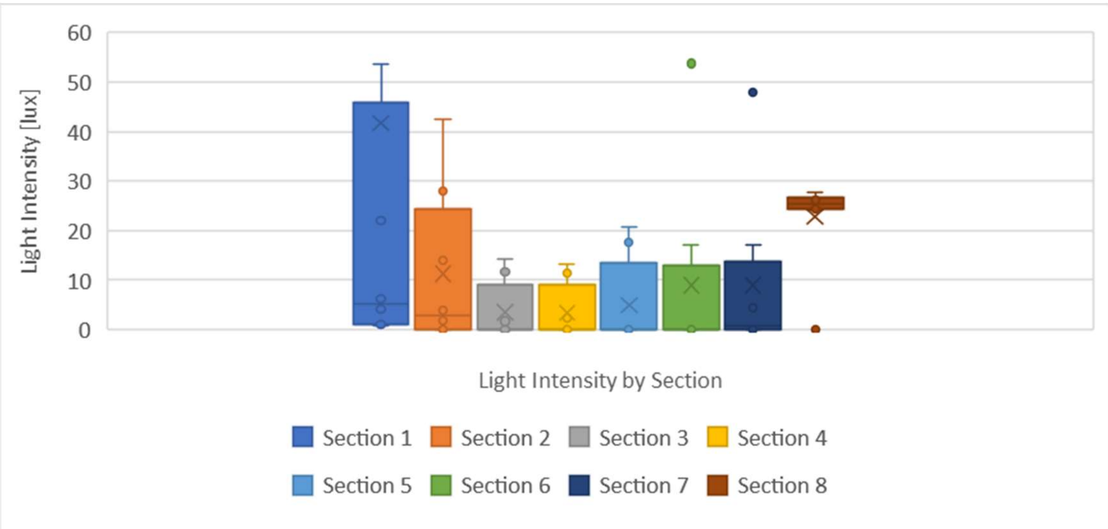

Figure 4-10: Box and Whisker plot for light intensity measurements by section

SmAvo 2 experiences more light in Section 1 than the other devices. This is due to the device being located at the top of the crate. Not all devices which were at the top of the crate picked up large amounts of light, which may be due to the orientation of the device and the sensor being covered.

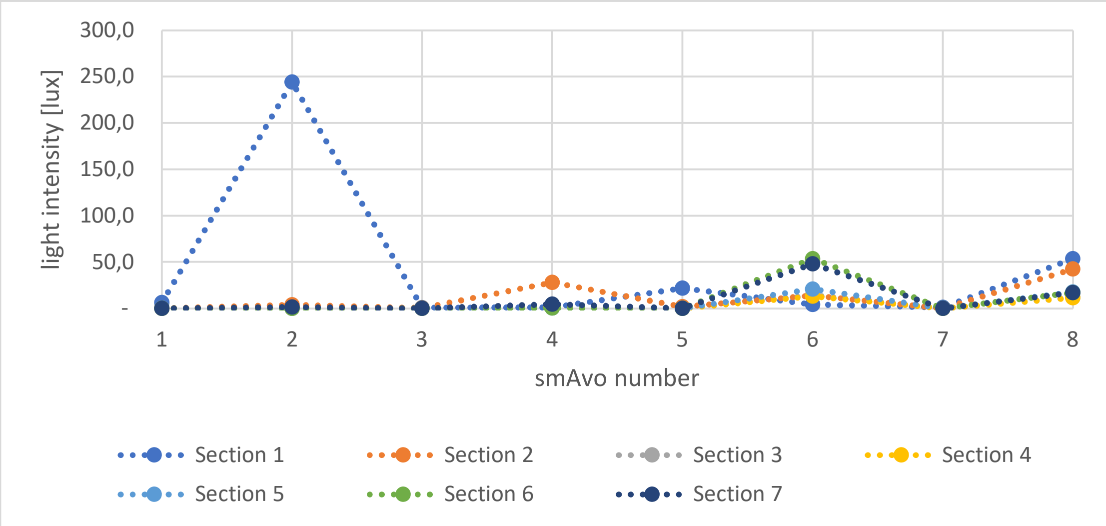

Figure 4-11: Light intensity measured for smAvo 1 to 8

Whiley et al. (2002) stated that avocados should be covered once picked to prevent excess heating, dehydration, sunburn and a general decrease in quality of the fruit. Covering the fruit once picked is beneficial.

As these results indicate, it appears the devices were in shaded areas at the start of the test run. This is not an indication that the produce did not receive high volumes of light during pre-harvest stage, however in the event this is a true indication of pre-harvest conditions it may have an effect on the shelf life of the produce.

4.2.7 Kinetic Energy

Kinetic energy was calculated for each section (Figure 4-12). The product of the rotational velocity measured and the radius of the device was calculated to determine the linear velocity. This was used to calculate the relative kinetic energy exerted on the avocados.

The kinetic energy is expressed as J/kg due to a change in the smAvo weight when improvements were made during the packhouse testing. This allows for a like for like comparison between sections. The results indicate that there is significantly more kinetic energy experienced during the packhouse processes than in any of the other sections.

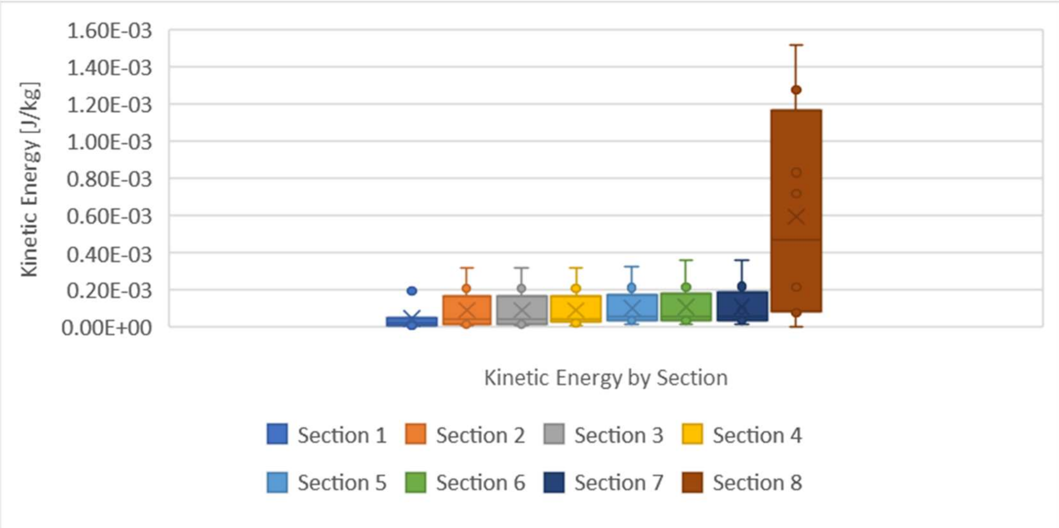

Figure 4-12: Kinetic Energy experienced by section

Upon analysis it was noted that the placement of the smAvo plays a large role in the amount the smAvo moves. It was calculated that the smAvo experienced almost five (5) times as much kinetic energy at the top of the crate than at the bottom of the crate. smAvos at the centre did as much work as each other with the centre devices doing 0.95 times the work as the bottom device. This indicates that the most stable place for the smAvo is in the centre of the crate as movement is very restricted. The device in the corner of the crate did 4.3 times the work as the device located in the centre of the crate.

The Articulated truck resulted in the devices experiencing 4.1 times the work than the Rigid truck. The placement of the crate in the truck had a further influence on the kinetic energy. The crate placed at the top front of the truck did 4.5 times the work than the crate at the centre of the truck, and 1.5 times the work than the crate at the bottom of the truck. The crate at the bottom front did 2.8 times as much work as the centre crate. Due to an error on site, the location of the fourth smAvo run was not recorded and so a fourth location is not analysed.

Realistically there will be a variation in the position of the crate in the truck, as well as the avocados in the crates. It is not practical to transport the produce at half the potential capacity in an attempt to mitigate these risks. Future studies could look into possible mitigation measures, such as fixing crates in the truck, as there is a significant difference in kinetic energy experienced and the position of the avocado in the truck.

The average cumulative kinetic energy across all smAvos tested was calculated and is plotted in Figure 4-13. The Figure illustrates that there is a noticeable increase in kinetic energy experienced in Section 1 and 2, followed by a series of events where minimal work is done in comparison. Until Section 8 where considerable amount of work is done during the packhouse procedure. This indicates that a large amount of damage is done to the fruit at the packhouse when considering these sections.

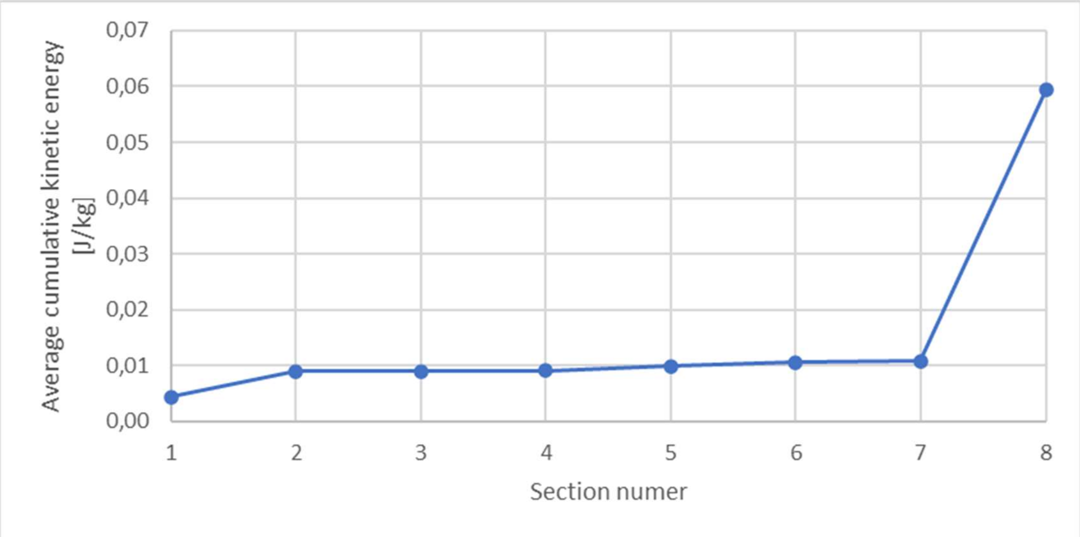

Figure 4-13: Cumulative kinetic energy

4.3 Summary

The data analysis conducted in this Chapter summarising the smAvo data obtained from the field is summarised as follows:

- The temperature experience by the smAvos increased by almost 9 °C on average, and only decreasing once the processed in the packhouse. The temperature was above 26 °C for the majority of the time, this is above the recommended levels according to literature;
- The humidity gradually decreased between sections and all recorded below the harmful levels;

- Acceleration varied significantly between sections and position of the avocado in the crate. The highest accelerations recorded were in Section 1 and 8, followed by Section 4 and 6. The manner in which the workers pick the avocados has a significant effect on the accelerations the avocados experience;
- The avocados experience the highest rotational velocities in Section 8, followed by Section 1 and 6. This further emphasizes the importance on the workers handling of the avocados, the packhouse procedures and the state of the gravel roads;
- The smAvos are exposed to light mostly in Section 1 and 2. There is a risk of sun damage in these sections which is a risk factor although these tests may not be a completely accurate representation of the sun exposure due to the position of the smAvo and its sensor, and
- The kinetic energy was calculated to determine the amount of energy the avocados absorb during the transportation process. There is a sharp increase in kinetic energy in Section 8 that further emphasises the importance of the packhouse network.

It was noted from the analysis that the produce located at the top centre of the crate, and transported in a rigid truck, are more likely to be damaged and have a lower shelf life relative to the other device readings at different positions.

5 BAYESIAN NETWORK DEVELOPMENT

This chapter describes the variable trends and probabilities identified during the data collection phase of this investigation. The various risk factors are identified and scored according to severity based on the variable trends identified in Chapter 5.1, from literature in Chapter 2 and expert knowledge. The process used to identify nodes is partially based on a variation of the HAZOP analysis method. The probabilities that could not be identified during the smAvo investigation have been identified by means of the Delphi Fuzzy Logic method that is detailed in Chapter 5.3 and Appendix B.

Chapter 5.4 illustrates the Bayesian Network developed and quantifies the risks in transporting the avocados from farm to harbour.

5.1 Variable trends

The following subsections discuss the hazard effects from the smAvo data collected.

5.1.1 Kinetic Energy and Road Roughness

Pretorius (2017) noted that high roughness values, i.e. about 8 m/km, which mainly consist of poorly maintained farm roads, result in the top two layers of tomatoes experiencing a significant amount of damage. When compared to roads with a lower roughness value, i.e. 3.5 m/km, the tomatoes at the top layers display significantly less damage. The concluding models indicated that with increasing roughness, the damage to produce is also increased.

The road sections under analysis in this study vary between rough farm roads and less rough asphalt roads. Section 2, 3 and 6 are gravel road sections, where the tractor is the mode of transport in Section 2 and the truck in Section 3 and 6. These sections are considered to have high IRI values and are considered areas where a higher amount of damage can occur.

The kinetic energy difference, as discussed in Chapter 4, between Section 3 to 7 was minimal when compared to the kinetic energy experienced at picking or in the packhouse. When comparing Sections 3 to 6, the highest kinetic energy is felt along Section 5 (R 36), which is the pavement section with the best IRI compared to the other Sections. The next highest kinetic energy is felt in Section 6, followed by Section 4 and then 3.

Due to the varying amount of time spent in each section, the kinetic energy was divided by the average amount of time experienced in each section, as indicated in Figure 5-1. By doing so the effect of each section’s length and time can be taken out of the equation. In doing so the kinetic energy per minute experienced in Section 6 is the highest, followed by Section 4, 5 and 3. This indicates that the gravel Jachtpad section has a significant effect on the smAvo considering the short amount of time spent in this section.

It appears there is some effect the IRI and pavement condition have on the kinetic energy experienced by the smAvo. However, in comparison to other factors such as picking and packhouse procedures, the effect is minimal. Therefore, the rating applied to the IRI difference will be lower than that of the other factors to consider this effect. This is done following the logic that increased kinetic energy is directly proportional to the amount of damage (bruising) the avocado potentially receives.

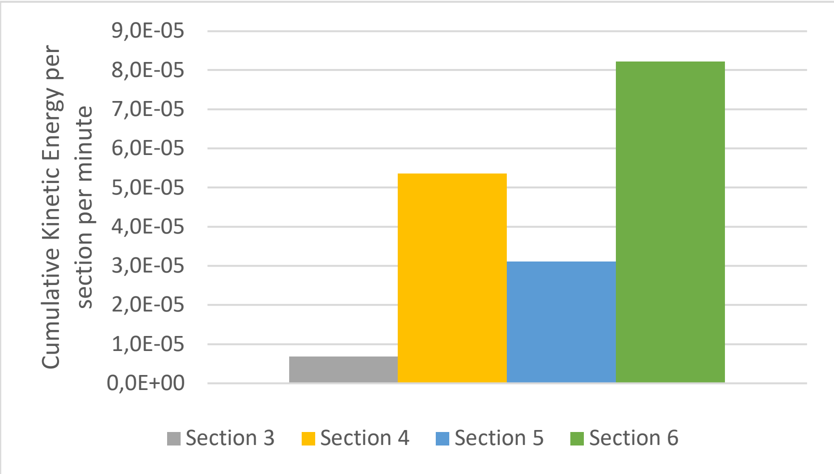

Figure 5-1: Kinetic Energy comparison between Sections 3 to 6

5.1.2 Kinetic Energy and truck type

As discussed in Chapter 4.2.7 the truck type plays a role in the amount of damage done to the avocados. Based on the kinetic energy calculations, the Articulated truck does 4.1 times the damage when compared to the Rigid truck.

5.1.3 Kinetic energy and position in the crate

The position of the crate in the truck and the smAvo in the truck plays a major role in the damage done to the avocado. Whilst it is not practical to partially load a truck or limiting the stacking height of the crates, the crates at the top of the truck are damaged more than the other areas in the truck. The effect has been documented by Jarimopas et al. (2005) as described in Chapter 2.3.2 and has been calculated in Chapter 4.2.7.

5.2 Hazard and risk factors

A HAZOP or Hazard and Operability study provides a detailed method for a systematic examination of a well-defined process or operation, whether the intent is for a planned or existing operation (Crawley et al., 2008). A variation of the systematic examination approach used in the HAZOP studies is used as a technique in this thesis to systematically approach and identify possible risks in agricultural transportation.

In a HAZOP study one must ask what might cause the deviation, which consequences or effects will result due to the risk and which system and actions are available or required to prevent these effects.

It is important to note the difference between hazard and risk. Hazard is a situation which can result in the physical injury of the avocado in this situation, whereas risk can be described as the likelihood of an event happening. This study is focused on identifying the hazard and risk in the transportation network and is not intended to provide solutions to the hazards identified.

Figure 5-2 indicates the processes that occur within each section. These sections are broken down and the effect of the individual parameters on the shelf life of the avocado assessed.

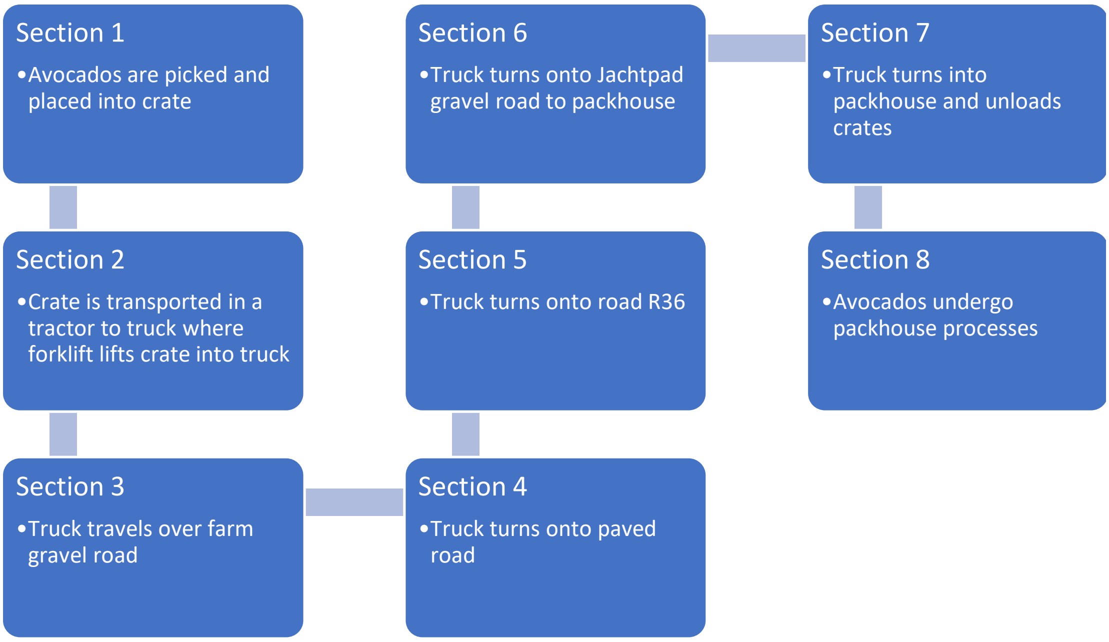

Figure 5-2: Section breakdown and their processes

Each hazard identified contains a state and probability. The effect of each state, representing plausible intervals, has been scored between the range of value of 1 and 5 which will aid in the system analysis in BayesiaLab. The scoring system is structured with 5 as the most detrimental /will reduce shelf life and 1 as a positive or neutral effect.

The scoring system has been introduced to identify whether the particular state of the node has a positive or negative effect on the shelf life of the avocado once it reaches market.

The scoring system used in this study will be:

- 1 - indicating there is a minimal or positive effect on the shelf life;
- 2 - indicating a very small detrimental effect;
- 3- indicating a marginally detrimental effect;
- 4 - indicating some detrimental effect, and
- 5 - indicating there is a large detrimental effect on the shelf life.

Effects and probabilities that will be determined using Fuzzy Logic have been indicated with an ***F*** in the Hazard tables (Table 5-1 to Table 5-4). The remaining probabilities and effects will be determined from literature or smAvo experimentation. The Fuzzy Logic calculations and methodology can be found in Appendix B.

When considering environmental effects, the effect within the truck type and placement in the crate was not considered, only the overall effect. The temperature is above the recommended levels throughout the duration of the transportation network largely due to the local temperature at this time of year. The same is considered for the humidity, however the humidity conditions were not considered damaging. The avocado should not be exposed to sunlight for an extended period to avoid sun damage. However, the placement of the sensor was not reliable enough to determine the amount of sun exposure the avocados received during the entire journey.

Table 5-1 to Table 5-4 contains the hazards identified between the point the avocado is picked from the tree to the point the avocado is packed at the packhouse. Figure 5-3 illustrates where these factors are taken into account in the Bayesian Network. There are interlinking factors that carry a similar risk across sections, which have been shown by the arcs in network.

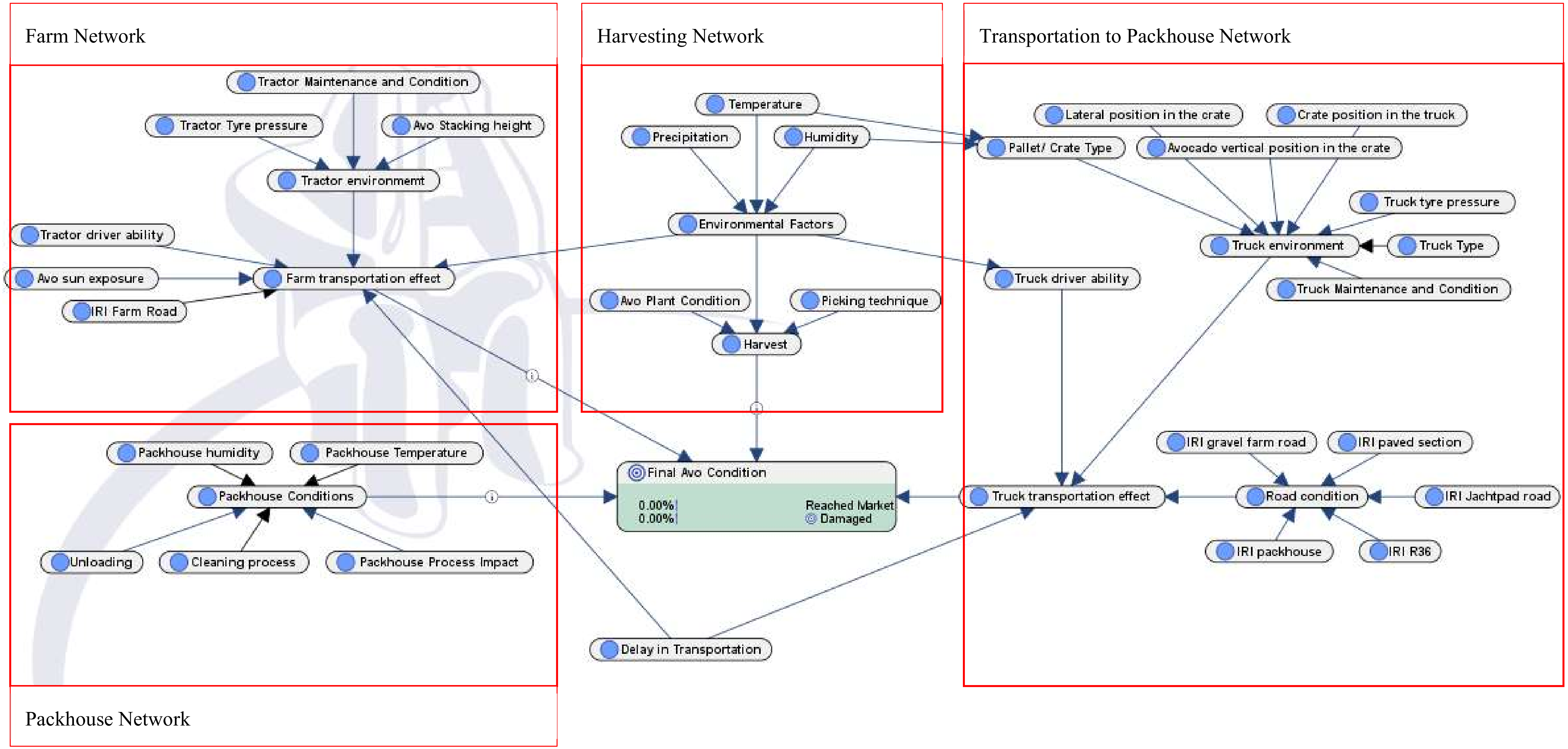

Figure 5-3: Bayesian Network indicating the Hazardous areas withing the supply chain under consideration

5.2.1 Harvesting Network

The harvesting network will encompass all aspects of Section 1.

Table 5-1: Harvest network hazards

Node/ Aspect	Description/ Guide	State and rank		Result and Section
Plant Condition	The condition/ health of the avocado plant.	Healthy	***F***	Effects the overall produce, a plant that is disease ridden cannot give healthy produce. (Chapter 2.2.2)
		Not Healthy		
Picking technique	How gentle are the avocados being picked?	Full hand	***F***	Factors such as temperature, humidity and precipitation could affect the workers work ethic or care taken when picking which can influence the avocado. This increases the risk of scratching or scuffing, bruising or chipping, crushing damage and cracking. (Chapter 2.3.6)
		Partial Hand		
		Stick		
Temperature	How hot is it during the time of picking?	< 13 °C	1	The temperature could affect the workers work ethic as extreme temperatures could cause unfavourable conditions and therefore lead to poor handling. The temperature has an influence on the shelf life of an avocado. (Chapter 2.2.5 and 2.3.6)
		>13 °C and <27 °C	2	
		>27 °C	3	
Precipitation	Is it raining?	No precipitation	1	Precipitation could cause the workers loose their grip on the avocados and decrease work ethic as well as increase the likelihood of disease. (Chapter 2.2.2)
		Light	2	
		Heavy	3	

Node/ Aspect	Description/ Guide	State and rank		Result and Section
Humidity	How humid is it?	< 85	1	High humidity conditions would have the same effect as extreme temperatures. (Chapter 2.2.5)
		≥ 85	3	

5.2.2 Farm network

The farm network encompasses Section 2 in relation to analysis. It should be noted the maintenance, condition and driver ability discussed in this section refers to the farm tractor itself and not the truck tractor-trailer. While it is acknowledged that the tractor-trailer has an influence on the avocado transportation experience, the condition of the tractor is considered the leading hazard in this study.

Table 5-2: Farm network hazards

Node/ Aspect	Description/ Guide	State and rank		Result and Section
Tractor Tyre pressure	Is the vehicles tyre pressure at the correct level?	High	***F***	If the tyre pressure is not at the correct level, the vehicle may experience increased vibrations. (Chapter 2.3.1.2)
		Correct		
		Low		
Tractor maintenance and condition	Is the tractor being maintained regularly?	Often Maintained	***F***	High vehicle vibrations cause damage to the produce. (Chapter 2.3.1.2)
		Rarely Maintained		
Farm track IRI	What is the tracks IRI?	≤ 3	1	IRI ranges have been selected based on a range between a new road and a rough unpaved road. Increased IRI results in an increase in kinetic energy
		>3 and ≤8	2	

Node/ Aspect	Description/ Guide	State and rank		Result and Section
		>8	3	the fruits experience. This may cause mechanical damage on the fruit during transportation. (Chapter 2.3.3 and 5.1.1)
Tractor driver's driving ability	Does the driver avoid unnecessary impact to the produce?	Poor	***F***	Driving in adverse weather conditions or fatigue may increase the likelihood of impact damage. (Chapter 2.3.5)
		Good		
Avocado stacking height	How high are the avocados being stacked?	> 35	5	Stacking heights vary during the process. At harvest it is acceptable to stack avocados up to 35 high, however during transportation only a single layer can remove the risk of scratching and bruising during transport. (Chapter 2.2.1 and 2.2.4)
		> 1 and ≤35	1	
Sunlight	Are the avocados covered once placed in the tractor?	Yes	***F***	It is beneficial to cover the avocados once picked to reduce the risk of excess heating, sunburn or skin discolouration and a general decrease in quality of fruit. A damaged fruit will not sell at market. (Chapter 2.2.2)
		No		
Temperature	How hot is it during the time of picking?	< 13 °C	1	The temperature could affect the tractor driver and result in a rougher with more sudden movements. The temperature has an influence on the shelf life of an avocado. (Chapter 2.2.5 and 2.3.6)
		>13 °C and <27 °C	2	
		>27 °C	3	

Node/ Aspect	Description/ Guide	State and rank		Result and Section
Precipitation	Is it raining?	No precipitation	1	Precipitation can decrease the farm road rideability, as well as increase the likelihood of disease. (Chapter 2.2.2)
		Light	2	
		Heavy	3	
Humidity	How humid is it?	< 85	1	High humidity conditions would have the same effect as extreme temperatures. (Chapter 2.2.5)
		≥ 85	3	

5.2.3 Transport to packhouse network

This analysis covers Section 3 through to 7. The avocados are transported by truck to the packhouse covering varying pavement sections that each have their challenges. As noted in the table the major difference between sections is the pavement conditions and the amount of times the truck would need to stop and start or turn along the route. Therefore, the risk for each section are analysed together.

Table 5-3: Hazards identified during the transportation between farm and packhouse

Node/ Aspect	Description/ Guide	State and rank		Result and Section
IRI	What is the tracks IRI?	≤ 3	1	IRI ranges have been selected based on the range between and new road and a rough unpaved road. Increased IRI results in an increase in kinetic energy the fruits experience. This may cause mechanical damage on the fruit during transportation. (Chapter 2.3.5)
		>3 and ≤8	2	
		>8	3	
		Often Maintained	***F***	

Node/ Aspect	Description/ Guide	State and rank		Result and Section
Truck Maintenance and condition	Is the truck being maintained regularly?	Rarely Maintained		High vehicle vibrations cause damage to the produce. (Chapter 2.3.1.2)
Tractor Tyre pressure	Is the vehicles tyre pressure at the correct level?	High	***F***	If the tyre pressure is not at the correct level, the vehicle may experience increased vibrations. (Chapter 2.3.1.2)
		Correct		
		Low		
Truck driver's driving ability	Does the driver avoid unnecessary impact to the produce?	Poor	***F***	Driving in adverse weather conditions or fatigue may increase the likelihood of impact damage. (Chapter 2.3.5)
		Good		
Truck Type	Whether the truck used was articulated or rigid.	Rigid	1	The truck type may influence the vibrations the avocados experience, to be included during data collection. (Chapter 4.2.4 and 5.1)
		Articulated	4.1	
Temperature	How hot is it during the time of picking?	< 13 °C	1	The temperature could affect the truck driver and result in a rougher with more sudden movements. The temperature has an influence on the shelf life of an avocado. The choice of pallet type could reduce this effect. (Chapter 2.2.5 and 2.3.6)
		>13 °C and <27 °C	2	
		>27 °C	3	
Precipitation	Is it raining?	No precipitation	1	

Node/ Aspect	Description/ Guide	State and rank		Result and Section
		Light	2	Precipitation can make it difficult for the driver to handle the truck and cause more impact damage. (Chapter 2.2.2)
		Heavy	3	
Humidity	How humid is it?	< 85	1	High humidity conditions together with high temperatures may cause the driver to lose concentration as well as decrease the shelf life of the fruit. (Chapter 2.2.5)
		≥ 85	3	
Avocado vertical position in the pallet	What is the position of the avocado in the pallet?	Top layer	5	The effect is noted in Chapter 5.1 and Chapter 4.2.7.
		Middle layer	1	
		Bottom layer	1	
Avocado lateral crate position	What is the lateral position of the crate in the truck?	Corner	4.3	As noted in Chapter 5.1 and Chapter 4.2.7.
		Centre	1	
Crate position	Is the crate located at the top or bottom of the truck?	Top	1.5	As calculated in Chapter 4.2.7 and discussed in 5.1 the crate at the top causes more damage to the avocados than at the bottom.
		Bottom	1	
Truck maintenance	How often is the vehicle maintained?	Often Maintained	***F***	High vehicle vibrations cause damage to the produce. (Chapter 2.3.1.2)
		Rarely Maintained		
Pallet type		Perforated	1	

Node/ Aspect	Description/ Guide	State and rank		Result and Section
	What pallet type is used?	Solid	3	The pallets should allow for efficient air flow for cooling. (Chapter 2.2.4)
Unloading at packhouse	How gently are the crates removed from the truck?	Low impact	1	Any impact the fruit experiences can result in bruising which reduces the shelf life of the fruit. It was noted that out of the 8 unloadings recorded, 1 event recorded significantly more kinetic energy. (Chapter 2.2.4)
		High impact	5	
Journey time from point of harvest/ delay	How long did the avocado take to get from the point of harvest to the packhouse.	≤ 2 hours	***F***	If the journey time from farm to packhouse is longer than 2 hours then the avocado stands at risk of premature ripening. (Chapter 2.2.4)
		>2 hours		

5.2.4 Packhouse network

The packhouse network encompasses the point the avocados are put through the processing facilities to the point the avocados are packed. This section encompasses Section 8, as analysed in Chapter 4.

Table 5-4: Packhouse hazards

Node/ Aspect	Description/ Guide	State and rank		Result and Section
Cleaning processes	Is the packhouse often cleaned?	Clean	***F***	Avocados are continually at risk of disease. A clean packhouse is crucial in preventing further disease.
		Not clean		

Node/ Aspect	Description/ Guide	State and rank		Result and Section
Temperature	How hot is it during the time of picking?	< 13 °C	1	The temperature could affect the truck driver and result in a rougher with more sudden movements. The temperature has an influence on the shelf life of an avocado. The choice of pallet type could reduce this effect.(Chapter 2.2.5 and 2.3.6)
		>13 °C and <27 °C	2	
		>27 °C	3	
Humidity	How humid is it?	< 85	1	High humidity conditions together with high temperatures may cause the driver to lose concentration as well as decrease the shelf life of the fruit. (Chapter 2.2.5)
		≥ 85	3	
Impact	How often are the avocados dropped from a height or experience impact?	High	5	Any form of mechanical injury is detrimental to the shelf life of the avocado. (Chapter 2.2.6)
		Low	1	

5.3 Probabilities

The following subsections indicates the probabilities used in the Bayesian Network. A portion of the probabilities and effects were extracted from literature and data and the remaining portion was derived by means of expert elicitation. The calculations using data from the questionnaires is in Appendix B and discussed in Chapter 3.2.2 and 2.5.1.2.

5.3.1 Probabilities derived from literature and data collection

The known probabilities have been determined from the actual measurements taken by the smAvo instrumentation and are summarised in Table 5-5. The percentage distribution has been calculated by taking the average measurement between all smAvos, as discussed in Chapter 4. Due to lack of available data the IRI probabilities have been estimated based on the road category. The effects were predominantly based on the relative kinetic energy the avocado experiences en route as this is considered the best measure of impact damage which may cause bruising and therefore disease in the fruit.

Table 5-5: Literature and data derived effects and probabilities

Node	State	Probability (%)	Effect
Temperature	< 13 °C	0	1
	>13 °C and <27 °C	0	2
	>27 °C	100	3
Humidity	< 85%	100	1
	≥ 85%	0	3
Precipitation	No precipitation	100	1
	Light	0	2
	Heavy	0	3
Lateral position in the crate	In the corner	50	4.3
	In the centre	50	1
Avocado vertical position in the crate	Top	33.3	5
	Middle	33.3	1
	Bottom	33.3	1
Packhouse Humidity	< 85%	100	1
	≥ 85%	0	3
	< 13 °C	0	1

Node	**State**	**Probability (%)**	**Effect**
Packhouse Temperature	>13 °C and <27 °C	29	2
	>27 °C	71	3
Avocado stacking height	1 to 35	100	1
	>35	0	5
IRI farm road (Section 2)	≤ 3 m/km	0	1
	>3 m/km and ≤8 m/km	90	2
	>8 m/km	10	3
IRI gravel farm road (Section 3)	≤ 3 m/km	0	1
	>3 m/km and ≤8 m/km	90	2
	>8 m/km	10	3
IRI Jachtpad road (Section 4)	≤ 3 m/km	0	1
	>3 m/km and ≤8 m/km	98	2
	>8 m/km	2	3
IRI R36 (Section 5)	≤ 3 m/km	60	1
	>3 m/km and ≤8 m/km	40	2
	>8 m/km	0	3
IRI paved section (Section 6)	≤ 3 m/km	50	1
	>3 m/km and ≤8 m/km	48	2
	>8 m/km	2	3
	≤ 3 m/km	50	1

Node	State	Probability (%)	Effect
IRI packhouse (Section 7)	>3 m/km and ≤8 m/km	50	2
	>8 m/km	0	3
Packhouse Avocado Impact	High	100	5
	Low	0	1
Unloading at the packhouse	Low impact	87.5	1
	High impact	12.5	5

5.3.2 Probabilities derived from fuzzy Logic

The expert knowledge was sought from six experts in the field. The expert's qualifications and experience range between civil engineering, industrial engineering, mechanical engineering and extensive experience within the agricultural transportation industry. The results are summarised in Table 5-6. Further information regarding the exact effect and weighting used for each expert is in Appendix B. The Fuzzy Delphi method was used for this study, with effects ranging between no or positive effect (1) and a detrimental effect (5).

Table 5-6: Hazard probability and effect

Node	State	Probability (%)	Effect
Avocado plant condition	Healthy	92	1.00
	Not healthy	8	4.90
Picking technique	Full hand	33	1.50
	Partial hand	20	1.31
	other detrimental method	47	2.71

Node	State	Probability (%)	Effect
Sunlight	Full sun	16	3.00
	Partial sun	84	1.60
Truck Maintenance and condition	Often Maintained	84	1.22
	Rarely Maintained	16	3.50
Truck tyre pressure	High	19	4.68
	Correct	72	1.32
	Low	9	1.94
Tractor Maintenance and condition	Often Maintained	79	1.12
	Rarely Maintained	21	2.40
Tractor tyre pressure	High	11	3.34
	Correct	76	1.42
	Low	13	1.64
Delay in Transportation	No delay	58	1.07
	Significant delay	42	4.00
Truck or Tractor drivers ability and care taken during transport	no effect on produce	49	1.32
	detrimental effect on produce	51	4.00
Cleanliness of the packhouse	Clean	93	1.32
	Not Clean	7	4.07

5.4 Bayesian Network

The hazards identified in this chapter, along with the respective probabilities and effects have been incorporated into the Bayesian Network. The resulting network is seen in Figure 5-4.

The Conditional Probability Tables (CPT) used in analysis can be found in Appendix C. The conditional probabilities have been determined based on the perceived effect of each node /hazard identified. This effect has been determined by means of Fuzzy Logic and by consulting literature as discussed.

Each hazard has been scored based on its severity in terms of reducing the shelf life of the avocado. The scores range anywhere between 1 and 5, for example, a tractor at the correct tyre pressure can have a score of 1.42 and the tractor with a high tyre pressure can have a score of 3.34. This indicates that the high tyre pressure has a marginally more detrimental effect on the shelf life of the avocado when compared to a tractor with the correct tyre pressure. The probability effect of each of these independent hazards and the combination of the hazards have been calculated in these CPT.

As noted in in Figure 5-4, the current estimated conditions and resulting effects would mean that 99.81 per cent of the avocados picked at ZZ2 will reach their optimum shelf life conditions, when taking into account the possible risks between harvest and the avocado being packed at the packhouse. The damaging effects the avocados are subject to once the avocado is placed into storage and embarks on its journey to overseas consumers is not considered.

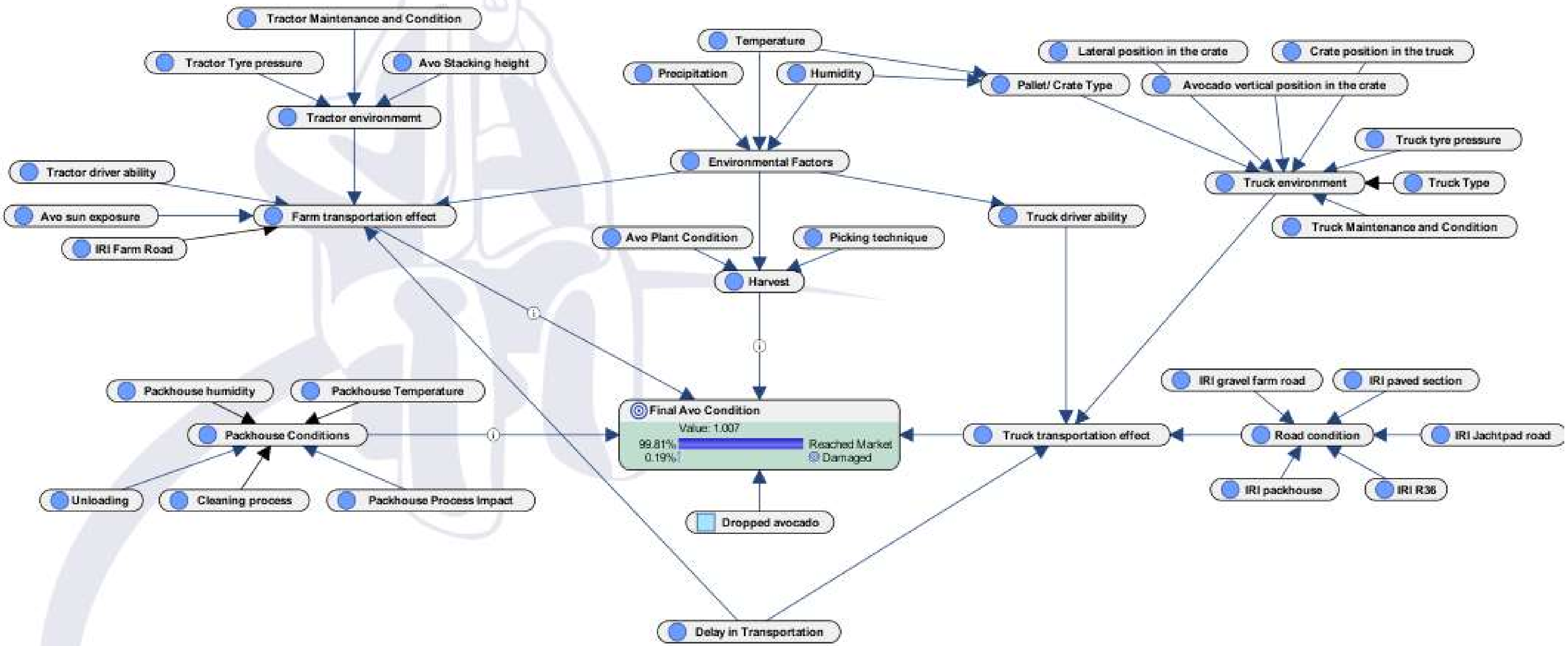

Figure 5-4: Bayesian Network for hazards identified between avocado tree and packhouse

Based on the initial Bayesian Network analysis the chance of damage has been indicated in Table 5-7.

Upon consulting with ZZ2, it was determined that approximately 3 per cent of the produce that is picked and transported to the packhouse gets discarded based on defects or other forms of disease. This evidence can be introduced to the network (and replace the 1.13 per cent initially calculated before any introduction of evidence) and the probabilities for each node can be back calculated and adjusted accordingly. Table 5-7 includes the updated probabilities based on these results.

Table 5-7: Avocado damage

Hazard	Percent damage (per cent)	
	1.13 per cent damaged (prior evidence)	3 per cent damaged (including evidence)
Farm transportation effect	0.29	0.32
Packhouse Conditions	0.47	0.52
Harvest	2.12	2.34
Truck Transportation Effects	1.01	1.12

The table indicates that the two most damaging areas within the network are at harvest and within the truck transportation network. A decision node has been added to the network, which represents the avocado being dropped anywhere along the transportation route. If the node is switched to dropped, the avocado's probability of reaching its full shelf life is reduced to zero immediately. An avocado has very little chance of withstanding high impact damage. This node can also be translated to an unfortunate event where the truck is involved in a collision en route. If this were to occur, the impact would probably result in the entire load being discarded.

BayesiaLab (Bayesia, 2020) has the ability to calculate the arc force. The arc force compares two Joint Probability Distributions within the network for the same set of variables. From this, the node force can be determined, which can be done based on the incoming node force, the outgoing node force or the total node force. Figure 5-5 is a diagram showing the total node force for each node.

The diagram indicates that the nodes with the highest node force is the avocado plant condition, and the delay in transportation. This is then followed by the picking technique, the truck driver ability and the unloading of the avocados at the packhouse.

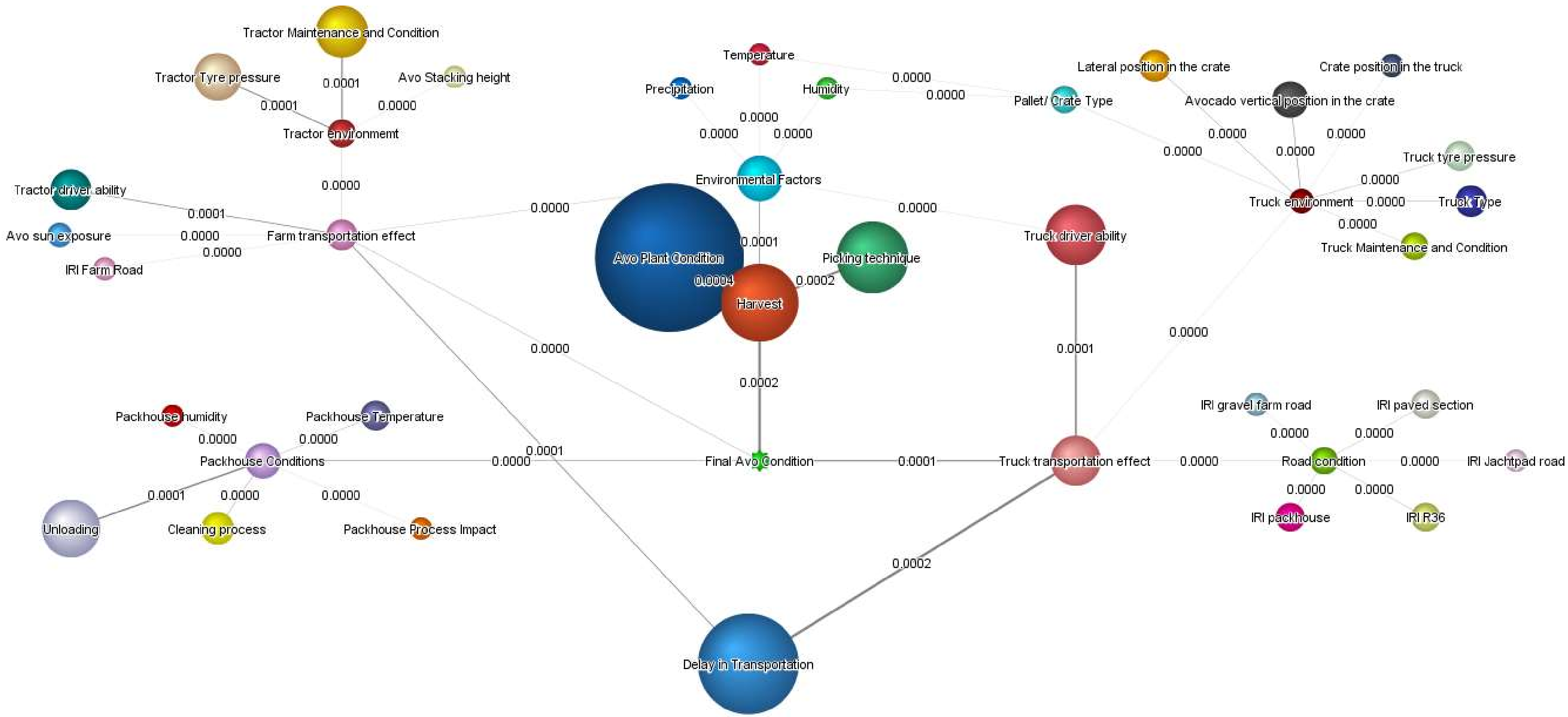

Figure 5-5: Node force diagram resulting from the Bayesian Network

5.5 Summary

This chapter summarises all probabilities and effects used in the Bayesian Network model. The probabilities and effects have been determined from data collected from the smAvo, from literature and from expert elicitation by means of the Fuzzy Delphi method.

By following the steps of this methodology detailed in Chapter 3, literature in Chapter 2 and data analysis in Chapter 4, and taking advantage of the civiltronics available, science and engineering can be used to identify the cause of avocado damage more accurately and therefore eliminate the guessing game. The potential subjective view of possible hazards and risks can be eliminated by using the Delphi Fuzzy methodology and data collected from the smAvos.

6 BAYESIAN NETWORK INTERPRETATION AND DISCUSSION

6.1 Introduction

This chapter discusses the Bayesian Network identified in Chapter 5 for the transportation route between the ZZ2 avocado farm and packhouse. The largest risk factors have been identified and the sequence of events resulting in a loss in shelf life of the avocado have been discussed based on evidential reasoning.

The problem definition is to identify and quantify the key risks, their interrelationship and effect in transporting avocados from farm to packhouse. The interpretation of the Bayesian Network addresses this problem definition, as well as achieving the objective to gain a holistic assessment of the risks affecting the early stages of the supply chain and quantifying these effects.

6.2 Bayesian Network Analysis

A Tornado diagram, as seen in Figure 6-1 to Figure 6-3, resulting from the Bayesian Network identified in Figure 5-4, give a good indication of the relevance of a node in the network. The diagram illustrates how the value or effect of the node /predictions can affect our probability of the target node. In this case the prediction of whether the avocado will have a reduced shelf life, which is in this case the Final Avocado condition. For this study the final avocado condition can only be measured to the point the avocado is processed at the packhouse.

Figure 6-1, is a tornado diagram of all nodes in the network that was obtained by running a target analysis on the network. The target analysis was chosen as opposed to a direct analysis, due the prediction resulting from observations. The nodes with the highest chance of changing the outcome of the avocado (reduced or no reduced shelf life) are situated closer to the top of the graph and those with the least effect are located towards the bottom of the graph.

Figure 6-1 indicates that the Packhouse Temperature, the IRI of the truck transportation route (contributing 0.44 per cent to truck transportation effect damage), environmental effects (contributing 2 per cent to its connecting nodes), avocado stacking height and packhouse impact (i.e. avocados falling and getting bruised).

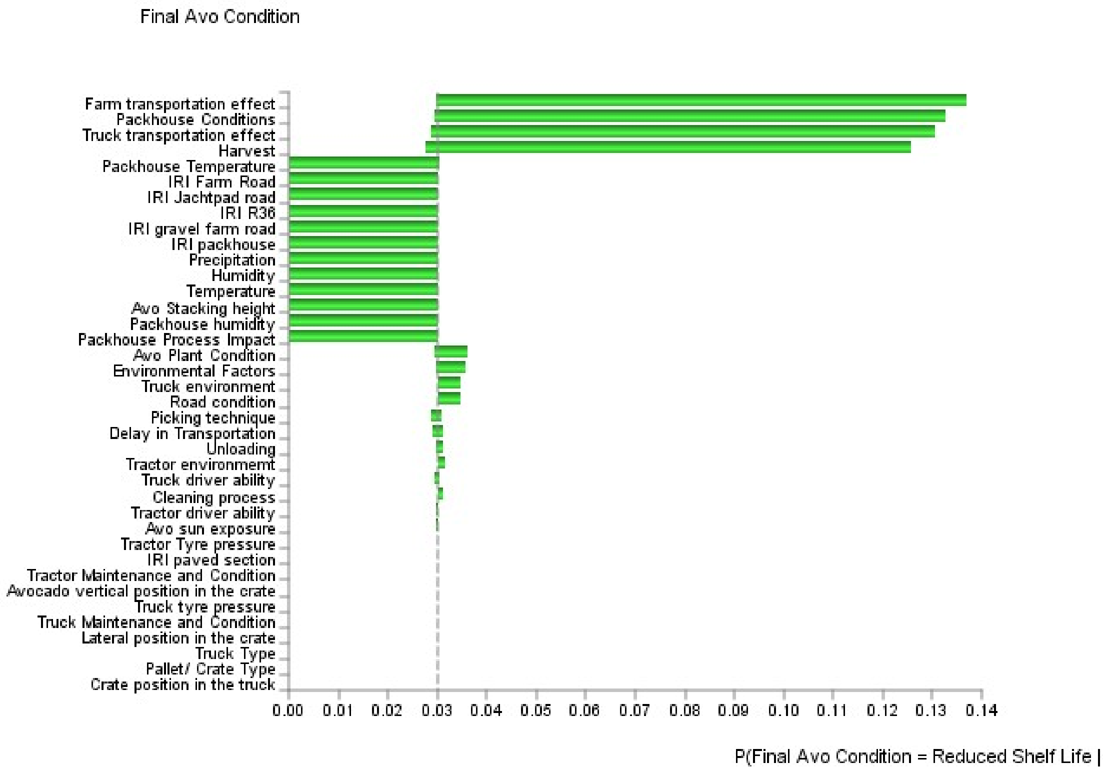

Figure 6-1: Reduced Shelf life /Damaged Tornado Diagram on all nodes

Figure 6-2 and Figure 6-3 indicate that the largest effect on reducing the amount of damage (i.e. reducing the shelf life) on the avocado lies within the packhouse and farm transportation network. The farm transportation network and packhouse conditions play an important role in keeping the damage to a minimum, as they have the potential of causing a lot more damage than is currently experienced. Figure 6-2 indicates that the effect on the produce being damaged or not is symmetrical. This indicates that each variable has the possibility of increasing the chances of the avocado reaching its full shelf life or not, the variable is not necessarily only detrimental to the network.

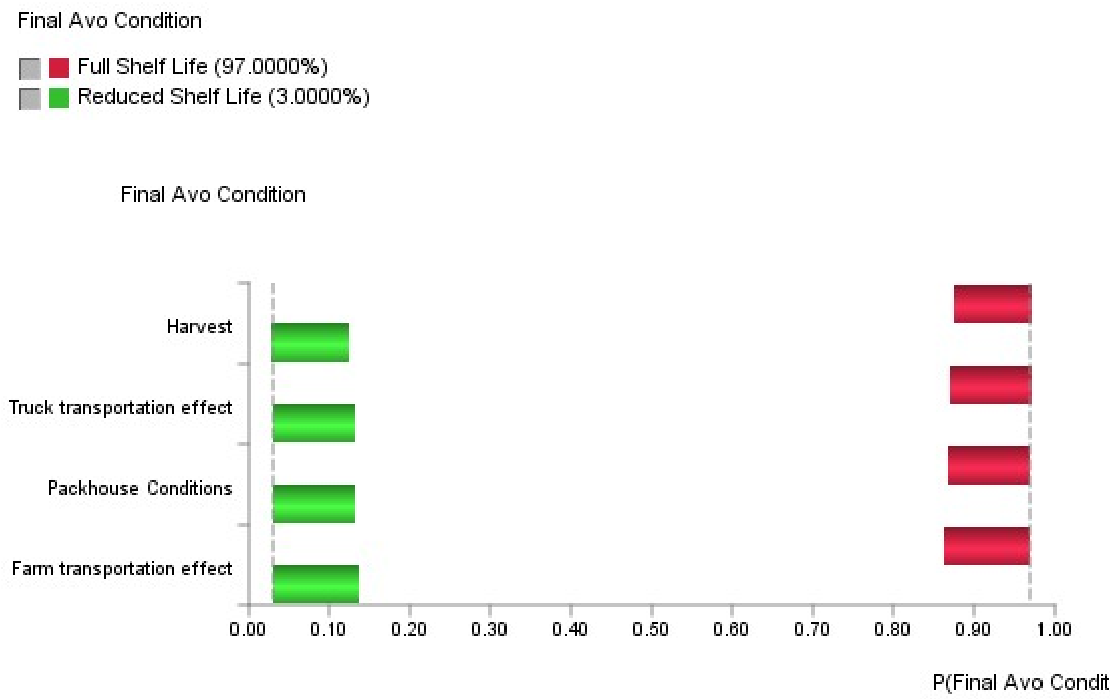

Figure 6-2: Tornado diagram effects on damaged and not damaged avocados

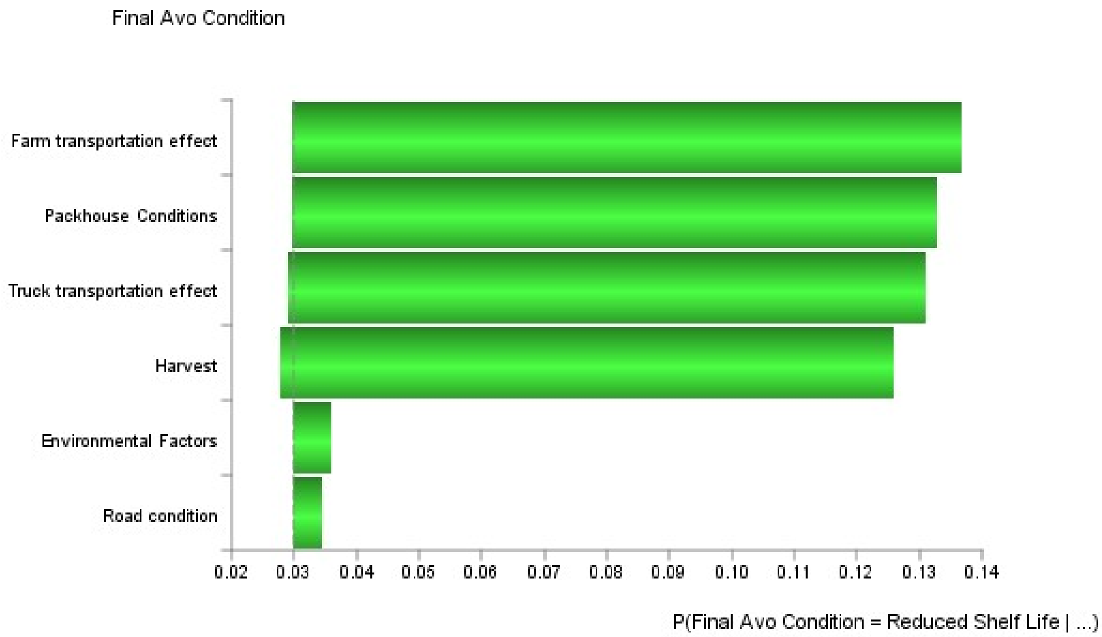

Figure 6-3: Tornado diagram indicating possible damage /reduced shelf life to the avocado

Figure 6-4 indicate the total standardised effect on the final avocado condition compared to the value the hazard adds to the network. The figure, only considering the four main factors within the network, indicates that the harvest has the highest effect on the network and carries the highest weight. When considering literature, pre-harvest fruit disease, such as black spot, has the potential to cause losses of up to 69 per cent in some scenarios (Korsten et al., 1997). However, with the application of pre-harvest fungicides, this loss can be reduced significantly. This analysis shows that it is imperative that the pre-harvest disease is controlled, however the adverse effects should be monitored to avoid detrimental effects to human health. Future analysis should consider these pre-harvest effects on human health and the environment. The picking technique plays a vital role in the harvesting operation, which would help keep mechanical damage to a minimum (Baryeh, 2000).

When taking the smAvo data into account, it was perceived that the Packhouse was the most likely hazard causing a reduction in shelf life. When looking at the cumulative kinetic energy in Chapter 4.2.7, the highest gain in kinetic energy as experienced in the Packhouse (Section 8), with the second highest being in Section 1 (i.e. representing the harvest). Literature tells us that one of the leading causes in avocado damage (and therefore a reduced shelf life) is mechanical or impact damage of any sort which can occur at any point in the transportation network (Van Zeebroeck, et al.,2007). In this analysis the packhouse does not cause as much damage as during harvest, however ZZ2 is known to have sophisticated operations and therefore this effect may vary in different packhouse scenarios.

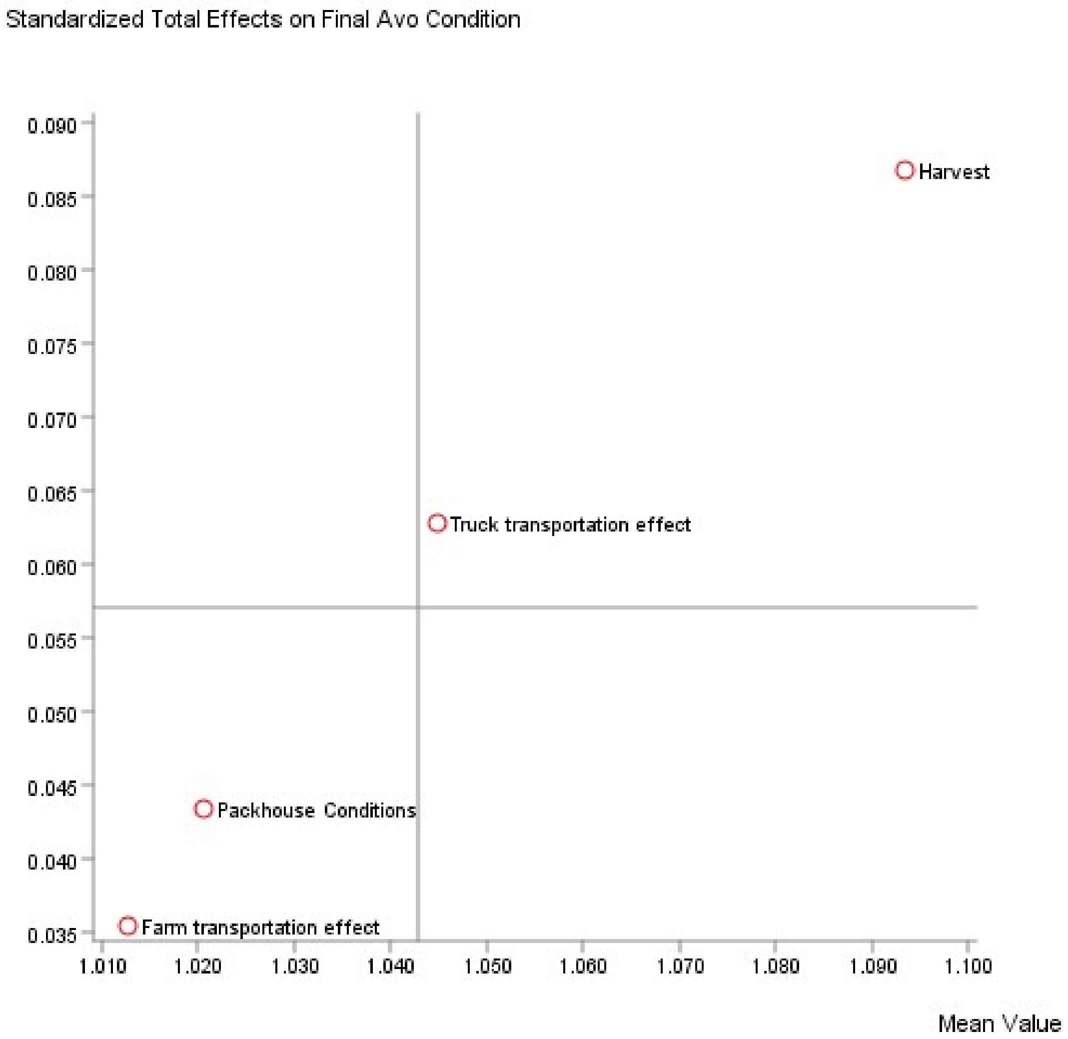

Figure 6-4: Standardised Total effects on Final avocado condition

Figure 6-5 indicates the standardised total effects when considering the total network. The analysis indicates that a large number of the contributing hazards may vary in value. However, the effect on the total network is variable. The Packhouse process, whilst carrying the most damaging value (5 relating to most damaging and 1 to no damage), has a small overall effect on the avocado condition when all aspects are considered. The Truck transportation effect, whilst itself not causing a large amount of damage, having a low value, has a large effect on the condition of the avocado.

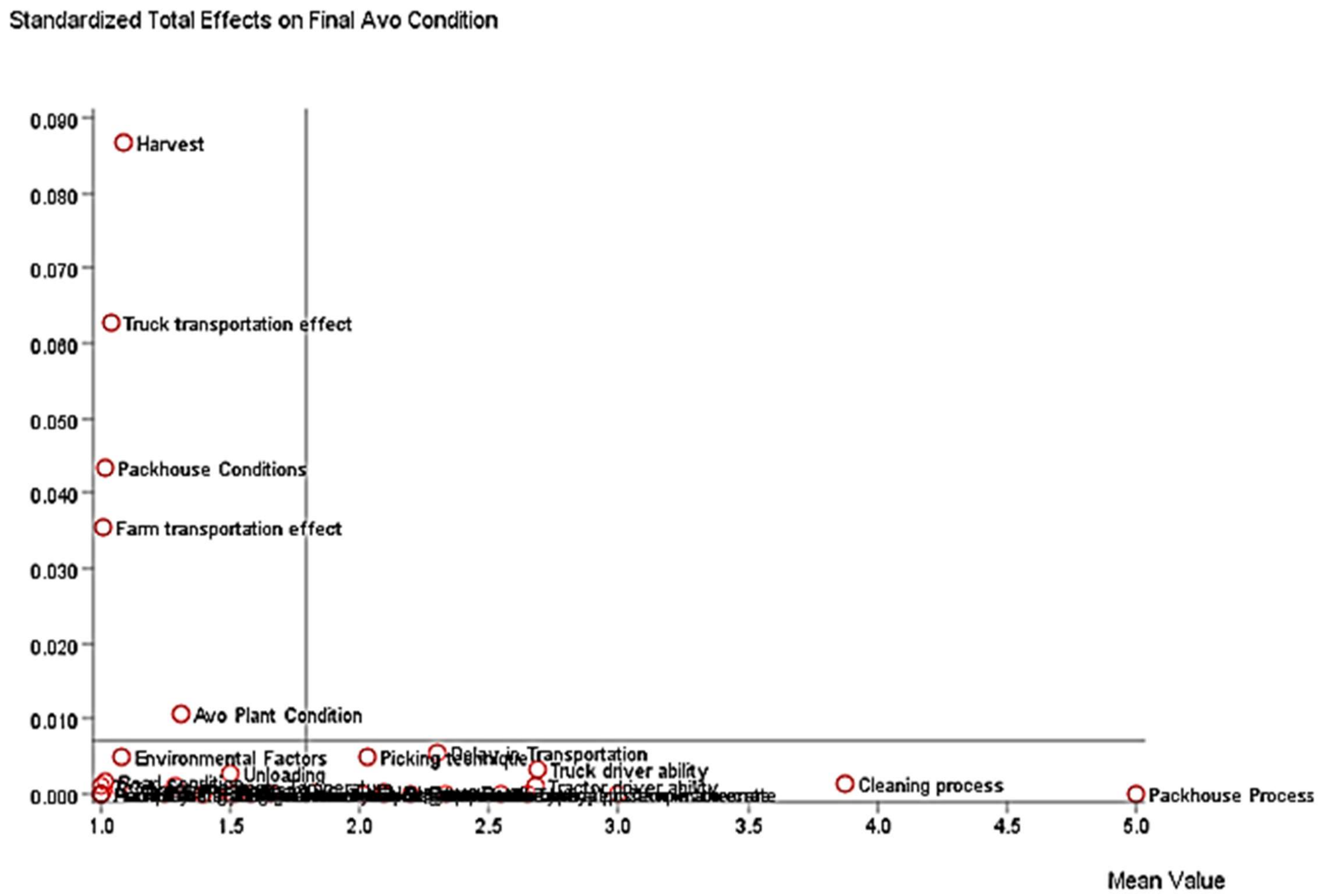

Figure 6-5: Standardised effect considering the total network

6.3 Optimisation

The network was analysed with BayesiaLab in order to obtain the most optimum transportation route by minimising the damaging effect on the avocado. This is done by minimising the percentage damage the avocado experiences.

The optimisation process is done so that the underlying distributions are varied by keeping the distributions as close as possible to the original input. This means that the new solution will be as close to reality as possible. For example, this means that when considering the maintenance of the truck, the possibility that the truck is sometimes not maintained will still be considered, and the probabilities may not necessarily be changed so that the vehicle is always maintained. There is allowance for reality that in some cases the vehicle could be used a few days passed the point the vehicle needs to be maintained.

It is important to note that the effect and value described in Chapter 6.2 does not necessarily directly translate into this optimisation analysis. The optimisation picks out specific values that can be changed which will result in a decreased chance of the avocado not reaching its full shelf life. It is possible that certain areas of the farm transportation network are already optimised and although they can have a large effect on the network, the current conditions are keeping the possible damage to a minimum.

The results from the optimisation check is shown in Table 6-1 (please refer to Appendix D for the full printout of results from BayesiaLab).

Table 6-1: Optimisation variables resulting for the BayesiaLab Optimisation analysis

Node	**Posterior Probability (per cent)**
A priori	*3.0000*
Avo Plant Condition	2.9458
Delay in Transportation	2.8663
Picking technique	2.7738
Unloading	2.7572
Truck driver ability	2.7319
Packhouse Temperature	2.7245
Tractor Driver ability	2.7167
Cleaning process	2.7135
Avo sun exposure	2.7114
IRI Farm Road	2.7113
IRI R36	2.7110
Lateral Position in the crate	2.7110
IRI packhouse	2.7109
IRI paved section	2.7109
Tractor Maintenance and Condition	2.7108
Tractor Tyre pressure	2.7108

The results indicate that the best way to reduce the damage of an avocado is to ensure the avocado plant condition is good (100 per cent healthy), this can reduce the loss to 2.95 per cent. The next best things to do is to eliminate any delay in transportation as this increase any negative environmental effects on the avocados and increase risk of damage, which can result in a reduced 2.87 per cent damage. The avocado plant condition can also be extrapolated to include mechanical damage whilst growing due to abrasion, as well as puncturing from the branches as noted by Van Zeebroeck, et al. (2007).

If the picking techniques used on site is improved (only full hand or at least partial hand, no other detrimental methods are used) and reduced impact is experienced in unloading (no damage is done to the avocado), the damage can be reduced to 2.76 per cent. Improving unloading methods could potentially improve the shelf life of the avocados as some of the damage experienced here (bruising) may only be realised with a loss in shelf life due to the effects presenting themselves once the fruit has matured (Van Zeebroeck, et al.,2007).

If these measures are followed, then when considering a yearly export of 55 000 tonnes of avocados, a 3 per cent loss could be as much as 1 650 tonnes. If a kilogram of avocados were taken as R22.10, then this equates to a yearly loss of approximately R36.5 million. If the loss were to be reduced to 2.76 per cent, then the yearly loss would reduce to R33.5 million, with a total saving of approximately R3 million. This represents a significant gain in yearly revenue.

Once those listed hazards are addressed, there can be a noticeable decrease in damage done to the avocados. From the optimisation analysis done, once the first four nodes are optimised, there is only a small benefit realised in the resulting damage. For example, by varying the truck type, there is only a very small benefit realised in the amount of damage experience.

The Bayesian Network also presents additional cost saving, by avoiding investment into areas that would previously have thought to decrease damage in the produce. The truck or tractor driver ability displayed very little benefit /effect in the overall damage. This can be extrapolated to conclude that sending tractor or truck drivers for training with the intent on making the ride smoother would not provide any additional benefit.

6.4 What-if Analysis

It should be noted that the operation at ZZ2 are very much optimised and therefore a large number of these hazards are already reduced to their optimum. Taking this consideration into account, similar to the optimisation done in Chapter 0, the inverse can be done where the effect of a certain hazard becoming more damaging can be analysed. The nodes can be set at different percentages, so that for example the more damaging farm road IRI condition can be assessed.

Figure 6-6 illustrates the effect of switching these nodes between their current state to a more detrimental state whilst keeping all other variables at their constant level. For example, if all road conditions along the truck transportation route were to deteriorate and therefore increase the IRI, the damage experienced would be at 3.44 per cent, resulting in a decrease in shelf life from what is currently experienced.

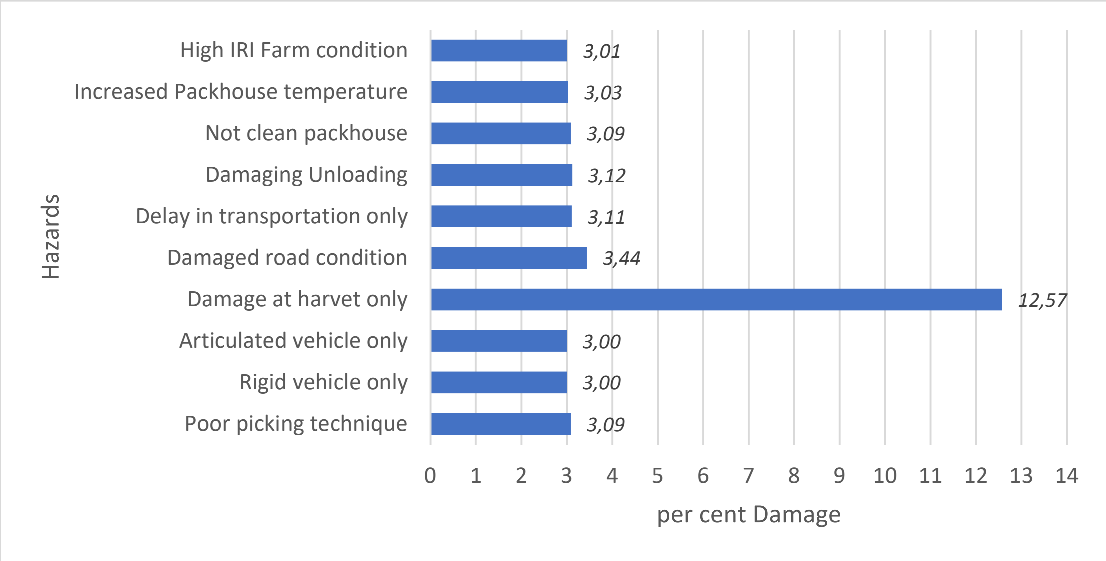

Figure 6-6: Impact Assessment resulting from the what-if analysis

This analysis can be beneficial to farms in identifying what the cause of neglecting or not focusing on a specific hazard along the route can do to the shelf life of avocado. The road condition has the potential of increasing the damage by 0.44 per cent. Converting this damage into a monetary loss (discussed in Chapter 0), this could result in a loss of R5.35 million. This emphasises the importance of maintaining current infrastructure and vehicle-pavement interaction. Similarly, a consistent delay in transportation of over 2 hours could result in a loss of R1.34 million, and poor plant health could result in a loss of R116.3 million. The analysis does indicate that the effect of the truck type has a minimal influence on the damage done to avocados.

This form of "what-if" analysis, along with the optimisation analysis done emphasises the importance of the pre-harvest condition of the plant and fruit as the effect of this has the potential of causing a severe decrease in the shelf life of the fruit.

6.5 Extrapolating and application of the new knowledge

The analysis done with BayesiaLab can be extrapolated from the point the avocado leaves the packhouse to the point the avocado reaches the shelves in shops across the oceans. This analysis identifies where the highest effects, influencing damage the avocado experienced, is realised.

Whilst this analysis does consider impact damage, it is important to note that if at any point the avocado is dropped or any kind of mechanical damage incident occurs within any of these events, the avocado will most likely not be able to reach their full shelf life in supermarkets.

These events have been incorporated into the network by means of including impact damage in packhouses and the picking techniques used for example, as well as a decision node representing an event where the avocado is dropped or an unfortunate major vehicle collision occurs along the route.

6.6 Summary

Data were collected by means of a smart avocado (smAvo) which recorded environmental indicators as well as indicators such as accelerations and GPS readings to name a few. The results, along with an extensive literature review and expert knowledge elicitation were used to derive a Bayesian Network.

The network has been analysed using BayesiaLab. The network was optimised to determine where improvements could be made, and a "what-if" analysis was done considering what would happen if a hazard were neglected. The optimisation results indicated the top nodes one can alter which will result in reducing the avocado damage the most when considering the agricultural transportation networks between the farm (harvest) and the packhouse, including the packhouse procedures.

The analysis concluded in the single most important variable being the avocado plant condition. If the avocado plant is not healthy, there is no chance of the remaining network reducing that damage experienced. From the "what-if" analysis, the effect of not maintaining the orchard could result in a yearly loss of approximately R116.3 million. The second most important factor is the delay in transportation, followed by the picking technique and then the unloading procedures.

The delay in transportation increases the effect of the truck and tractor transportation network. If the picking technique causes mechanical damage, as during the unloading procedures the shelf life of the avocado will be significantly reduced and may not get to the point of leaving the packhouse due to damage.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

Transporting avocados from farm to the supermarket shelves is the primary goal of the agricultural transportation network. To keep damage, and therefore a reduced shelf life and waste, to a minimum a better understanding of the risks and hazards involved in this process is required. Only by understanding these risks (by looking at the network holistically) can there be a meaningful reduction in damage to the transported avocados.

7.2 Conclusion

The main aim of the research was to gain a better understanding of the transport related factors/risks affecting avocados.

The <u>first objective</u> was to gain a better understanding of transportation related risks affecting avocados in order to identify areas causing damage to the fruit, that through mitigation, can reduce waste and increase the shelf life of the fruit.

An extensive literature review was done (Chapter 2), which achieves this objective. The literature review helped gain a better understanding of risks affecting avocados. A large range of hazards were identified during the agricultural transportation of avocados from the point of picking to the point the avocados were processed through the packhouses. The literature study concluded that along with the truck type and road condition, the temperature, humidity and general handling of the product for example within the truck, have the potential to reduce the quality of the avocado and should therefore be considered in the Bayesian Network.

The <u>second objective</u> was to quantify the impacts and risk factors involved in the transportation of avocados from farm to packhouse using data from an artificial smart avocado (smAvo). The <u>third objective</u> was to develop a Bayesian Network model which will provide a holistic assessment of the risks affecting the early stages of the avocado supply chain.

The data collected from the artificial smart avocado was used alongside the data obtained from expert elicitation. This was used to construct a Bayesian Network which would provide a holistic assessment of the risks affecting this early stage of the supply chain.

In summary and as noted in Figure 6-1, the main encompassing hazards (i.e. having an ability to increase/decrease the damage done to the avocados) identified in the network are as follows and have been quantified in the study:

- Farm transportation effects (0.32 per cent);
- Packhouse conditions (0.52 per cent);
- Truck transportation effects (1.12 per cent), and
- Harvest (2.34 per cent).

These effects were not necessarily the top optimisation tools identified, which may be attributed to the positive conditions already experienced in the network.

Using BayesiaLab the risks were updated based on evidence received from the farm and the most hazardous sections were identified by means of analysis. The network was run through optimisation tools and the events that would have the largest impact on decreasing the amount of damage the avocados are subject to were identified. These events are as follows:

- Ensure the avocado plant is 100 per cent healthy which can reduce the avocado loss to 2.95 per cent;
- Eliminate any delay in transportation which may amplify the environmental (high temperatures) effects and the avocado loss can be reduces to 2.87 per cent, and
- The picking techniques should be improved to avoid any mechanical damage that results in bruising, therefore only a full or partial hand should be used as a picking method. This will reduce the risk to 2.76 per cent according to the Bayesian Network.

The analysis aided in indicating areas that would not provide a large benefit in reducing the resulting damage. These include additional truck or tractor driver training if their ability is already considered good.

The fourth objective was to quantify and rank the risks within a sequence of events along the avocado journey from farm to packhouse through developing a Bayesian Network with data collected.

The "what-if" analysis highlighted the effect of neglecting certain hazards in the transportation route. This includes ensuring the current assets and roads used for transport are maintained. The operations at ZZ2 are already optimised to a high level and so the effect of poorer road conditions and harvest operations should be considered. The results are as follows (therefore completing the fourth objective):

- Poor Farm Road IRI conditions increases damage by 0.01 per cent;
- Increased delay in transportation increases potential damage by 0.11 per cent;
- Poor road conditions the truck travels on could increase damage by 0.44 per cent, and
- Poor harvest conditions could increase damage to 12.57 per cent to name a few.

By taking a holistic view of the possible risks to the avocado, the areas which can be improved and would have the most impact on decreasing waste have been identified.

In conclusion, the analysis succeeded in identifying areas where the transportation network can be improved. The analysis demonstrates that factors such as poor plant health can result in losses of approximately R116.3 million. By using this analysis technique of considering data collecting in the field by smAvos, expert elicitation and Bayesian Networks, the guesswork of how one can increase the shelf life of avocados can be eliminated.

The study combines expert knowledge gained over years of farming and science and technology in reducing produce loss, increasing their shelf life and increasing profits. This study can help farmers optimise their supply chain following a scientific process.

7.3 Recommendations

The following recommendations should be considered for research continuation:

- The Bayesian Network should be continually updated based on new knowledge gained and the effect therefore compared to predictions;
- The study can be extended to pre-harvest effects of fungicides on the environment, human health and their relation to shelf life;
- The maintenance history and maintenance techniques used on the roads during transportation could be taken into account and related to the IRI of the road sections. This would help farmers draw parallels and relate the IRI and maintenance routines to fruit damage;
- The expert base used in the Delphi Fuzzy Logic method could be expanded in subsequent studies to improve estimations;
- The study can be extended past the packhouse procedures to the point the avocados reach overseas markets which would help identify additional hazards and their effects, and

- The study can be broadened to include other farms and packhouses, as well as seasonal effects, to build a wider view of the general pitfalls in the agricultural transportation network.

7.4 Limitations

The following limitations were identified in this study:

- The availability of accurate pavement condition data, specifically IRI data which would aid in accurately predicting the damage done to the avocado;
- The experts used in the Delphi Fuzzy Logic method was limited to the contact base at present and can be extended to a wider range of experts which would improve the estimations, and
- Restrictions due to the pandemic caused by Covid-19 has prevented additional on-site testing, such as the pavement assessments and additional smAvo tests.

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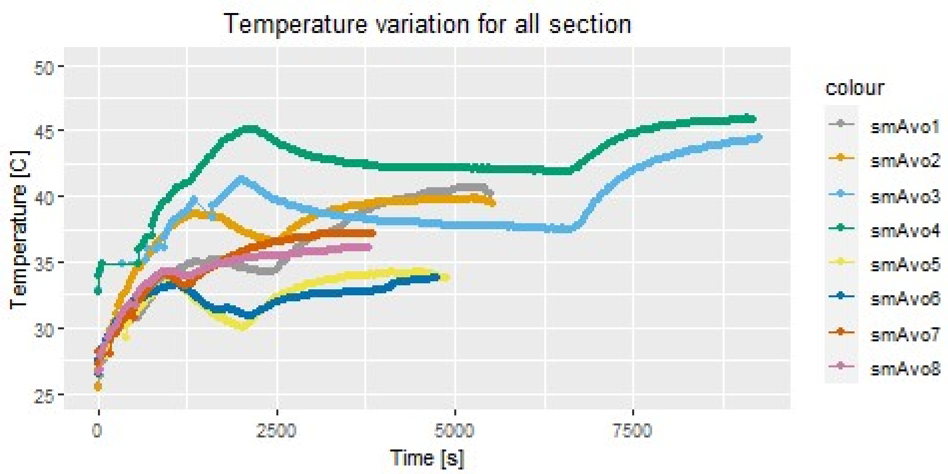
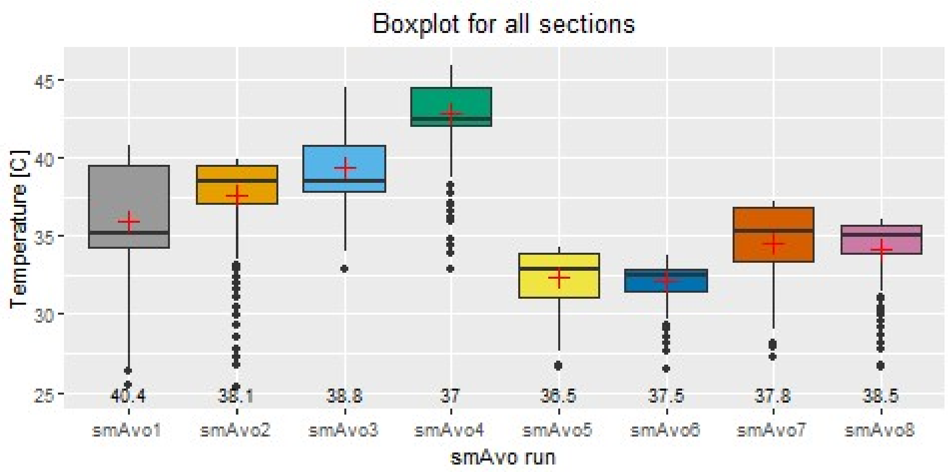
APPENDIX A

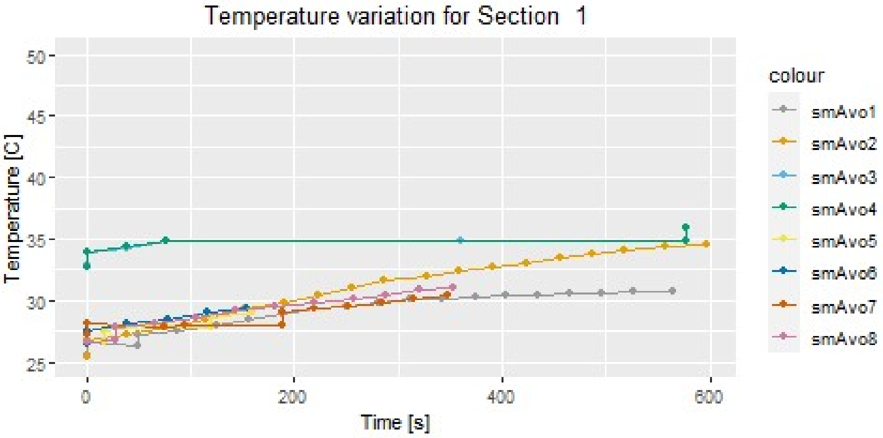
smAvo Data

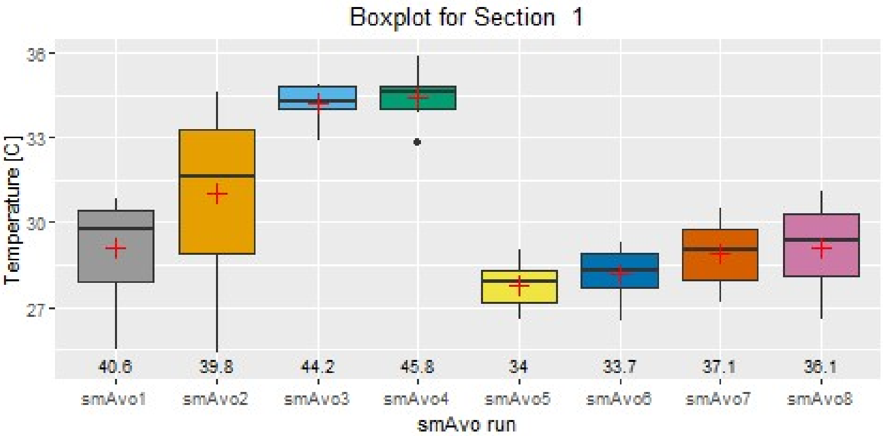
The graphs indicated in this appendix are summaries of the raw data collected from the smAvo devices.

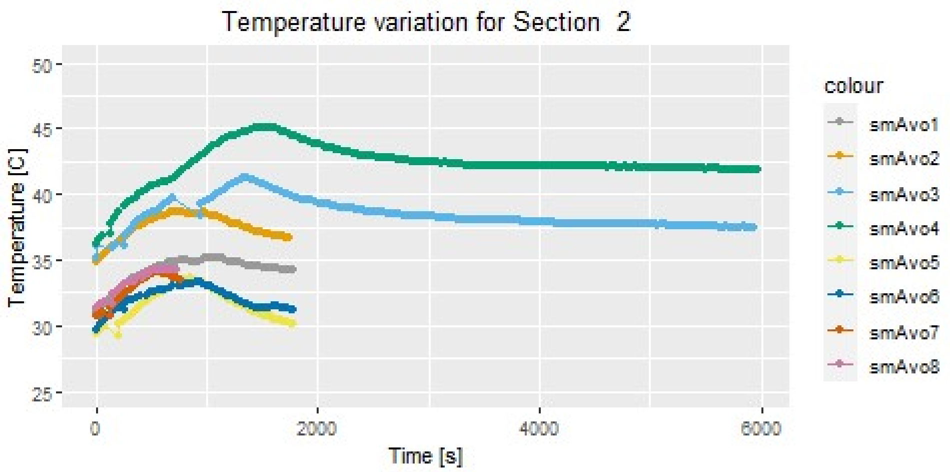
Temperature

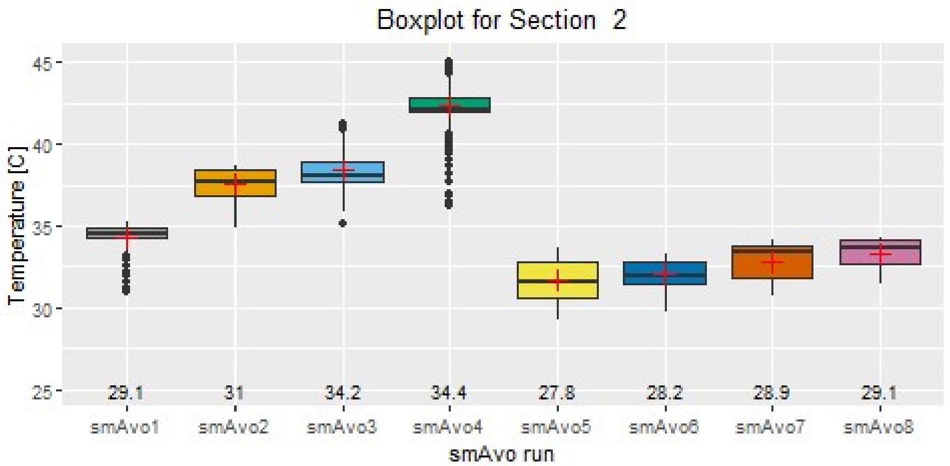


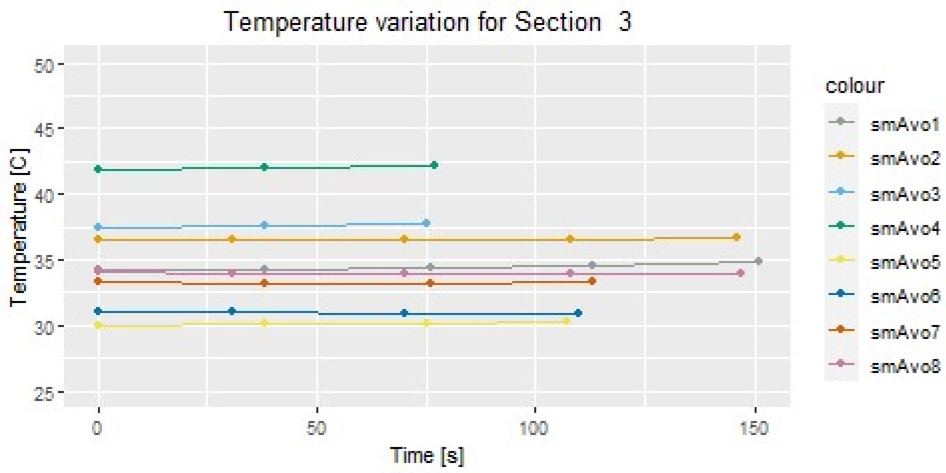


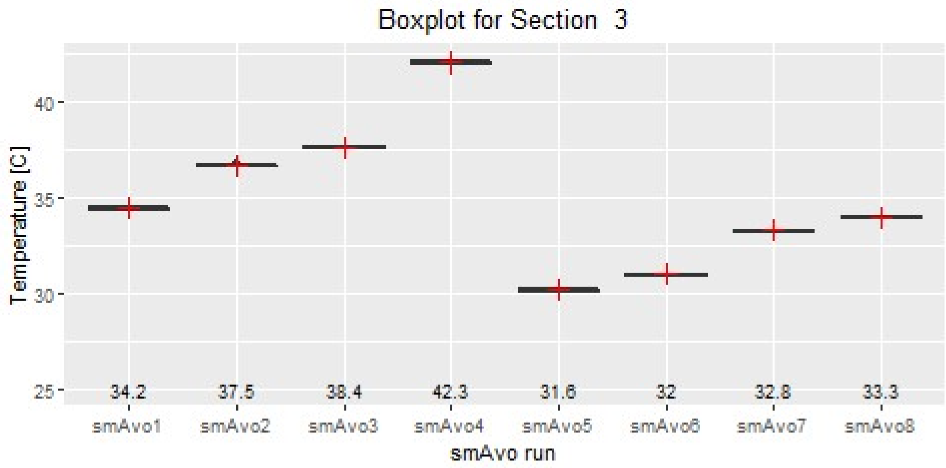

Temperature variation for Section 1
Temperature [C]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

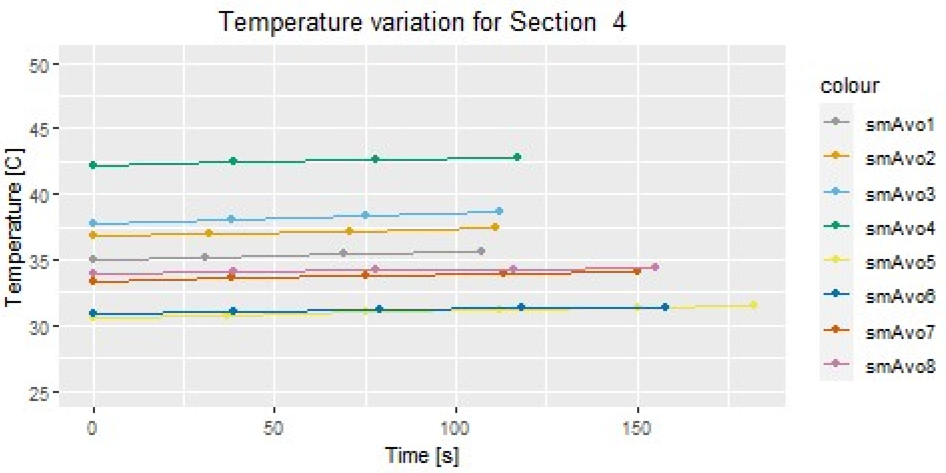

Boxplot for Section 1
Temperature [C]
40.6
39.8
44.2
45.8
34
33.7
37.1
36.1
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

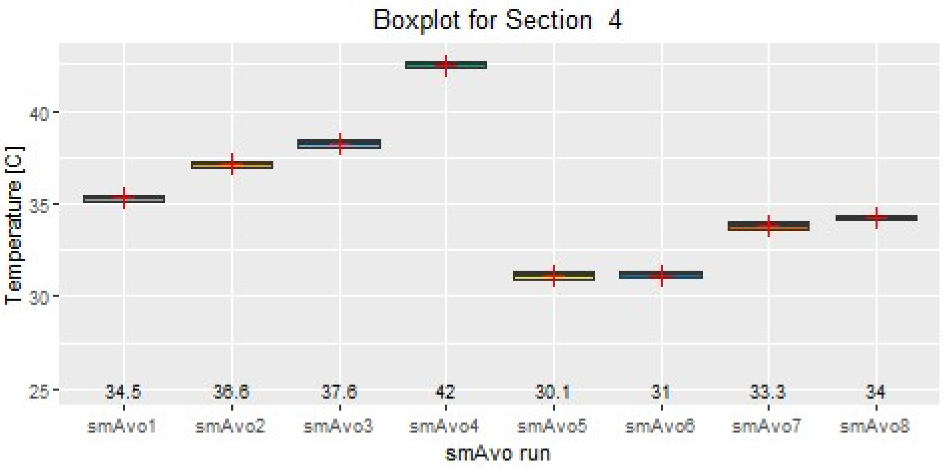

Temperature variation for Section 2
Temperature [C]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

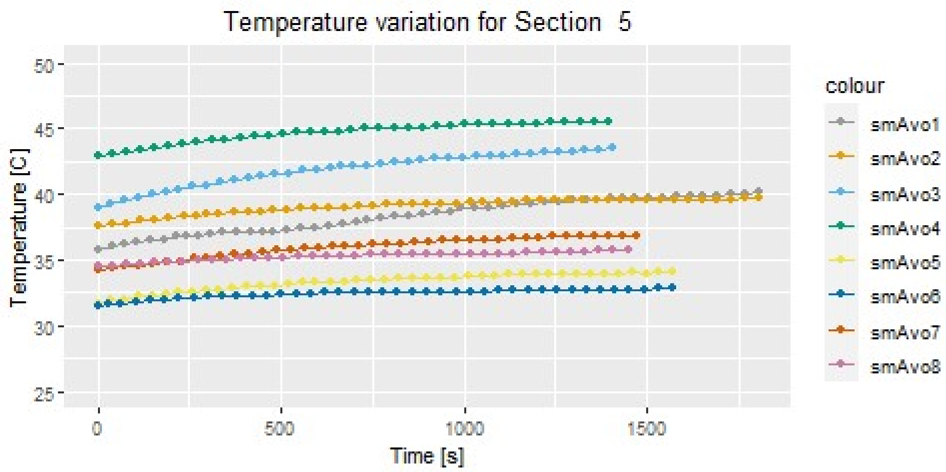

Boxplot for Section 2
Temperature [C]
29.1
31
34.2
34.4
27.8
28.2
28.9
29.1
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

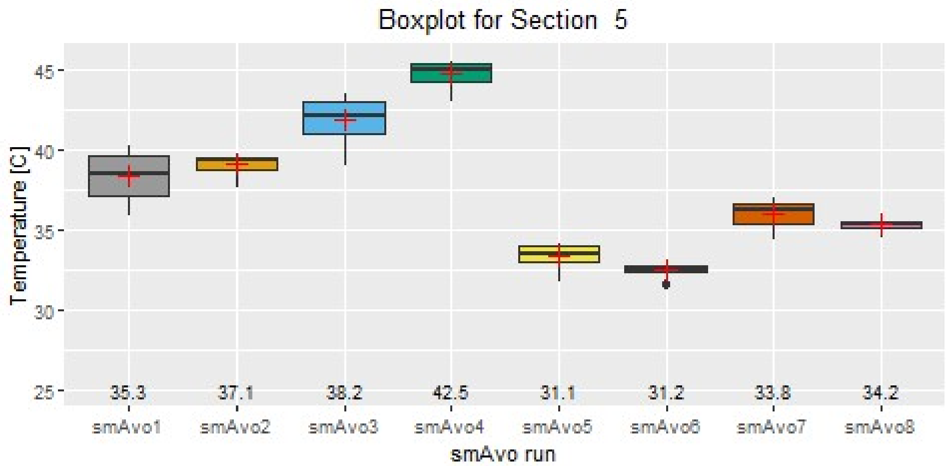

Temperature variation for Section 3
Temperature [C]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

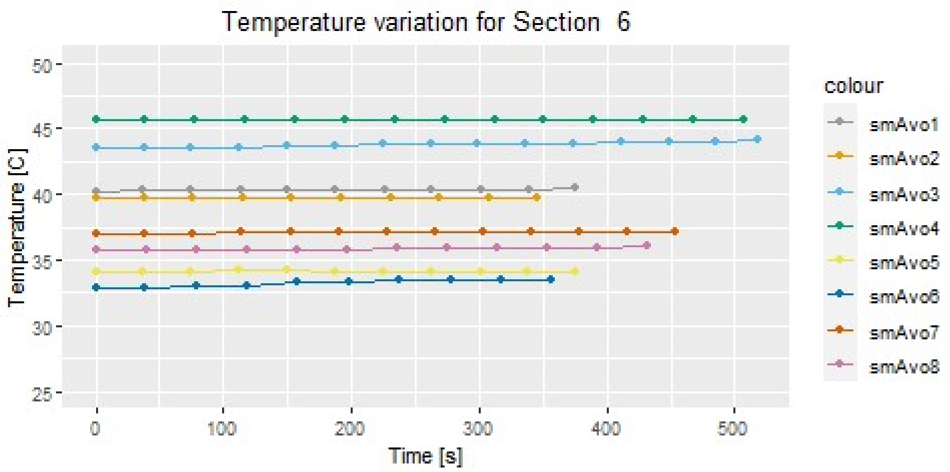

Boxplot for Section 3
Temperature [C]
34.2
37.5
38.4
42.3
31.6
32
32.8
33.3
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

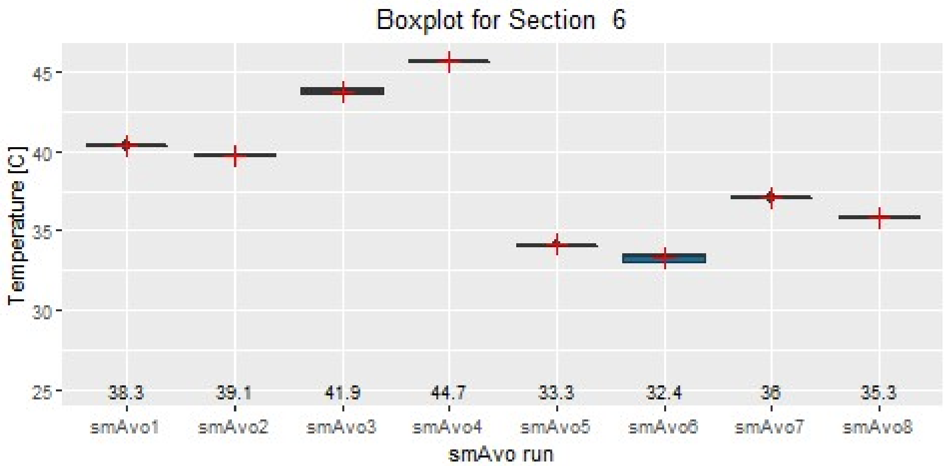

Temperature variation for Section 4
Temperature [C]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

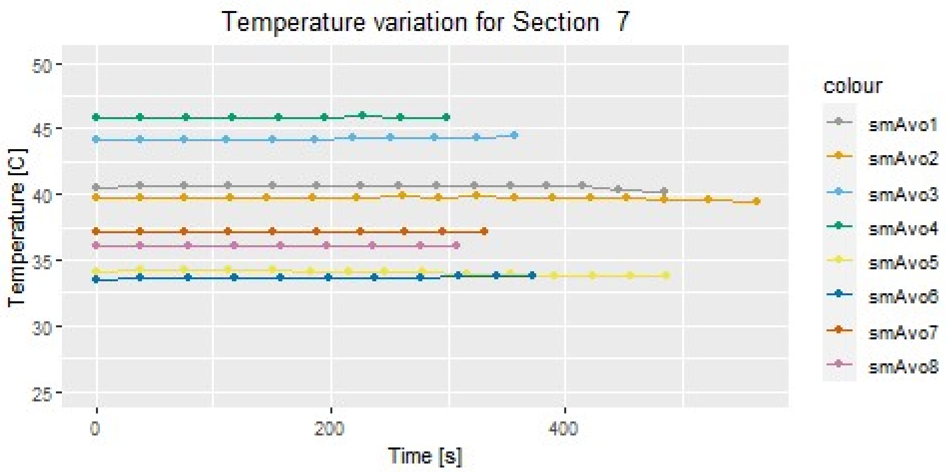

Boxplot for Section 4
Temperature [C]
34.5
36.6
37.6
42
30.1
31
33.3
34
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run


Temperature variation for Section 5
Temperature [C]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
50
45
40
35
30
25
0
500
1000
1500

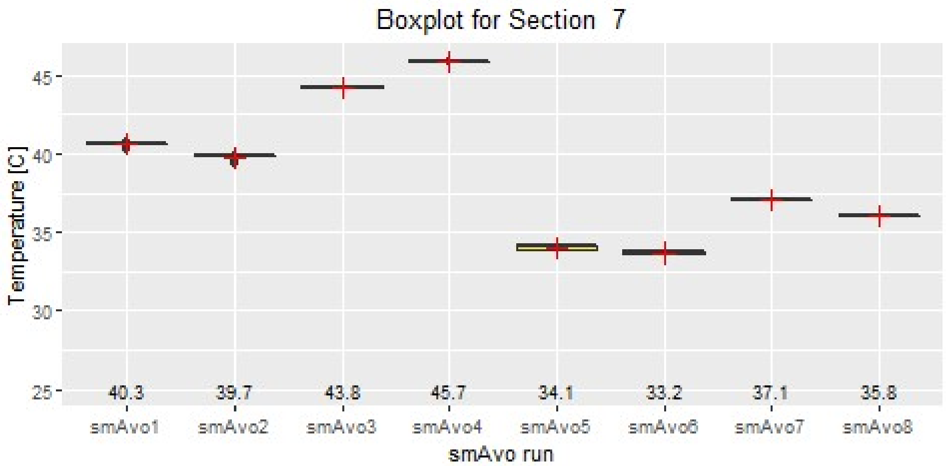

Boxplot for Section 5
Temperature [C]
smAvo run
45
40
35
30
25
35.3
37.1
38.2
42.5
31.1
31.2
33.8
34.2
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8


Temperature variation for Section 6
Temperature [C]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8


Boxplot for Section 6
Temperature [C]
38.3
39.1
41.9
44.7
33.3
32.4
36
35.3
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

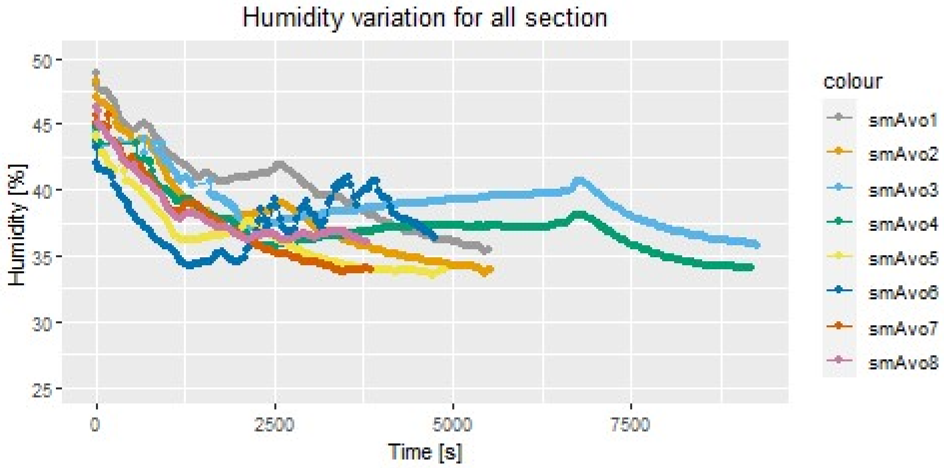


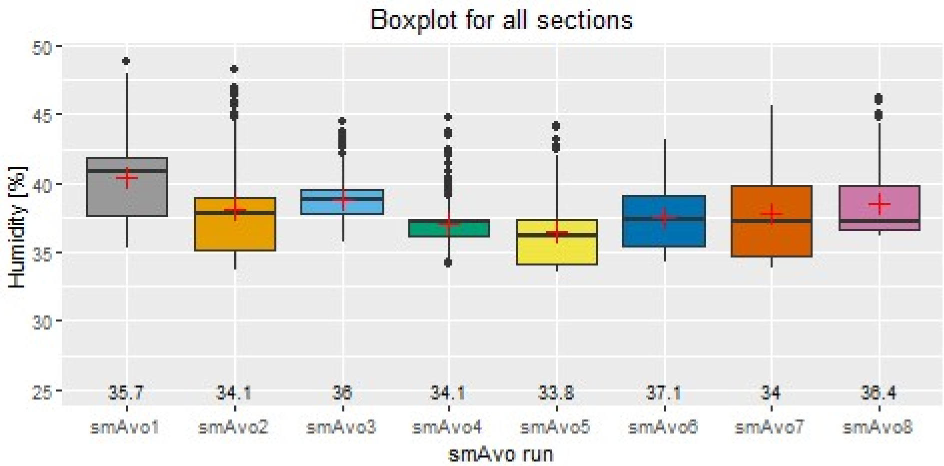
Temperature variation for Section 7
Temperature [C]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

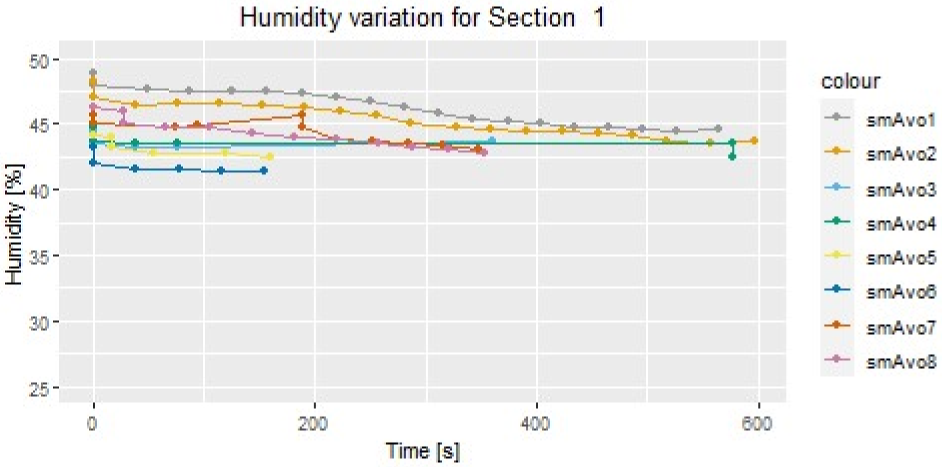


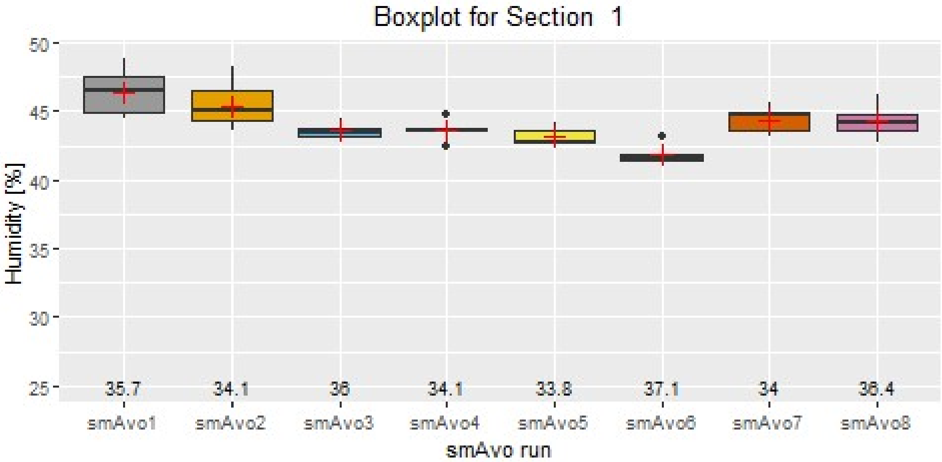
Boxplot for Section 7
Temperature [C]
40.3
39.7
43.8
45.7
34.1
33.2
37.1
35.8
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

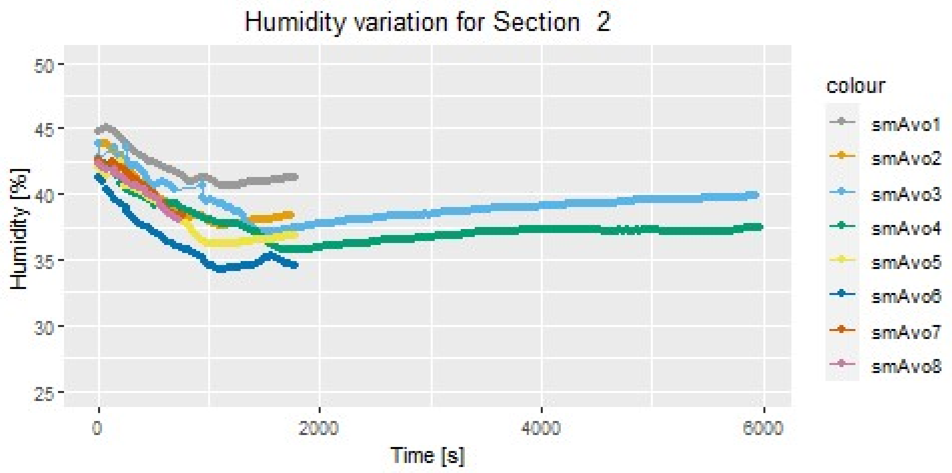
Humidity

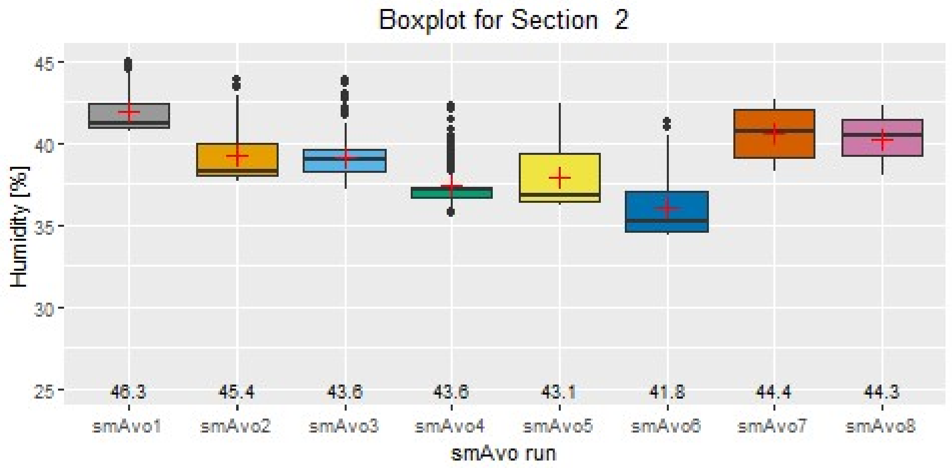

Humidity variation for all section
Humidity [%]
50
45
40
35
30
25
0
2500
5000
7500
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8


Boxplot for all sections
Humidity [%]
50
45
40
35
30
25
35.7
34.1
36
34.1
33.8
37.1
34
36.4
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run


Humidity variation for Section 1
Humidity [%]
50
45
40
35
30
25
0
200
400
600
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8


Boxplot for Section 1
Humidity [%]
50
45
40
35
30
25
35.7
34.1
36
34.1
33.8
37.1
34
36.4
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run


Humidity variation for Section 2
50
45
40
35
30
25
Humidity [%]
0
2000
4000
6000
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8


Boxplot for Section 2
45
40
35
30
25
Humidity [%]
46.3
45.4
43.6
43.6
43.1
41.8
44.4
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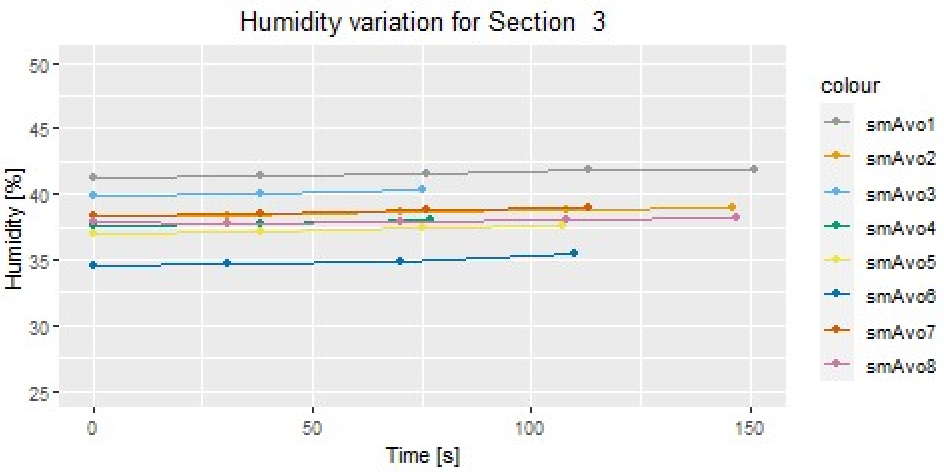
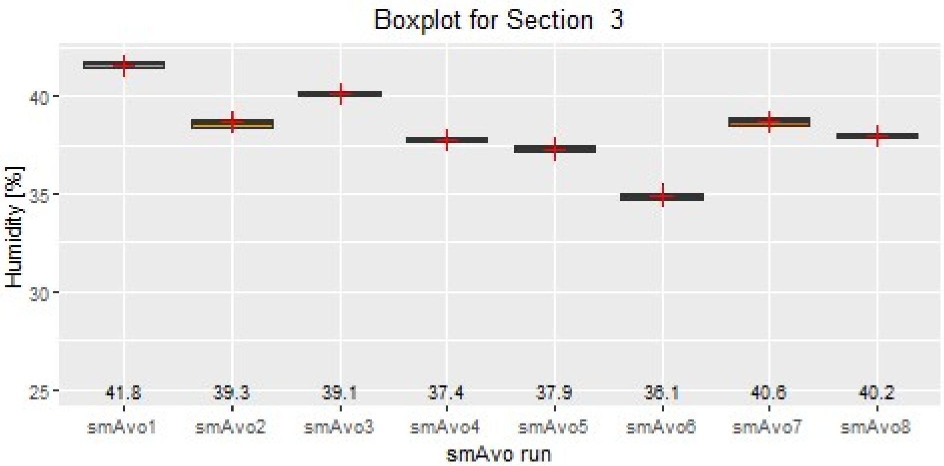
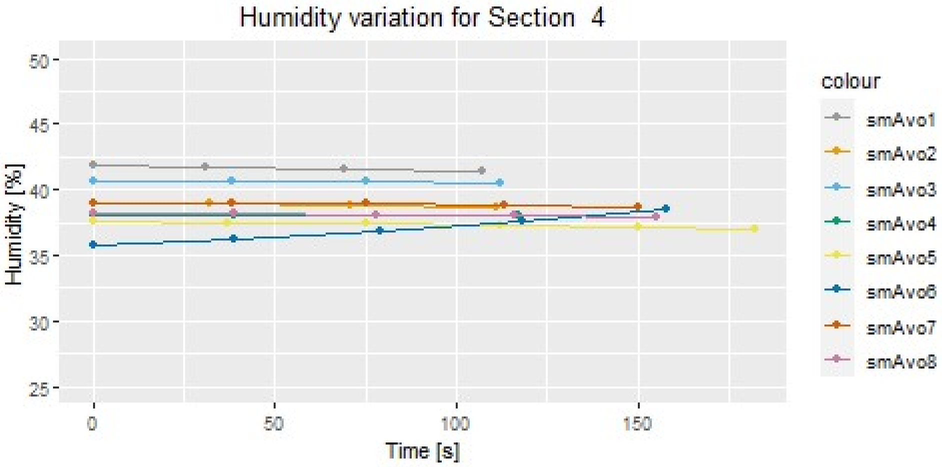
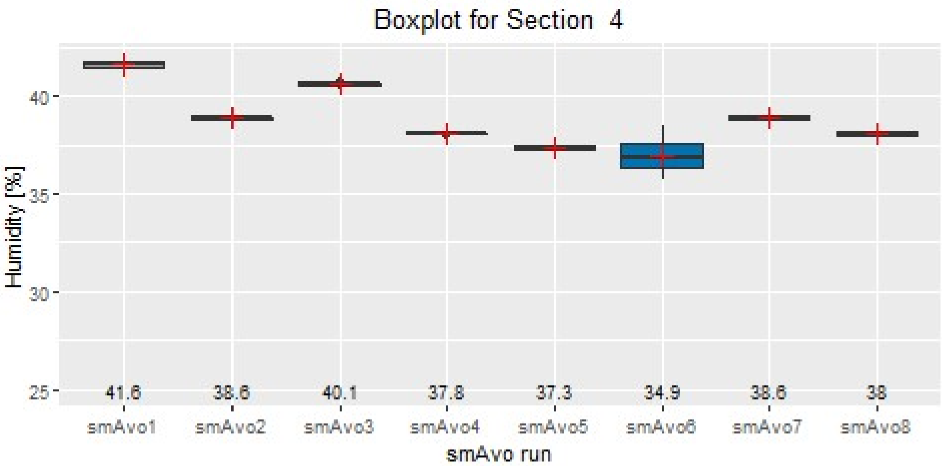
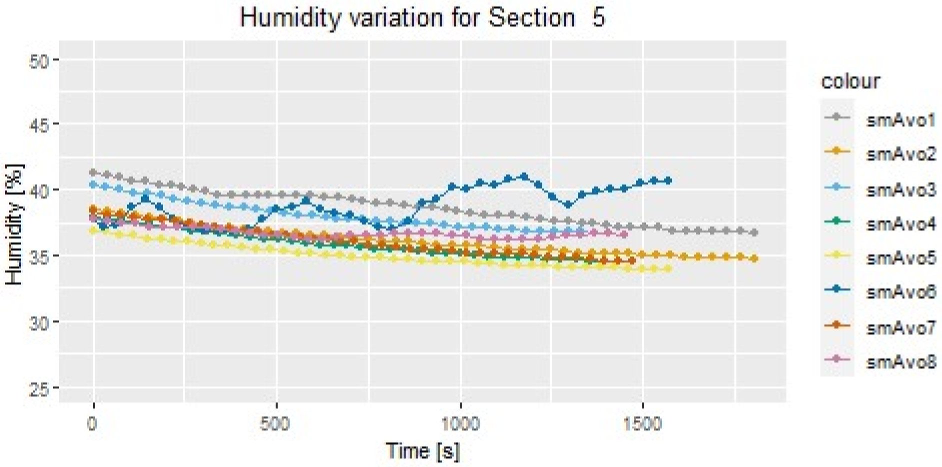
smAvo8
smAvo run

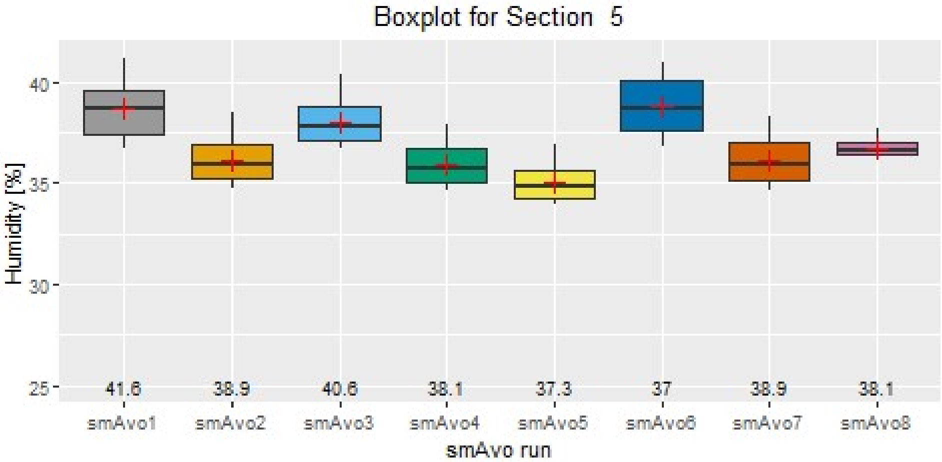

Humidity variation for Section 3
Humidity [%]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

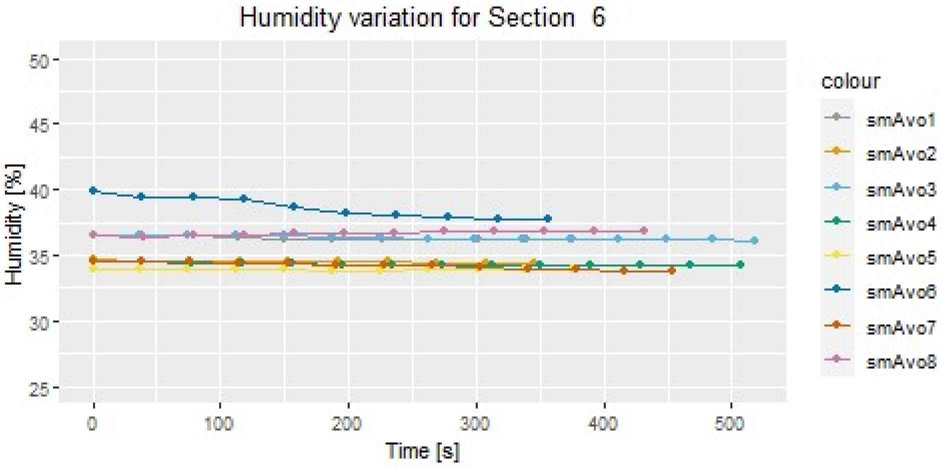

Boxplot for Section 3
Humidity [%]
41.8
39.3
39.1
37.4
37.9
36.1
40.6
40.2
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

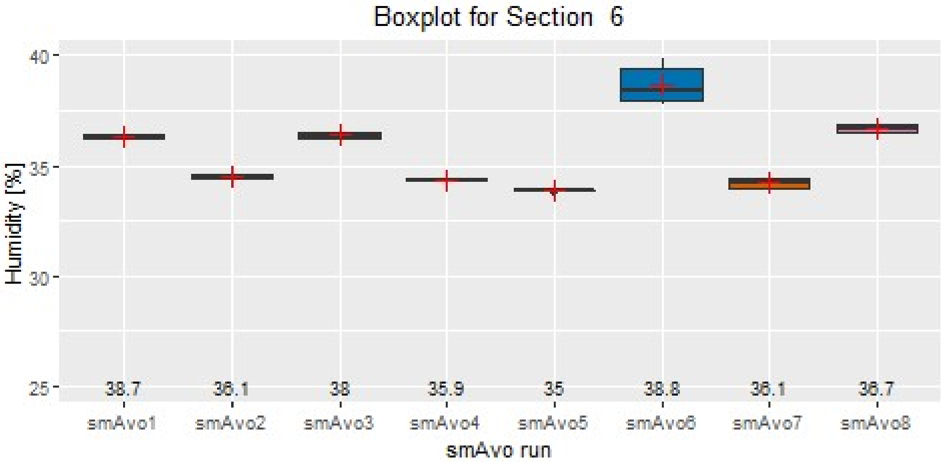

Humidity variation for Section 4
Humidity [%]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

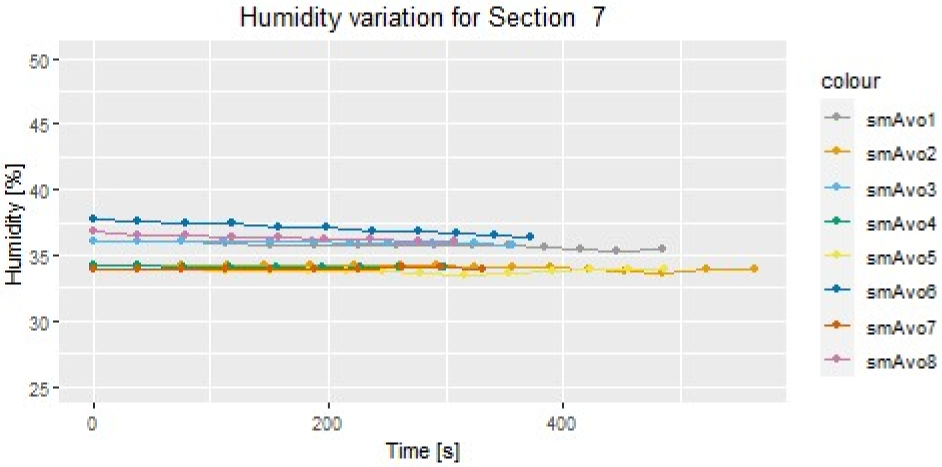

Boxplot for Section 4
Humidity [%]
41.6
38.6
40.1
37.8
37.3
34.9
38.6
38
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run


Humidity variation for Section 5
Humidity [%]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
50
45
40
35
30
25
0
500
1000
1500

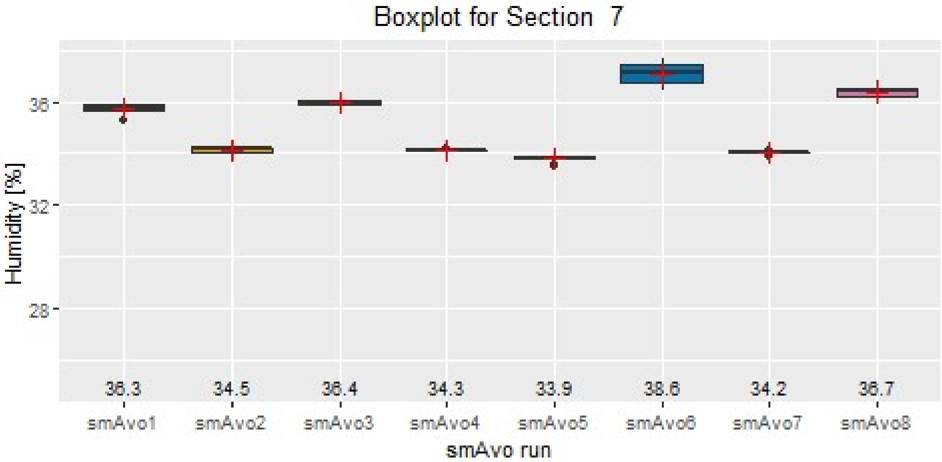

Boxplot for Section 5
Humidity [%]
40
35
30
25
41.6
38.9
40.6
38.1
37.3
37
38.9
38.1
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run


Humidity variation for Section 6
Humidity [%]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8


Boxplot for Section 6
Humidity [%]
38.7
36.1
38
35.9
35
38.8
36.1
36.7
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

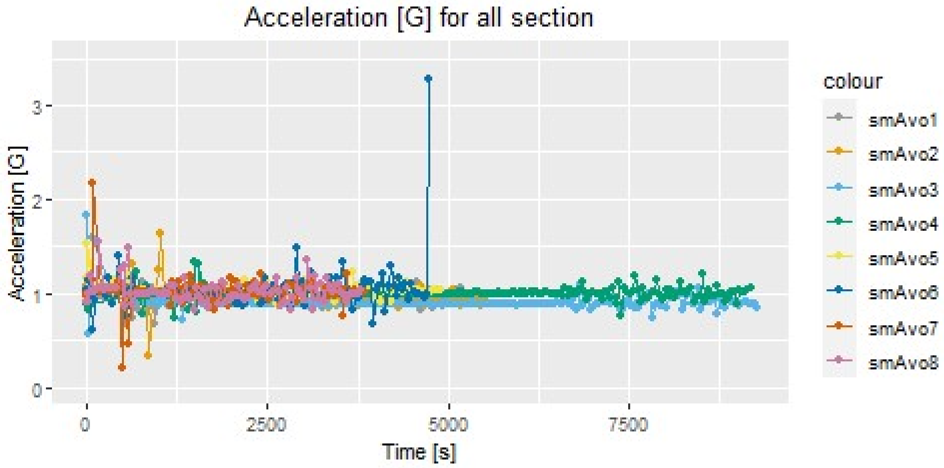


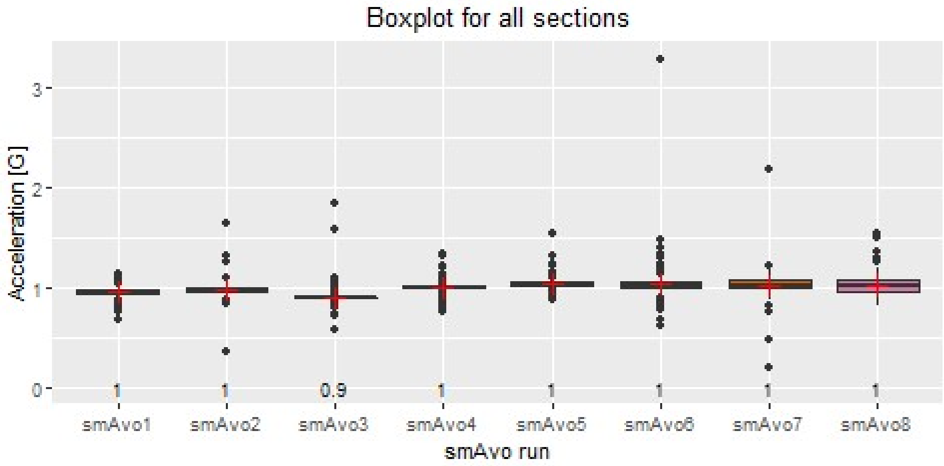
Humidity variation for Section 7
50
45
40
35
30
25
Humidity [%]
0
200
400
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

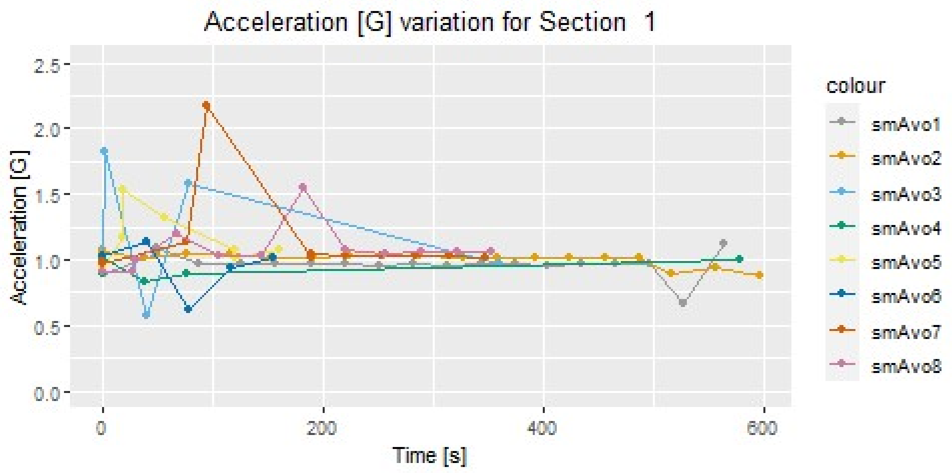


Boxplot for Section 7
36
32
28
Humidity [%]
36.3
34.5
36.4
34.3
33.9
38.6
34.2
36.7
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

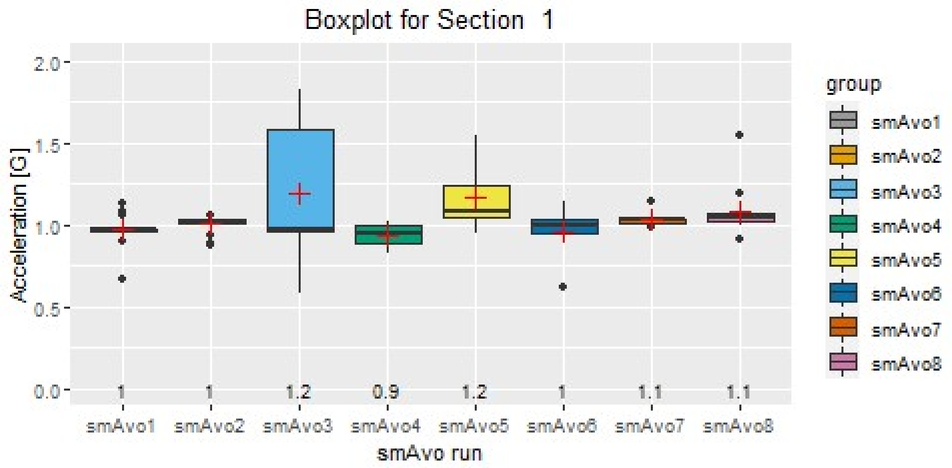
Acceleration



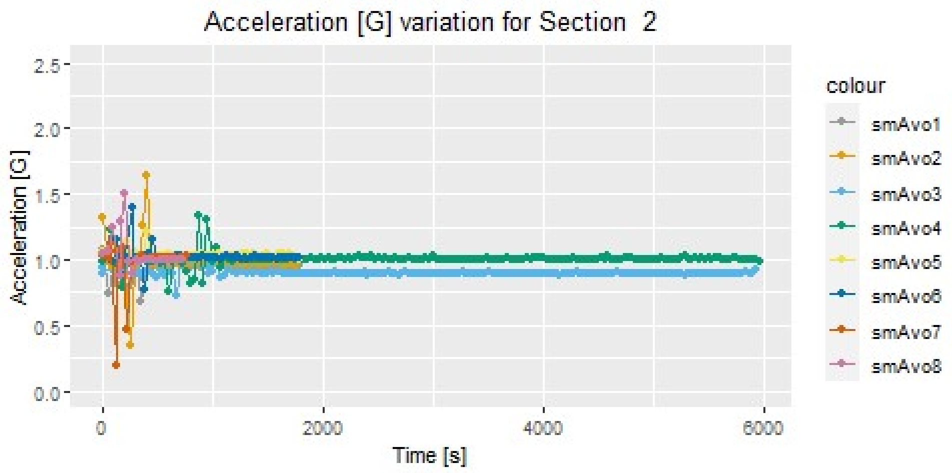




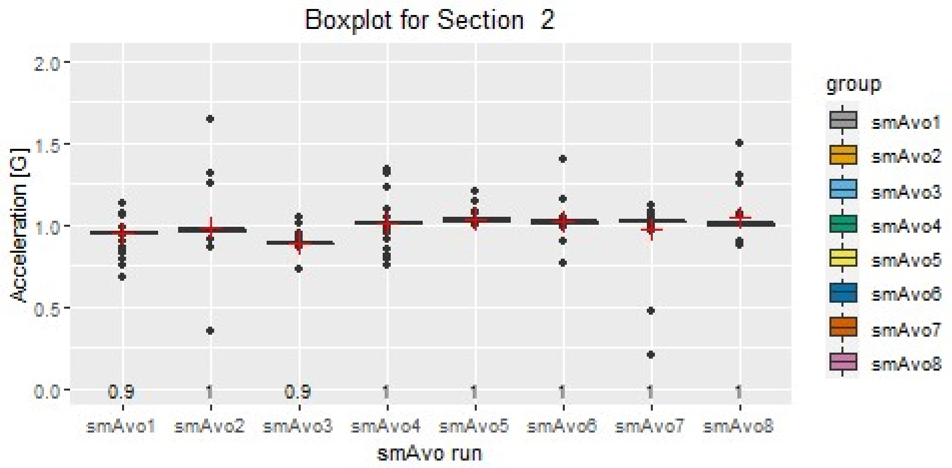
Acceleration [G] variation for Section 1
Acceleration [G]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8



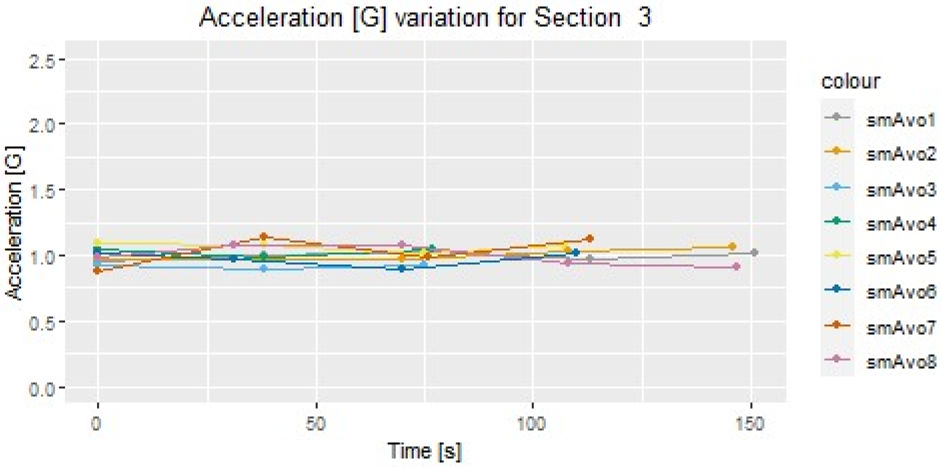
Boxplot for Section 1
Acceleration [G]
1
1
1.2
0.9
1.2
1
1.1
1.1
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run
group

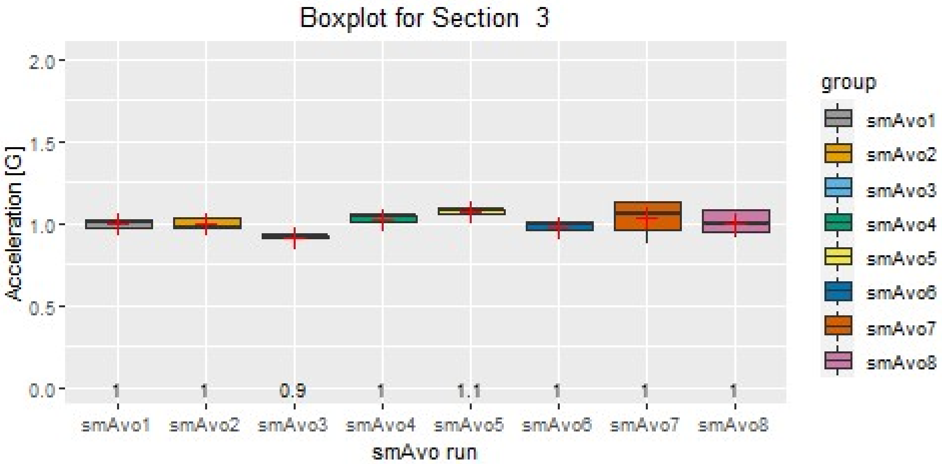


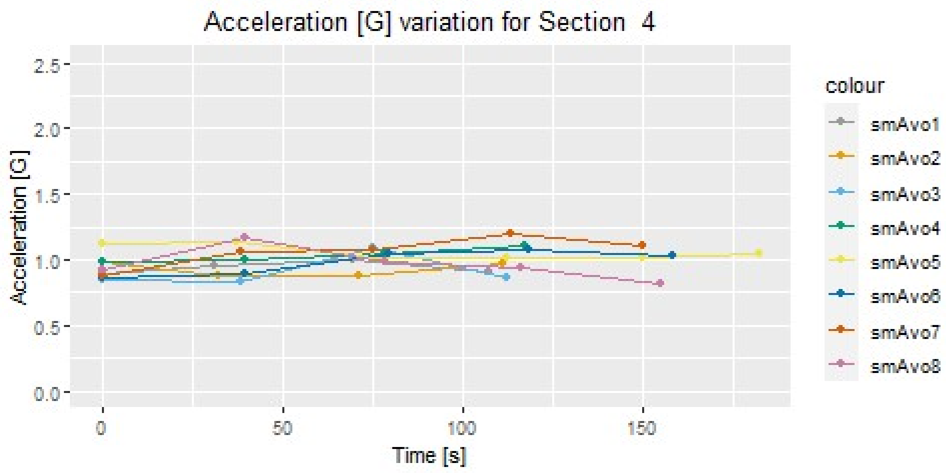
Acceleration [G] variation for Section 2
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
Acceleration [G]
0.0
0.5
1.0
1.5
2.0
2.5
0
2000
4000
6000
Time [s]

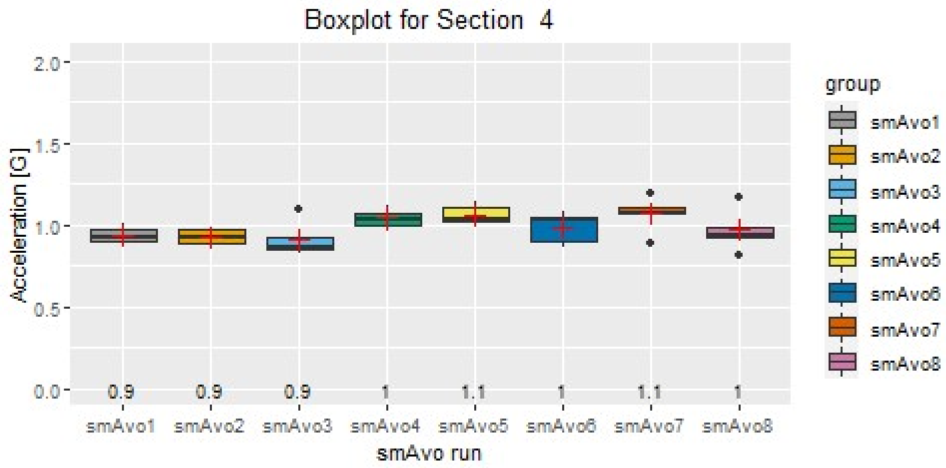


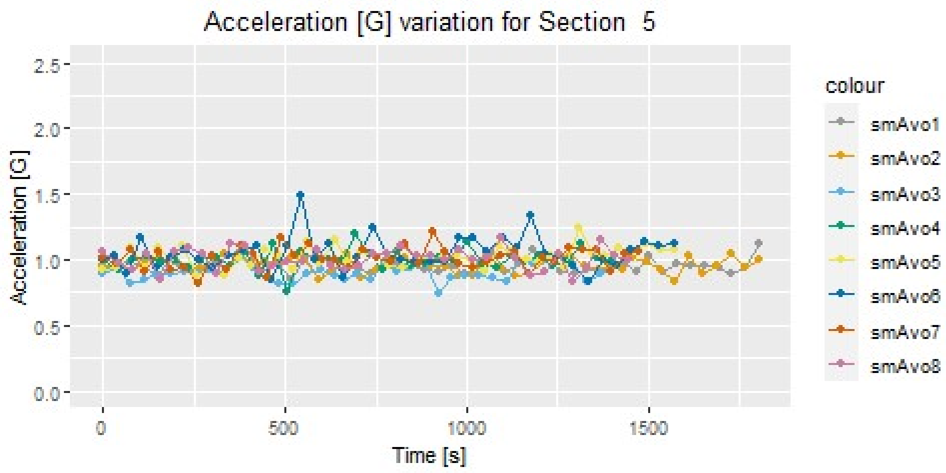
Boxplot for Section 2
group
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
Acceleration [G]
0.0
0.5
1.0
1.5
2.0
0.9
1
0.9
1
1
1
1
1
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

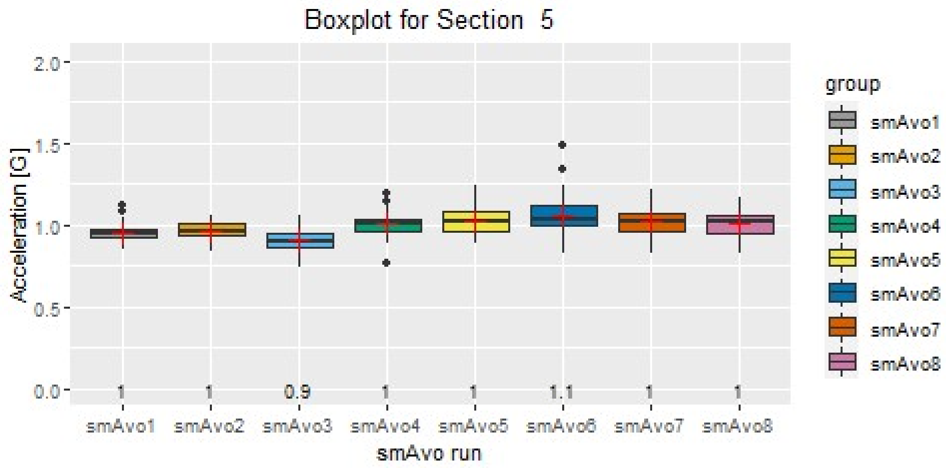

Acceleration [G] variation for Section 3
Acceleration [G]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

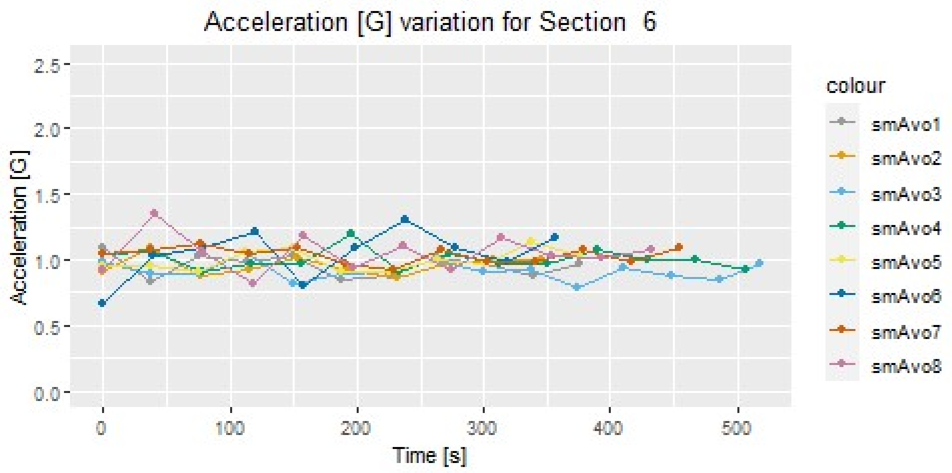

Boxplot for Section 3
Acceleration [G]
1
1
0.9
1
1.1
1
1
1
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run
group


Acceleration [G] variation for Section 4
Acceleration [G]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

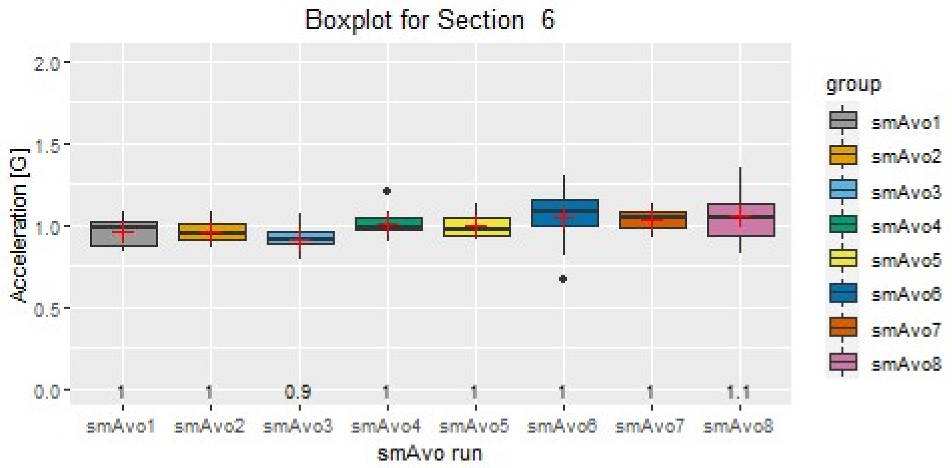

Boxplot for Section 4
Acceleration [G]
smAvo run
group
0.9
0.9
0.9
1
1.1
1
1.1
1
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8


Acceleration [G] variation for Section 5
Acceleration [G]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

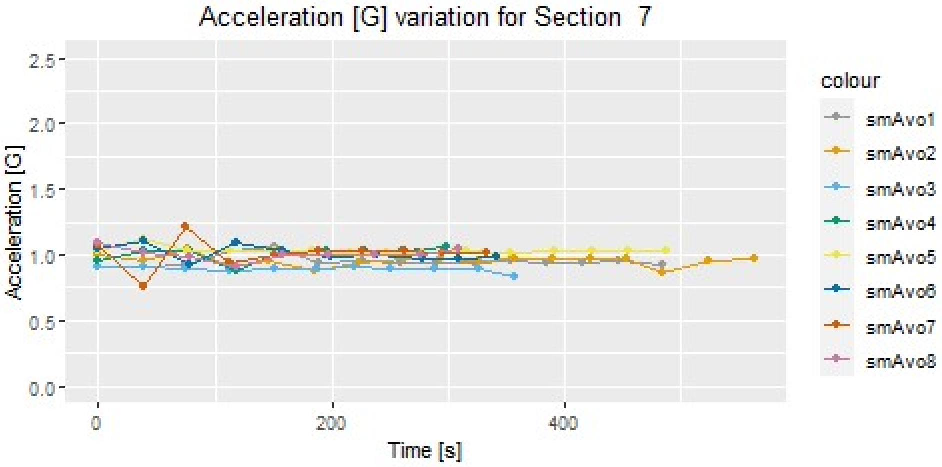

Boxplot for Section 5
Acceleration [G]
1
1
0.9
1
1
1.1
1
1
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run
group

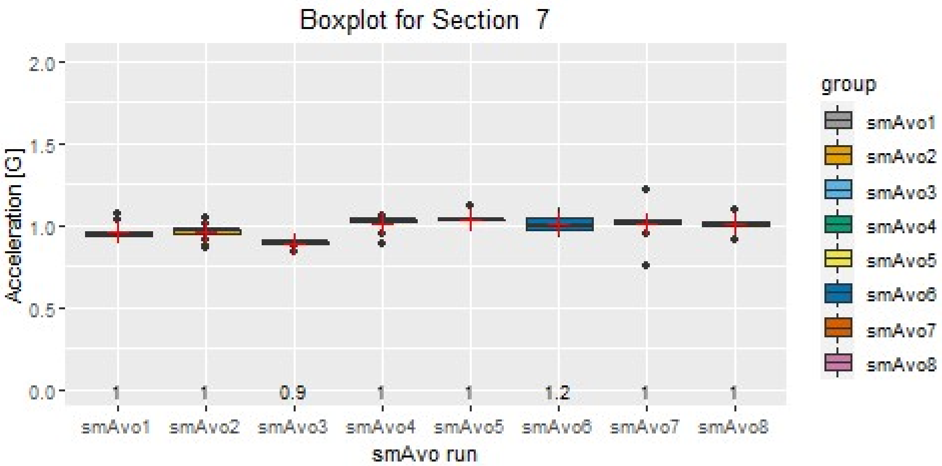


Acceleration [G] variation for Section 6
Acceleration [G]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

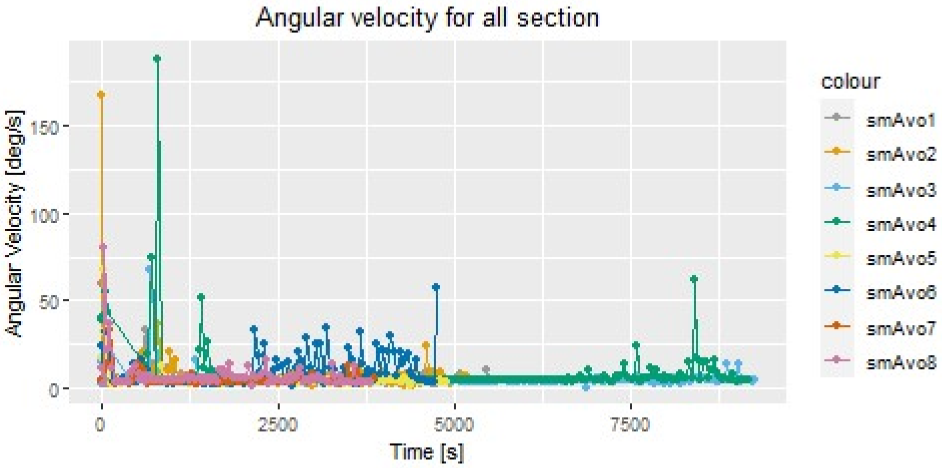


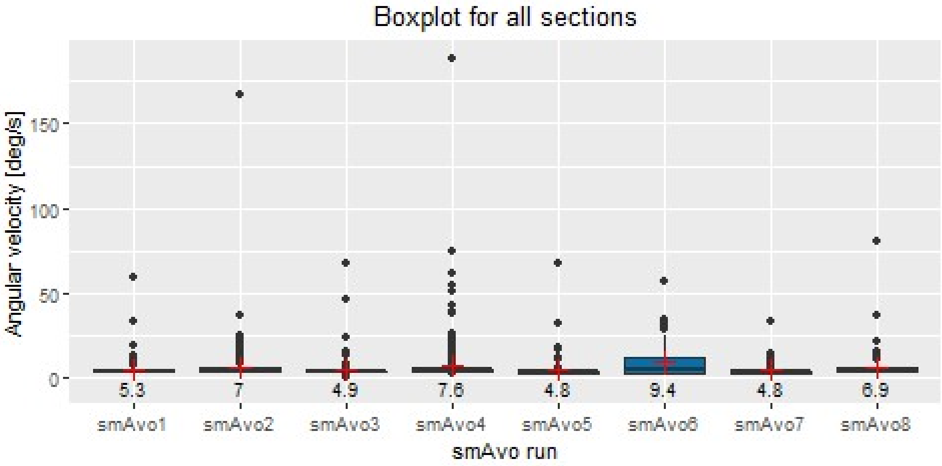
Boxplot for Section 6
Acceleration [G]
smAvo run
group
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

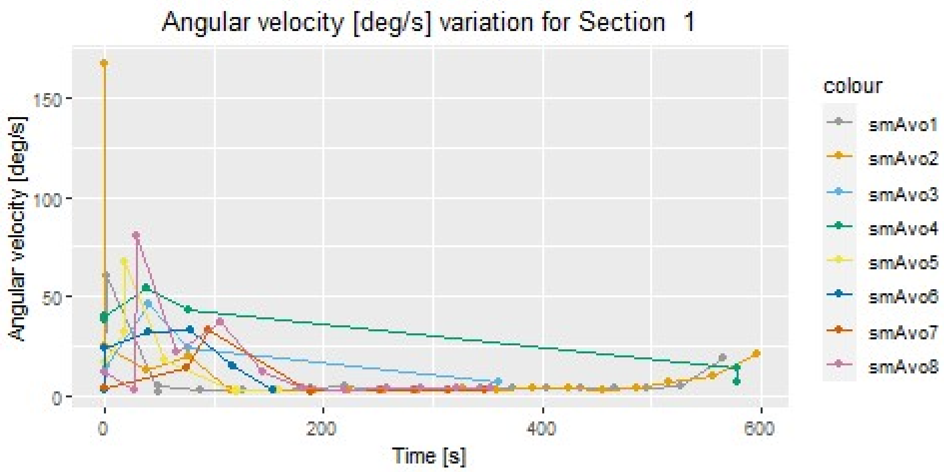

Acceleration [G] variation for Section 7
Acceleration [G]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

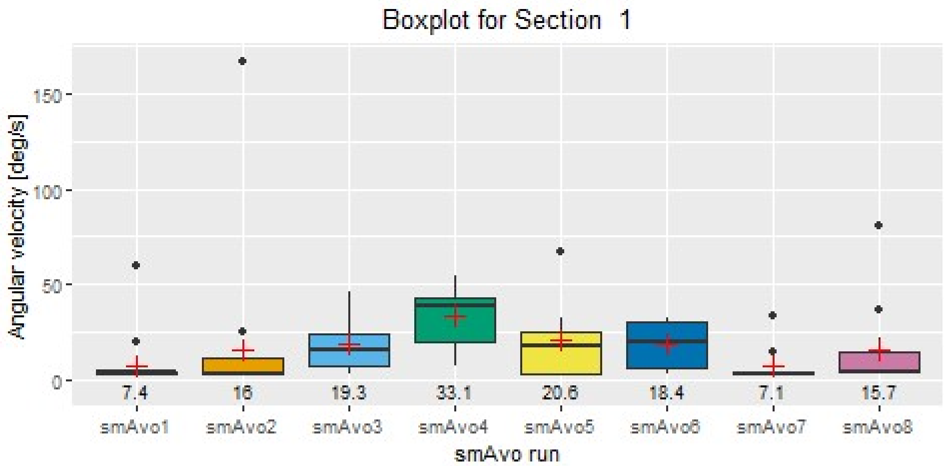

Boxplot for Section 7
Acceleration [G]
smAvo run
1
1
0.9
1
1
1.2
1
1
group
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

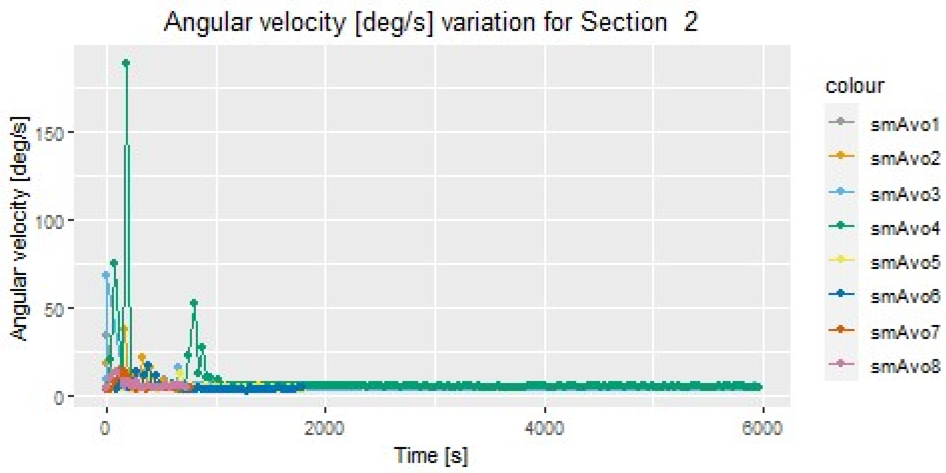
Angular Velocity



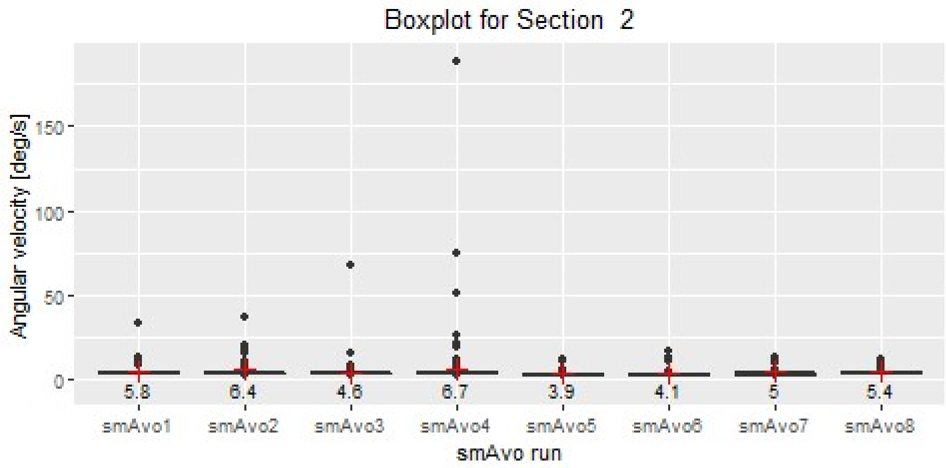



Angular velocity [deg/s] variation for Section 1
Angular velocity [deg/s]
Time [s]
0
50
100
150
0
200
400
600
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

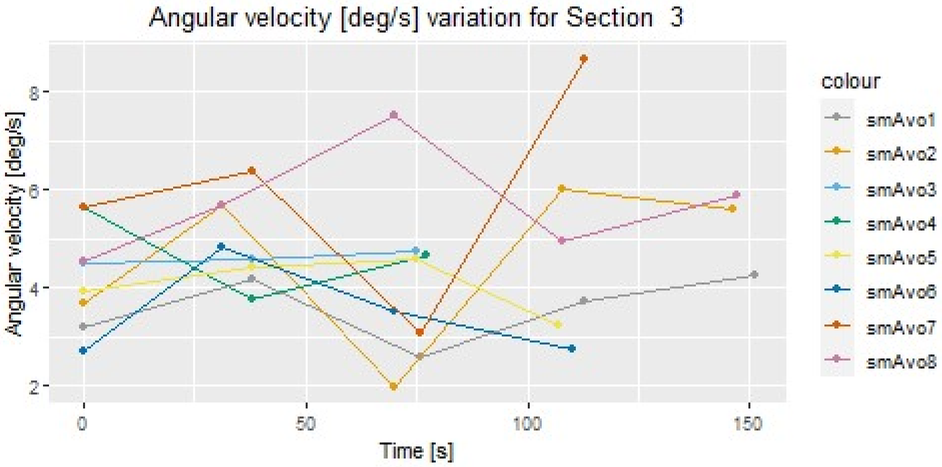

Boxplot for Section 1
Angular velocity [deg/s]
0
50
100
150
7.4
16
19.3
33.1
20.6
18.4
7.1
15.7
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run



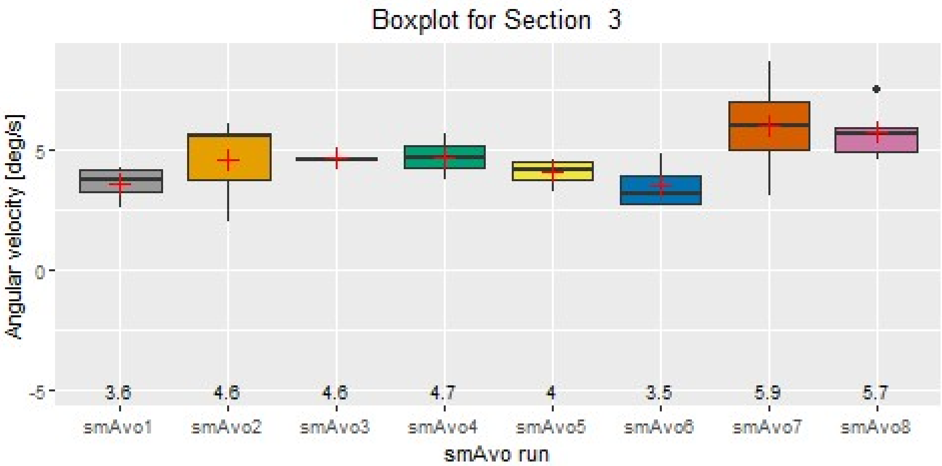
Angular velocity [deg/s] variation for Section 2
Angular velocity [deg/s]
150
100
50
0
0
2000
4000
6000
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8



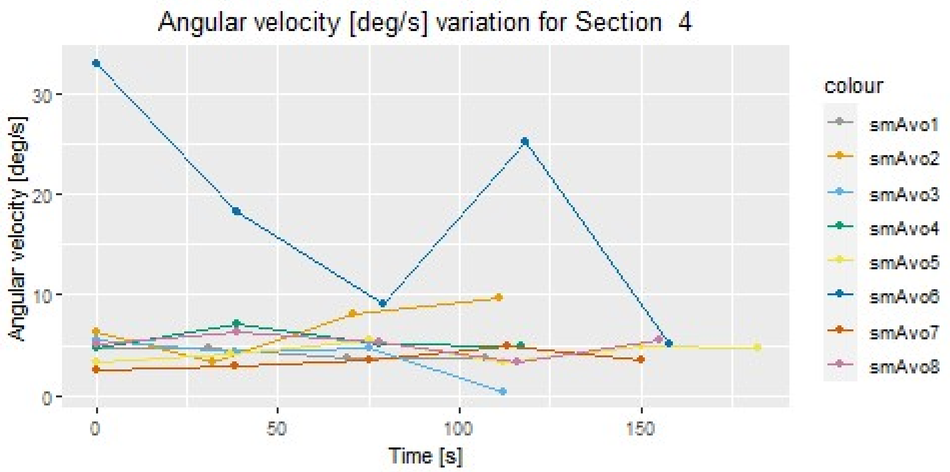
Boxplot for Section 2
Angular velocity [deg/s]
150
100
50
0
5.8
6.4
4.6
6.7
3.9
4.1
5
5.4
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

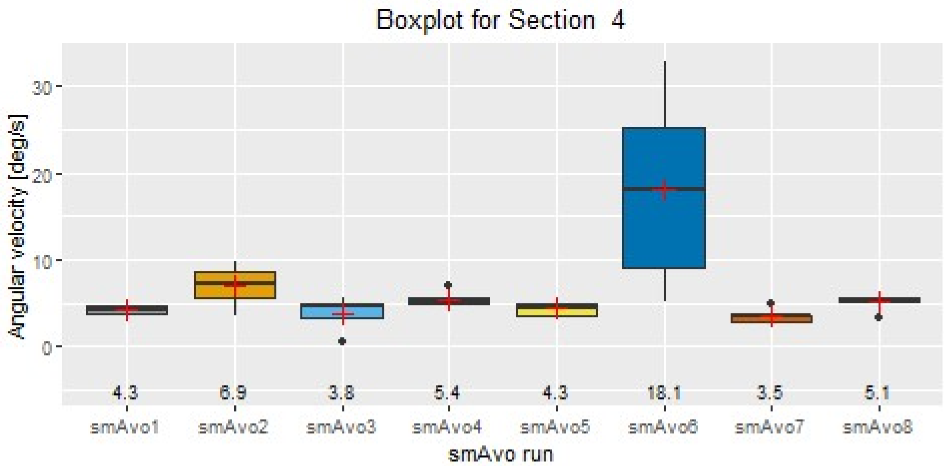


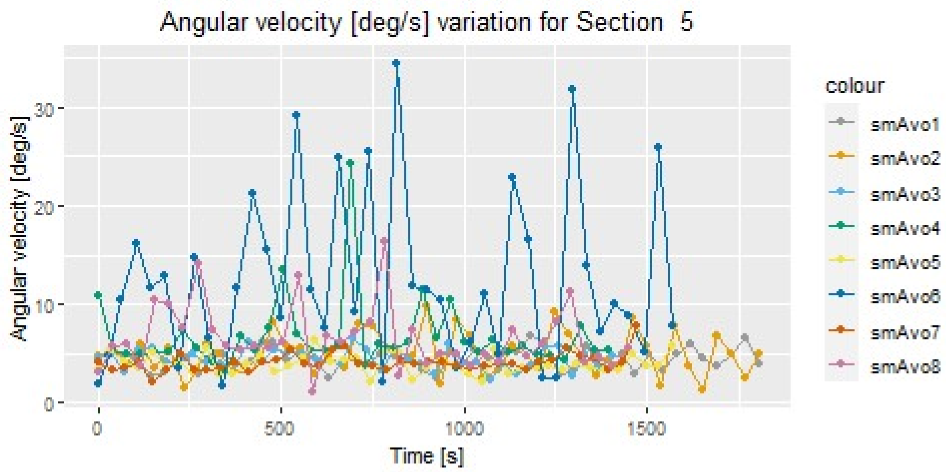
Angular velocity [deg/s] variation for Section 3
Angular velocity [deg/s]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8



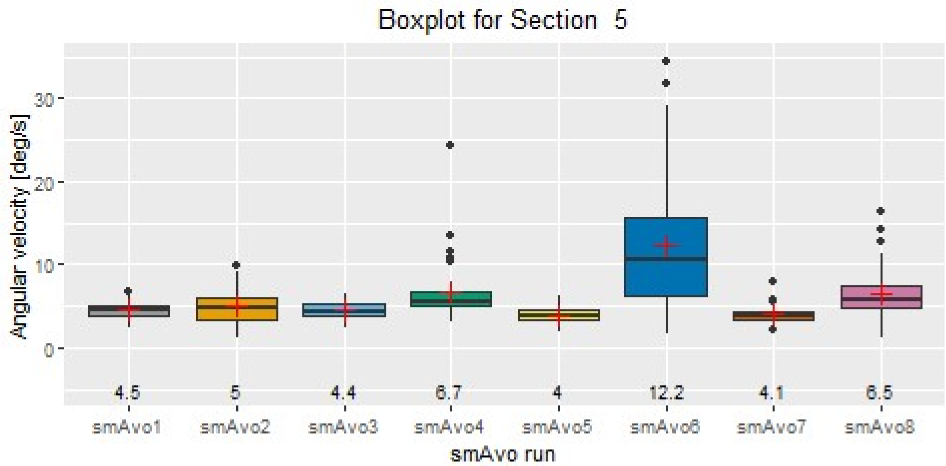
Boxplot for Section 3
Angular velocity [deg/s]
3.6
4.6
4.6
4.7
4
3.5
5.9
5.7
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run


Angular velocity [deg/s] variation for Section 4
Angular velocity [deg/s]
Time [s]
0
50
100
150
0
10
20
30
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

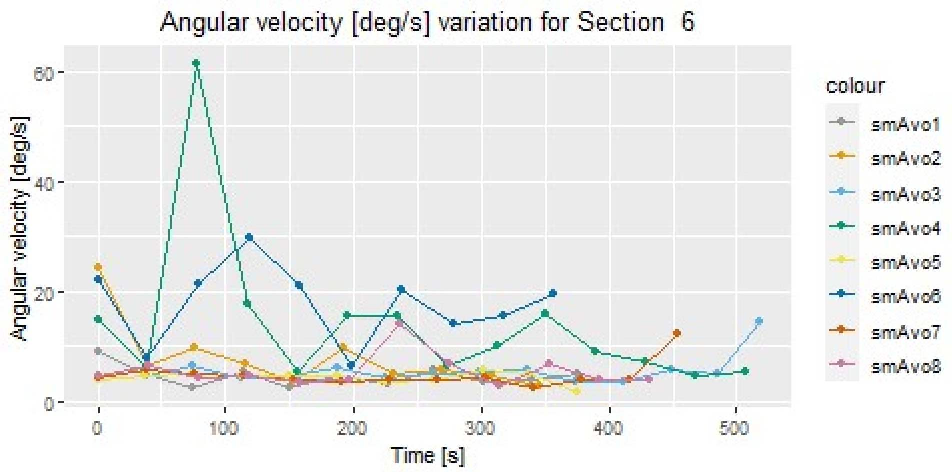

Boxplot for Section 4
Angular velocity [deg/s]
0
10
20
30
4.3
6.9
3.8
5.4
4.3
18.1
3.5
5.1
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

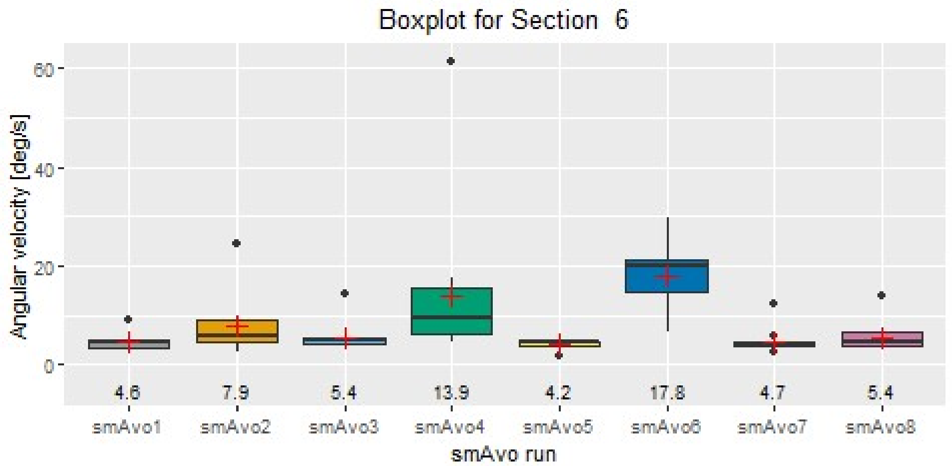


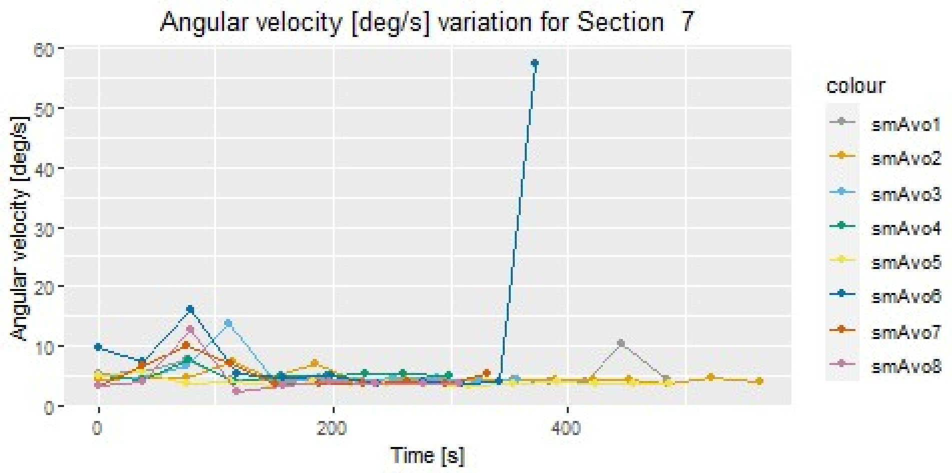
Angular velocity [deg/s] variation for Section 5
Angular velocity [deg/s]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

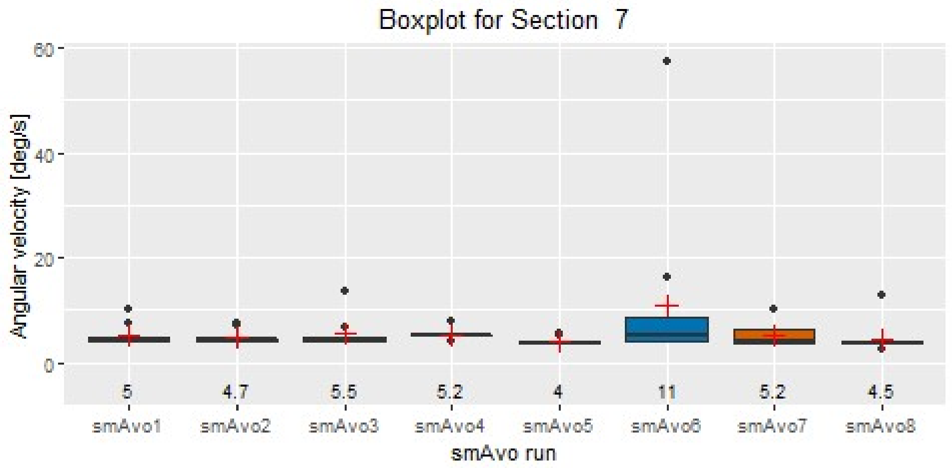


Boxplot for Section 5
Angular velocity [deg/s]
4.5
5
4.4
6.7
4
12.2
4.1
6.5
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

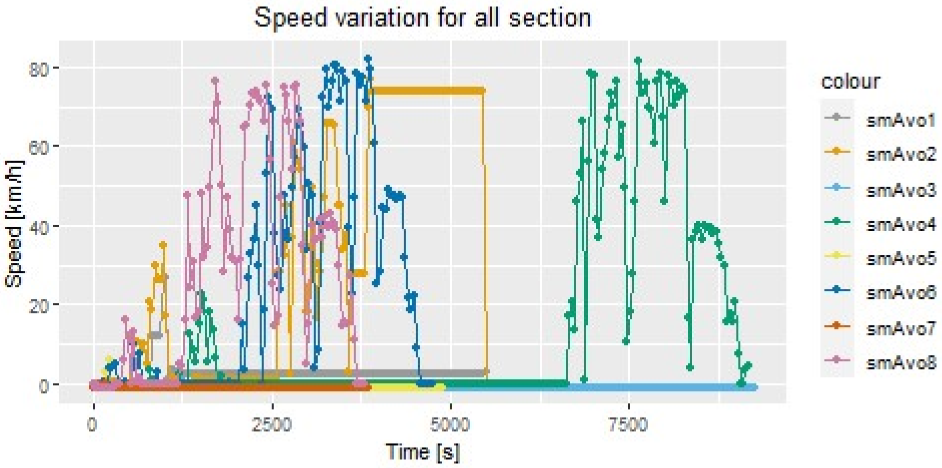

Angular velocity [deg/s] variation for Section 6
Angular velocity [deg/s]
0
20
40
60
0
100
200
300
400
500
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

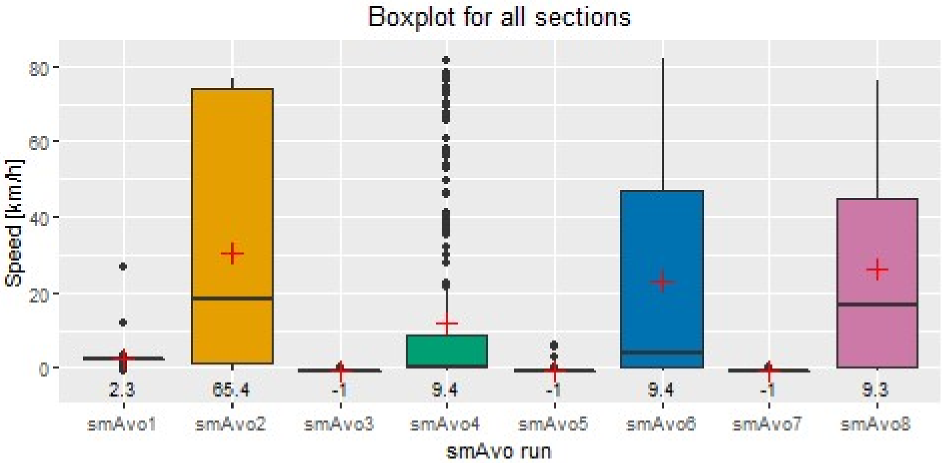

Boxplot for Section 6
Angular velocity [deg/s]
0
20
40
60
4.6
7.9
5.4
13.9
4.2
17.8
4.7
5.4
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

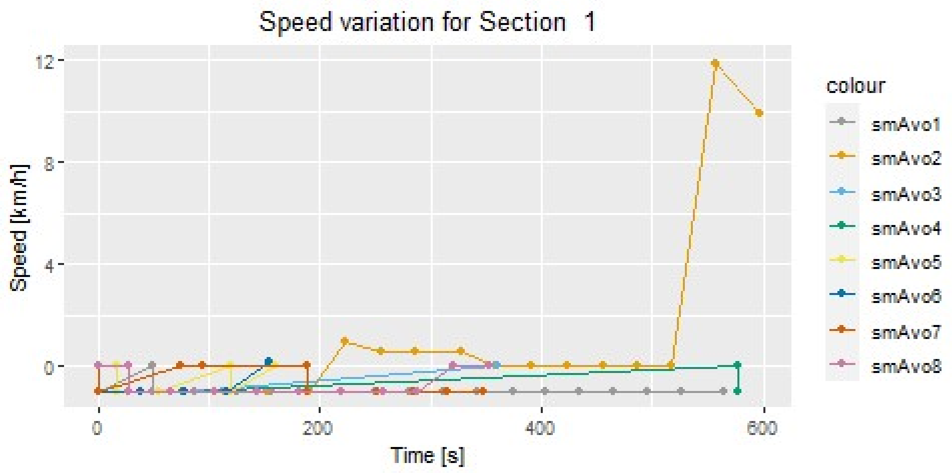

Angular velocity [deg/s] variation for Section 7
Angular velocity [deg/s]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

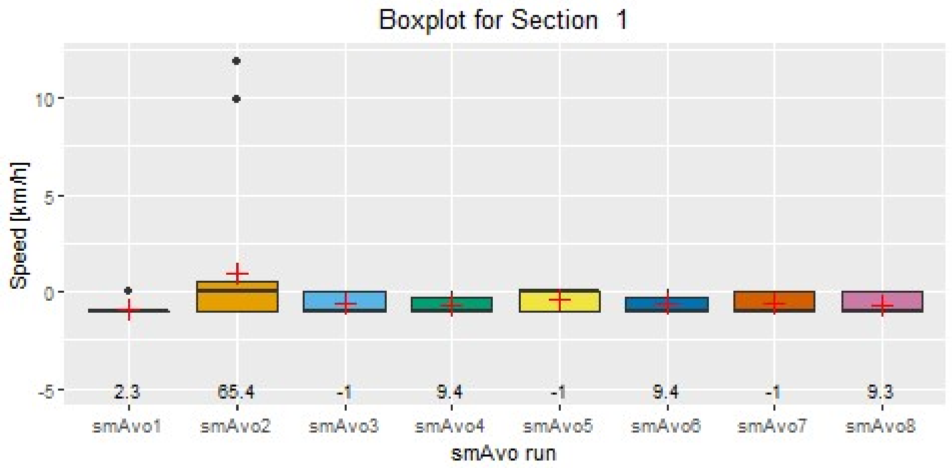

Boxplot for Section 7
Angular velocity [deg/s]
5
4.7
5.5
5.2
4
11
5.2
4.5
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

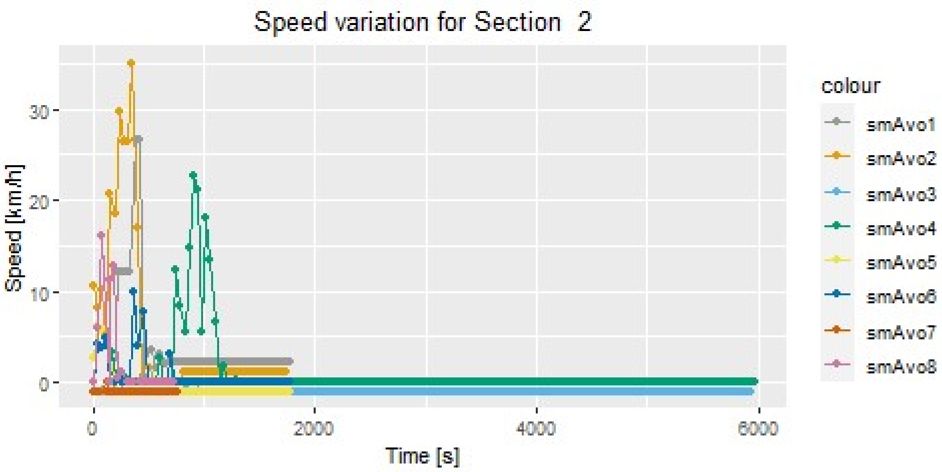
Speed

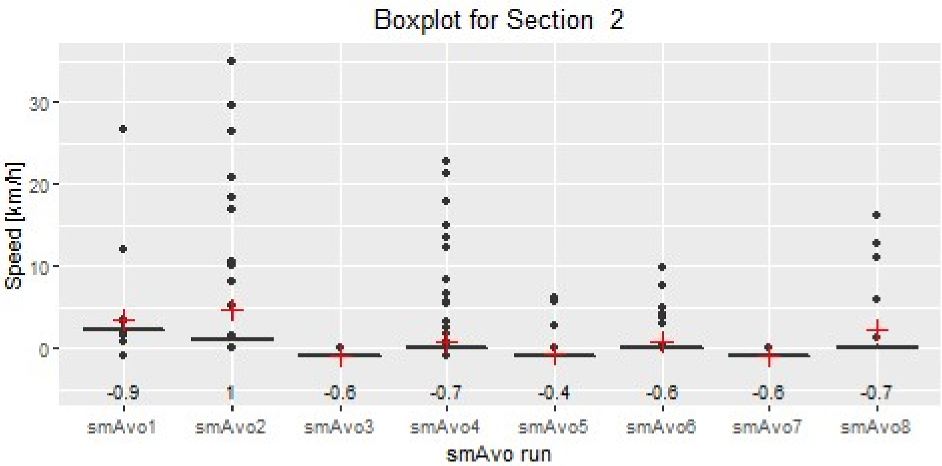

Speed variation for all section
Speed [km/h]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
0
2500
5000
7500
0
20
40
60
80

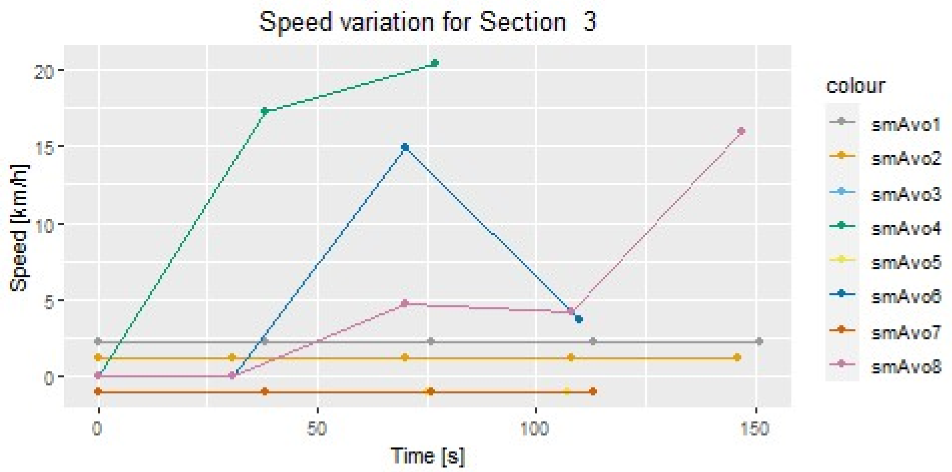

Boxplot for all sections
Speed [km/h]
smAvo run
2.3
65.4
-1
9.4
-1
9.4
-1
9.3
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

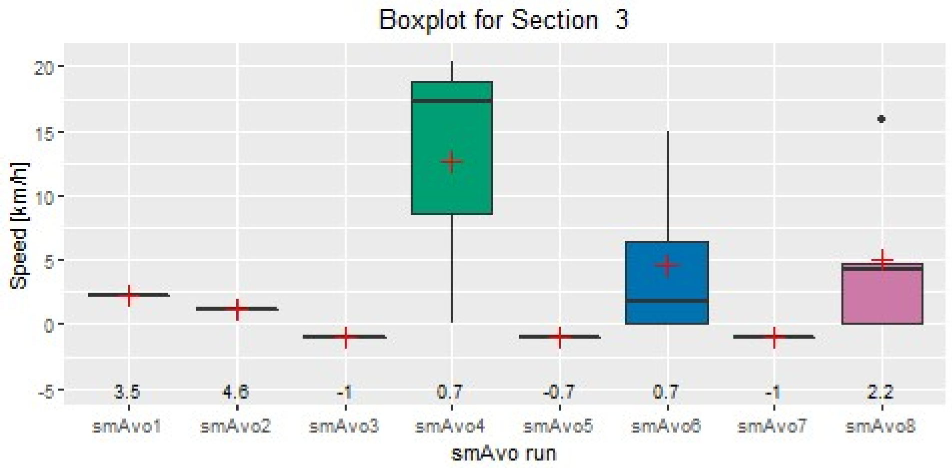

Speed variation for Section 1
Speed [km/h]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

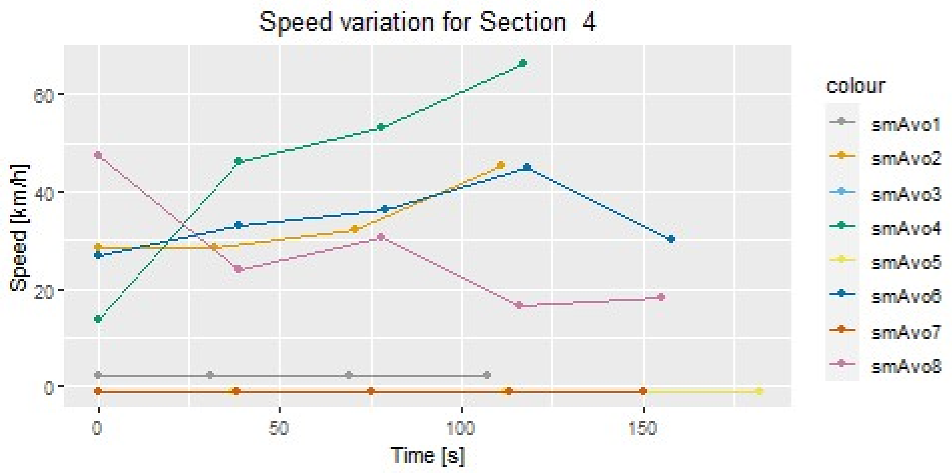

Boxplot for Section 1
Speed [km/h]
2.3
65.4
-1
9.4
-1
9.4
-1
9.3
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run


Speed variation for Section 2
Speed [km/h]
Time [s]
0
10
20
30
0
2000
4000
6000
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

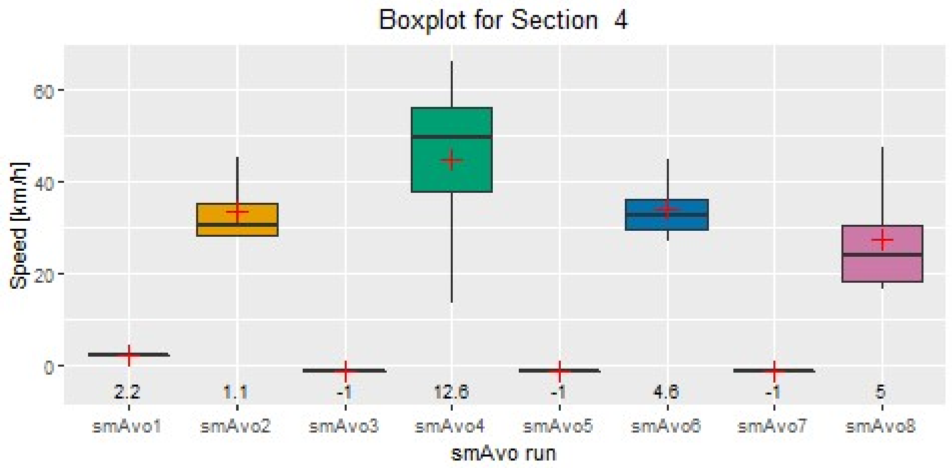

Boxplot for Section 2
Speed [km/h]
0
10
20
30
-0.9
1
-0.6
-0.7
-0.4
-0.6
-0.6
-0.7
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run


Speed variation for Section 3
Speed [km/h]
20
15
10
5
0
0
50
100
150
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

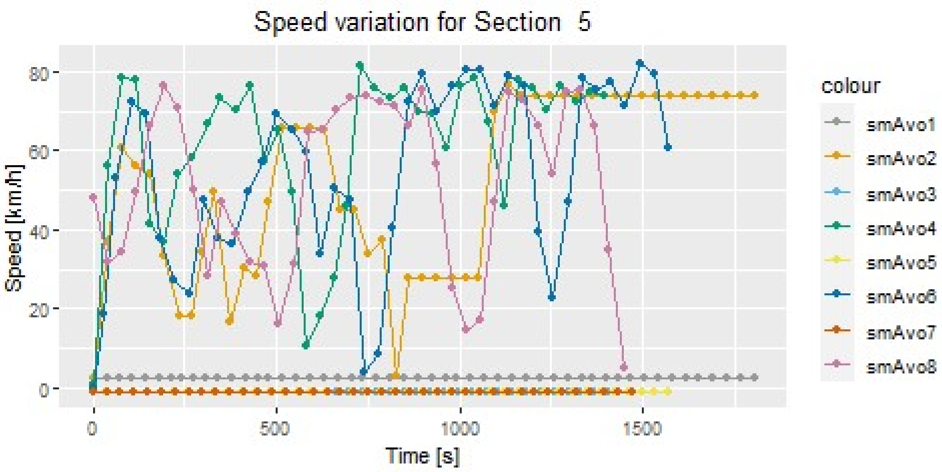

Boxplot for Section 3
Speed [km/h]
20
15
10
5
0
-5
3.5
4.6
-1
0.7
-0.7
0.7
-1
2.2
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

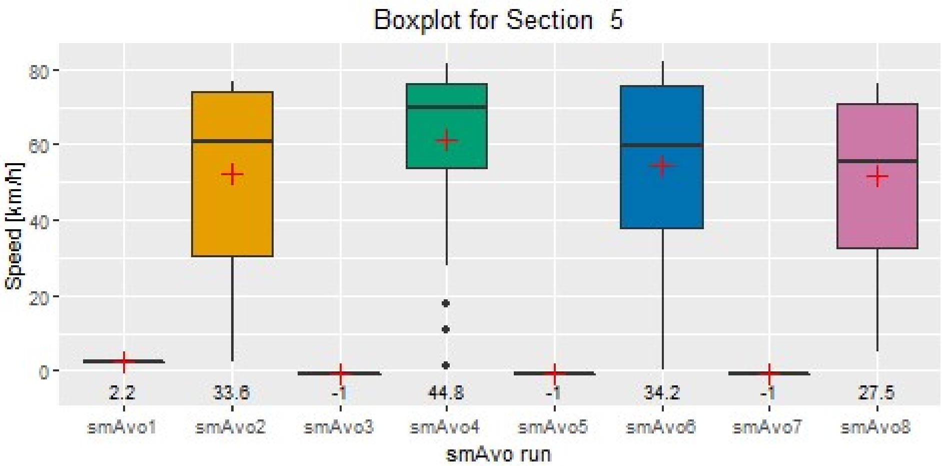


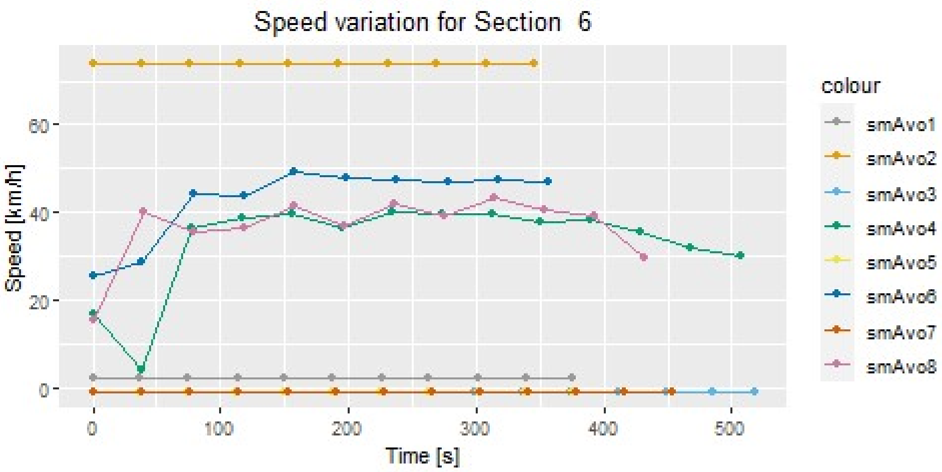
Speed variation for Section 4
Speed [km/h]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

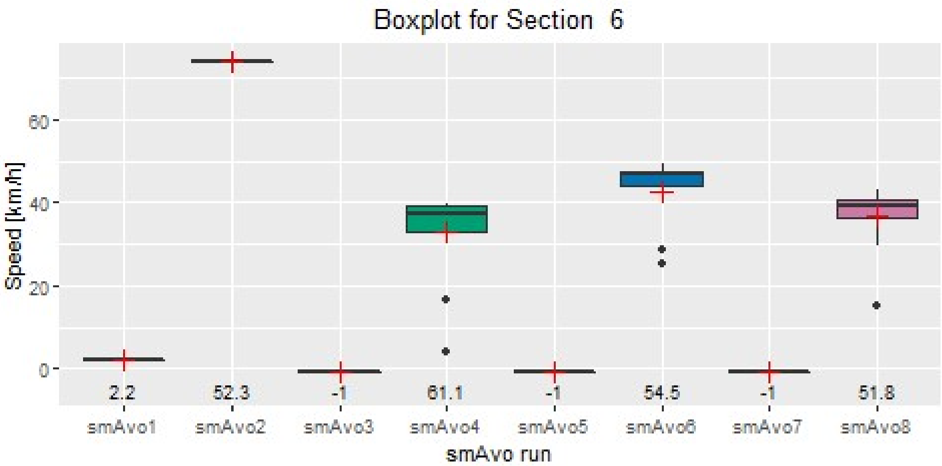


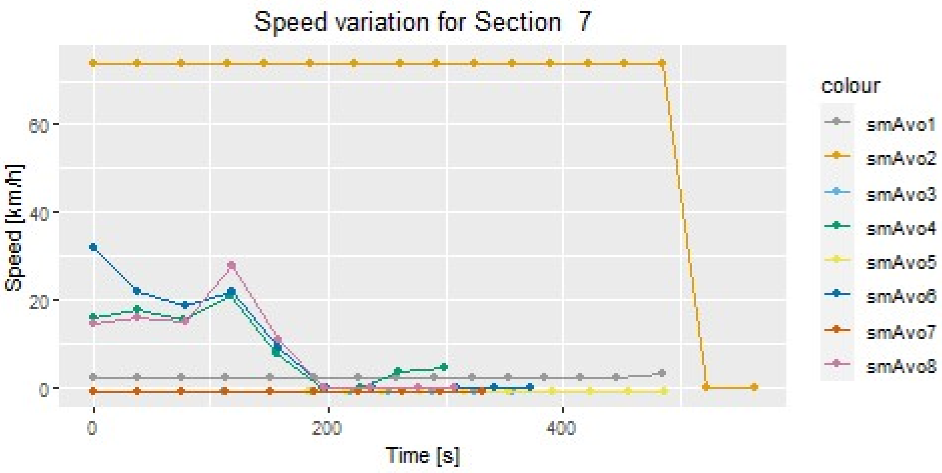
Boxplot for Section 4
Speed [km/h]
2.2
1.1
-1
12.6
-1
4.6
-1
5
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run


Speed variation for Section 5
Speed [km/h]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

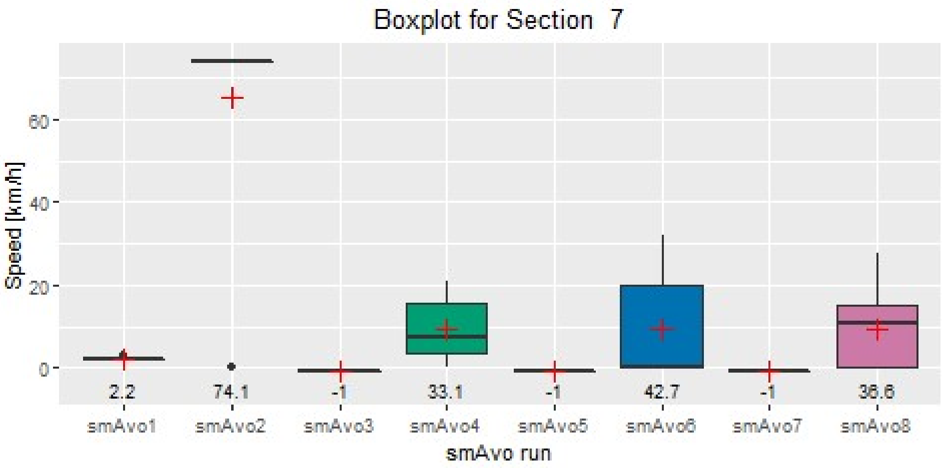

Boxplot for Section 5
Speed [km/h]
2.2
33.6
-1
44.8
-1
34.2
-1
27.5
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run


Speed variation for Section 6
Speed [km/h]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8


Boxplot for Section 6
Speed [km/h]
2.2
52.3
-1
61.1
-1
54.5
-1
51.8
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

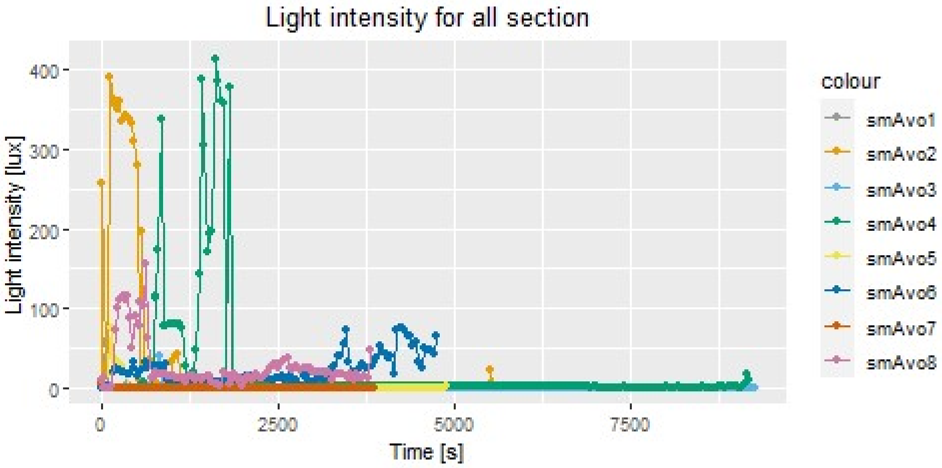


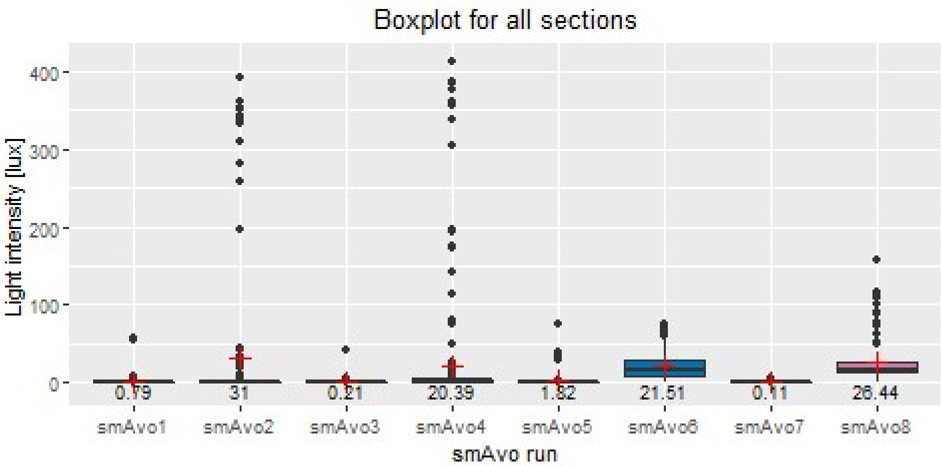
Speed variation for Section 7
Speed [km/h]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

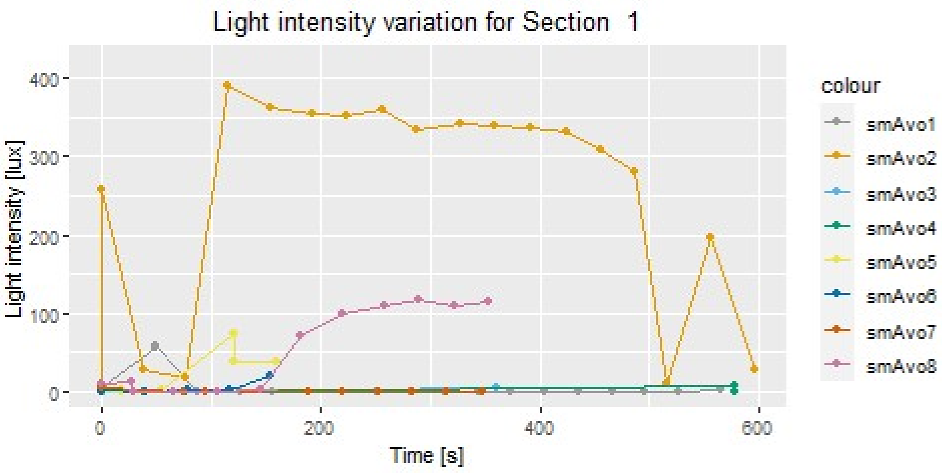


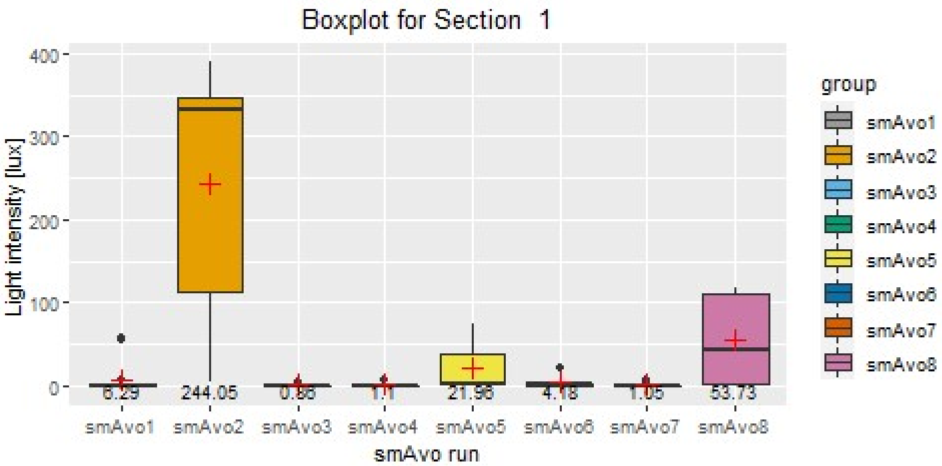
Boxplot for Section 7
Speed [km/h]
2.2
74.1
-1
33.1
-1
42.7
-1
36.6
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run

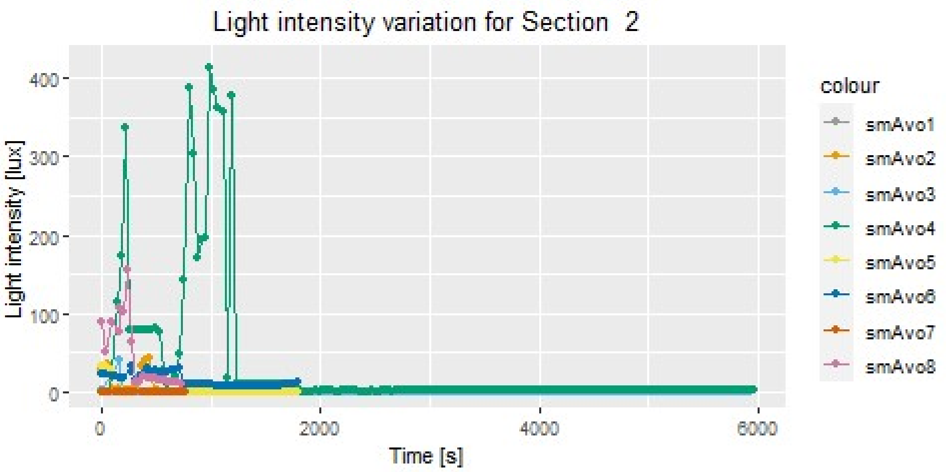
Light intensity

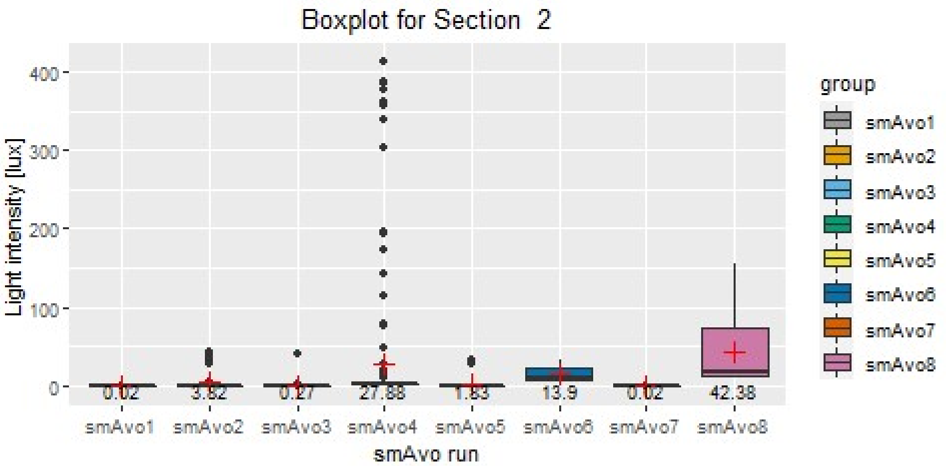


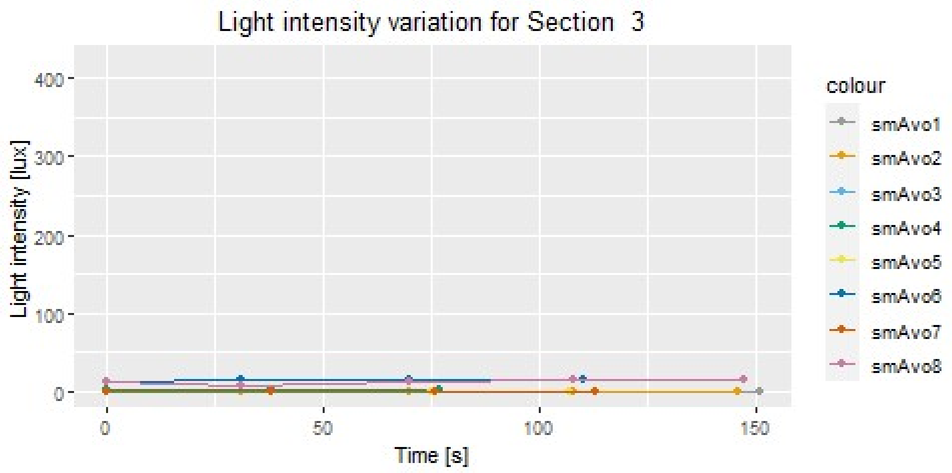


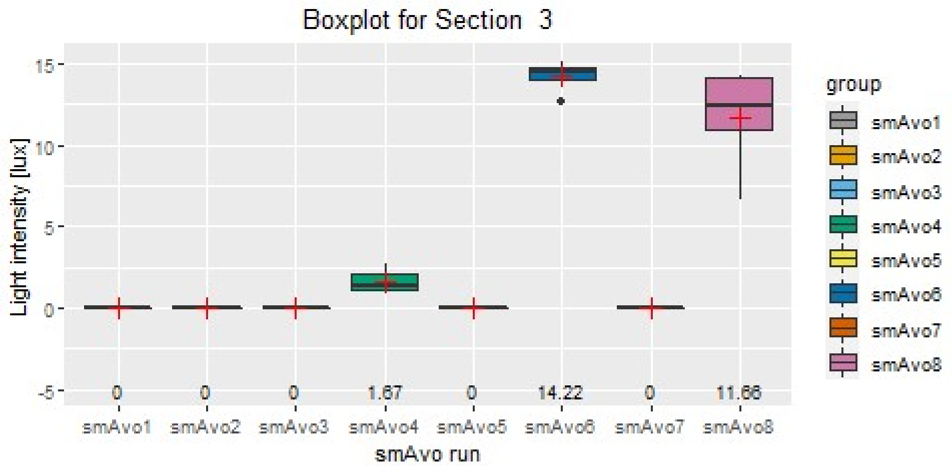

Light intensity variation for Section 1
Light intensity [lux]
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

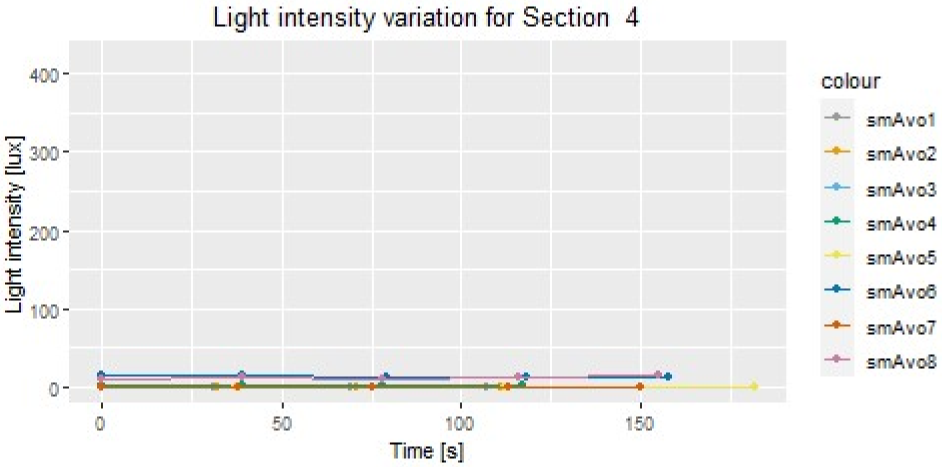

Boxplot for Section 1
Light intensity [lux]
smAvo run
group
6.29
244.05
0.86
1.1
21.96
4.18
1.05
53.73
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

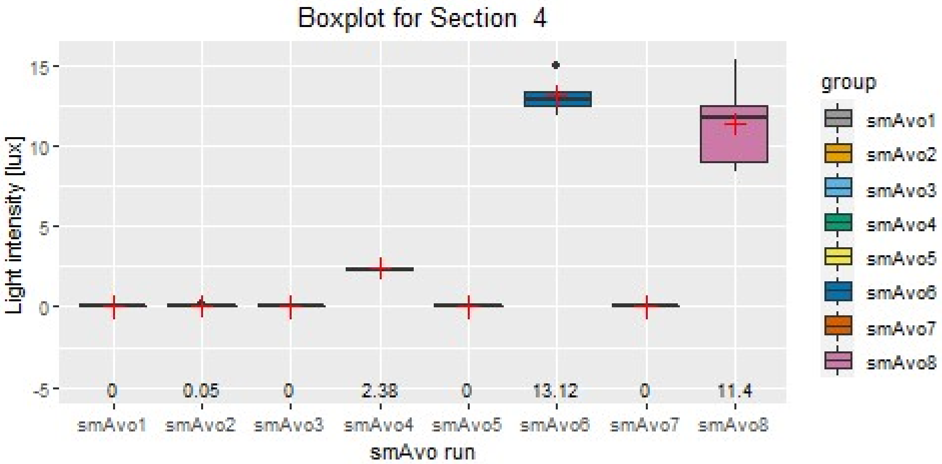

Light intensity variation for Section 2
Light intensity [lux]
0
100
200
300
400
0
2000
4000
6000
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

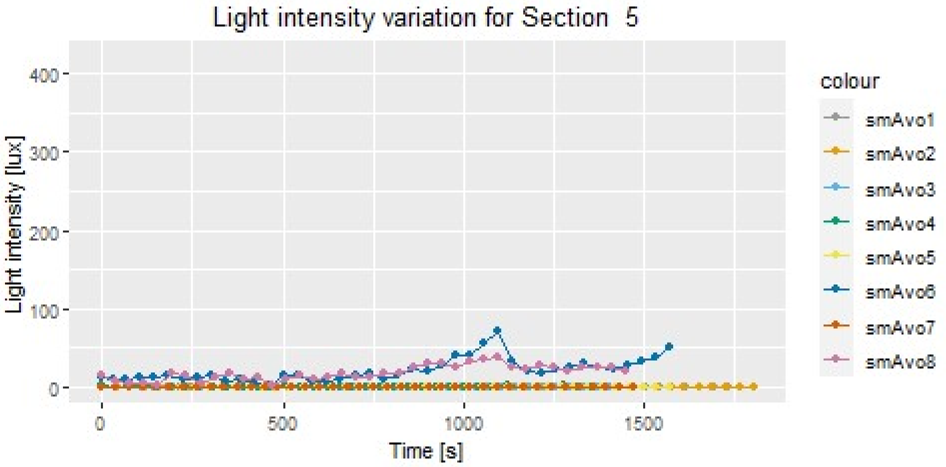

Boxplot for Section 2
Light intensity [lux]
0
100
200
300
400
0.02
3.82
0.27
27.88
1.83
13.9
0.02
42.38
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run
group
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

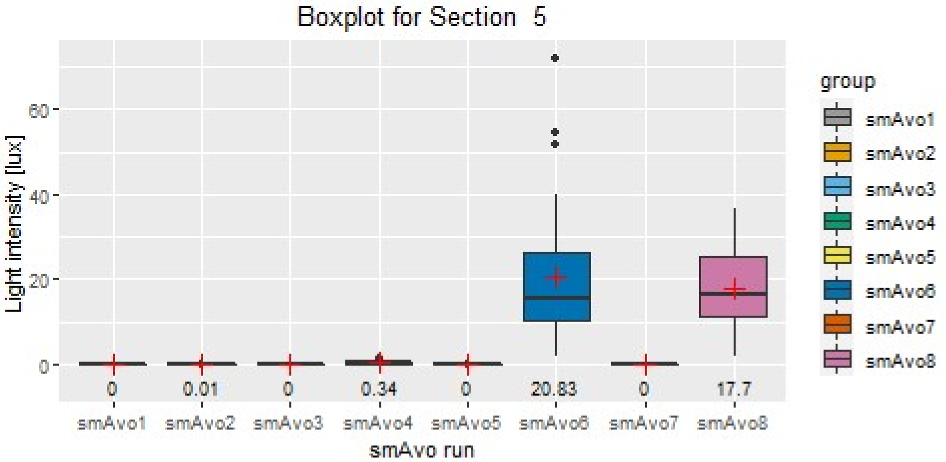

Light intensity variation for Section 3
Light intensity [lux]
400
300
200
100
0
0
50
100
150
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

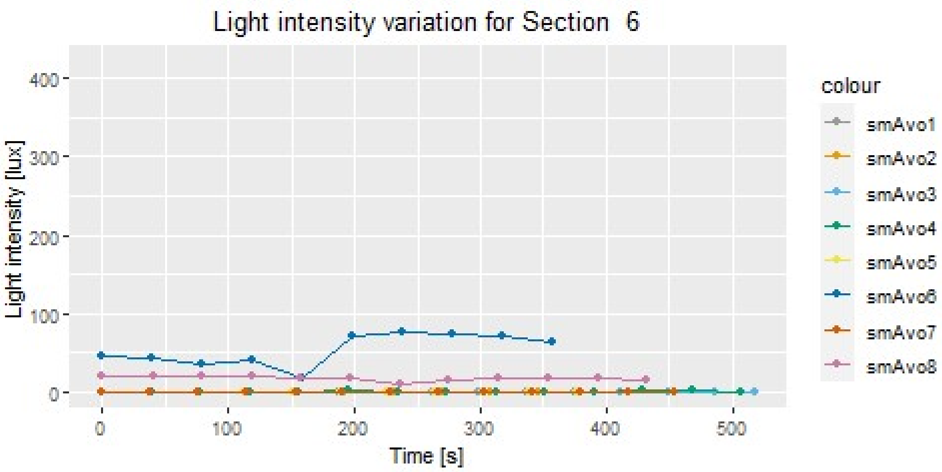

Boxplot for Section 3
Light intensity [lux]
15
10
5
0
-5
0
0
0
1.67
0
14.22
0
11.66
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run
group
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8


Light intensity variation for Section 4
Light intensity [lux]
400
300
200
100
0
0
50
100
150
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

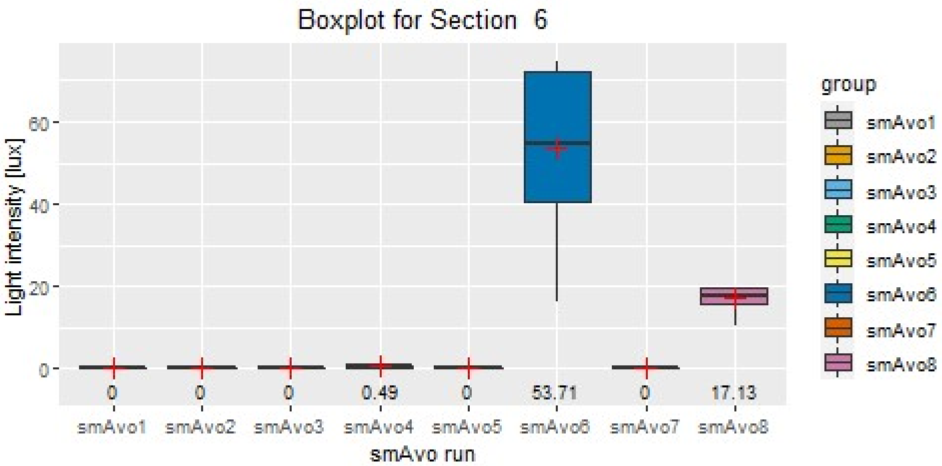

Boxplot for Section 4
Light intensity [lux]
15
10
5
0
-5
0
0.05
0
2.38
0
13.12
0
11.4
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run
group
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8


Light intensity variation for Section 5
Light intensity [lux]
400
300
200
100
0
0
500
1000
1500
Time [s]
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

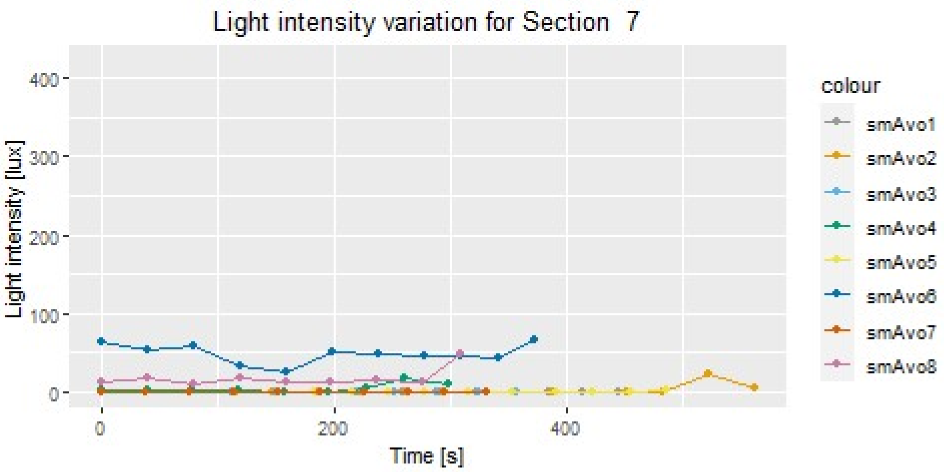

Boxplot for Section 5
Light intensity [lux]
60
40
20
0
0
0.01
0
0.34
0
20.83
0
17.7
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run
group
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8

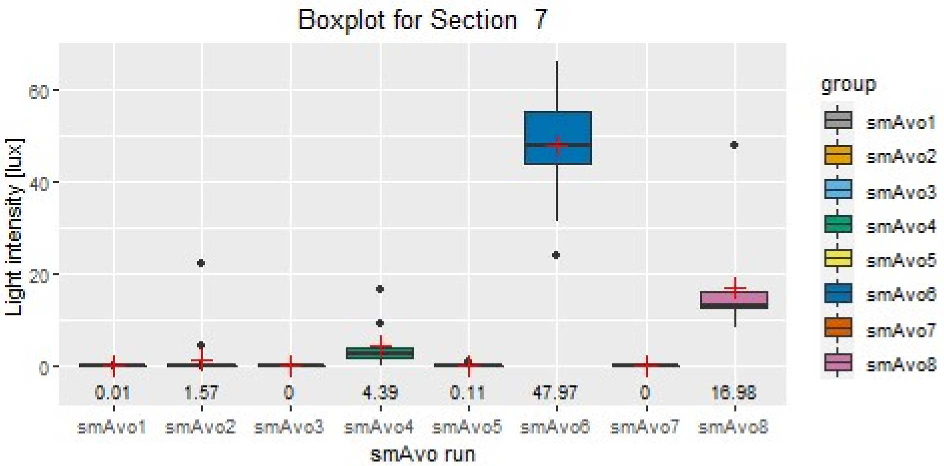


Light intensity variation for Section 6
Light intensity [lux]
Time [s]
400
300
200
100
0
0
100
200
300
400
500
colour
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8



Boxplot for Section 6
Light intensity [lux]
60
40
20
0
0
0
0
0.49
0
53.71
0
17.13
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8
smAvo run
group
smAvo1
smAvo2
smAvo3
smAvo4
smAvo5
smAvo6
smAvo7
smAvo8





Barometric Pressure

Barometric pressure measurements were taken by each smAvo device. The pressure readings were normalised and are plotted in Figure 8-1 and Figure 8-2.

There were slight variations in the positioning and type of truck used to transport the smAvo devices.

Table 8-1 describes the variation in the tests conducted. Three smAvos were used for each test run, however smAvo3 produced faulty results and therefore was not used in analysis (D1R1 refers to test conducted on Day 1 run 1).

Table 8-1: smAvo positioning variation

Test run	smAvo placement in the crate			Truck type used for transport	Crate placement in the truck
	smAvo1	smAvo2	smAvo3		
D1R1	Centre corner	Top corner	Centre corner	Rigid 11	Bottom front right of the truck
D1R2	Bottom corner	Top corner	Centre corner	Rigid 11	Top front right of the truck
D2R1	Bottom centre	Top centre	Corner	Articulated 122	Centre of truck
D2R2	Bottom centre	Top centre	Centre	Articulated 122	

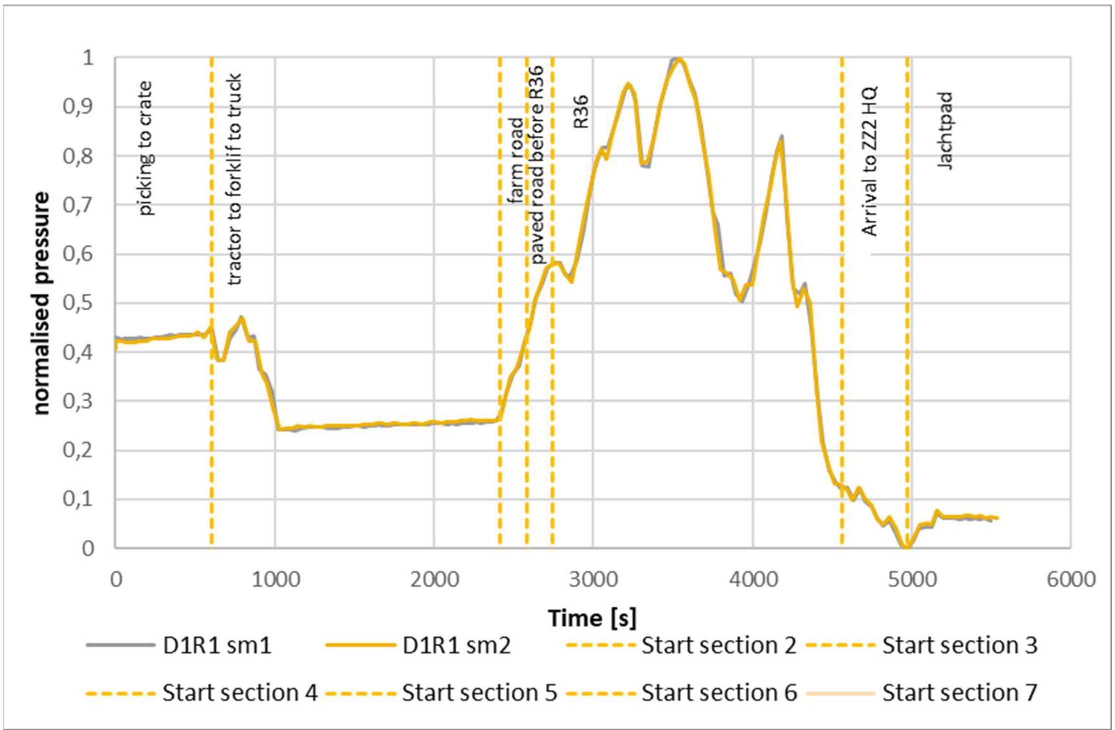


Figure 8-1: Day 1 Run 1 barometric pressure measurements

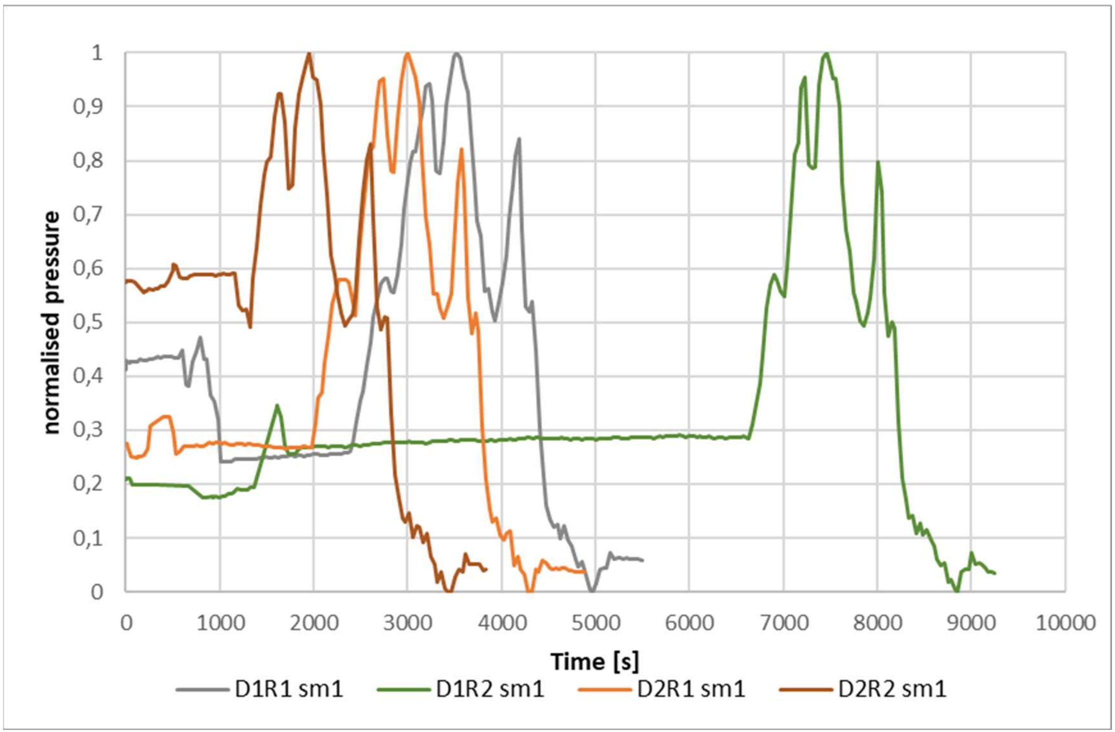


Figure 8-2: Normalised Barometric pressure measurements

APPENDIX B

Fuzzy logic

The experts prediction on the effect of specific hazards have on the shelf life of an avocado is summarised in Table 8-2. The experts were asked to rate the relevant node linguistically, choosing between no or positive effect, very little effect, marginal effect, some effect or detrimental effect. The answers were then transferred into numerical values with 1 indicating no or positive effect and 5 for detrimental effect.

There was an instance were an expert did not provide an estimation, in this instance the fuzzy logic was calculated considering the remaining 5 experts.

Table 8-2: Expert opinion

Node	State	Effect					
		Expert 1	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**
Avocado plant condition	Healthy	1	1	1	5	1	1
	Not healthy	2	5	5	5	x	4
Picking technique	Full hand	2	1	1	1	2	2
	Partial hand	2	1	1	1	x	2
	other detrimental method	2	5	5	2	2	3
Sunlight exposure	Full sun	2	1	5	2	4	4
	Partial sun	3	3	1	1	1	2
Truck Maintenance and condition	Often Maintained	1	1	1	1	2	2
	Rarely Maintained	5	4	5	2	3	2
Truck tyre pressure	High	4	5	5	2	5	3
	Correct	4	1	1	1	2	2
	Low	3	1	5	2	4	1
Tractor Maintenance and condition	Often Maintained	3	1	1	1	1	2
	Rarely Maintained	4	3	5	2	1	2
Tractor tyre pressure	High	3	5	5	3	2	3
	Correct	3	1	1	1	2	2
	Low	3	1	1	2	2	2.5
Delay in Transportation	No delay	1	1	5	1	1	2
	Significant delay	5	4	1	3	4	4
Truck or Tractor drivers ability and care taken during transport	no effect on produce	1	1	5	1	2	2
	detrimental effect on produce	4	5	1	4	4	3
	Clean	2	1	5	1	2	1

Node	State	Effect					
		Expert 1	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**
Cleanliness of the packhouse	Not Clean	4	5	4	4	4	4.5

The numbers were converted into fuzzy data sets by means of a triangular distribution as seen in Figure 8-3.

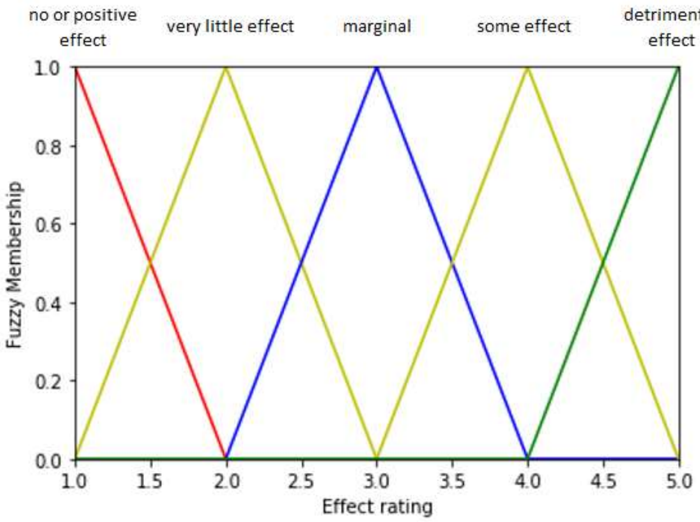


Figure 8-3: Triangular distribution for a five-point scale

The agreement degree between the experts is summarised in Table 8-3. It is noted that no agreement was achieved for the effect of low truck tyre pressure.

Table 8-3: Agreement degree between the experts

Node	State	Agreement degree					
		$\widetilde{R}_1$	$\widetilde{R}_2$	$\widetilde{R}_3$	$\widetilde{R}_4$	$\widetilde{R}_5$	$\widetilde{R}_6$
Avocado plant condition	Healthy	0.80	0.80	0.80	-	0.80	0.80
	Not healthy	-	0.56	0.56	0.56		0.19
Picking technique	Full hand	0.55	0.55	0.55	0.55	0.55	0.55
	Partial hand	0.44	0.69	0.63	0.63		0.44
	other detrimental method	0.45	0.20	0.20	0.45	0.45	0.15
Sunlight exposure	Full sun	0.25	0.10	0.10	0.25	0.25	0.25
	Partial sun	0.25	0.25	0.45	0.45	0.45	0.25

Node	State	Agreement degree					
		$\widetilde{R}_1$	$\widetilde{R}_2$	$\widetilde{R}_3$	$\widetilde{R}_4$	$\widetilde{R}_5$	$\widetilde{R}_6$
Truck Maintenance and condition	Often Maintained	0.70	0.70	0.70	0.70	0.40	0.40
	Rarely Maintained	0.25	0.15	0.25	0.25	0.15	0.25
Truck tyre pressure	High	0.20	0.45	0.45	0.05	0.45	0.10
	Correct	-	0.50	0.50	0.50	0.35	0.35
	Low	0.10	0.25	0.05	0.15	0.10	0.25
Tractor Maintenance and condition	Often Maintained	0.05	0.65	0.65	0.65	0.65	0.25
	Rarely Maintained	0.10	0.15	0.05	0.30	0.10	0.30
Tractor tyre pressure	High	0.45	0.20	0.20	0.45	0.15	0.45
	Correct	0.10	0.50	0.50	0.50	0.40	0.40
	Low	0.10	0.30	0.30	0.35	0.35	-
Delay in Transportation	No delay	0.65	0.65	-	0.65	0.65	0.20
	Significant delay	0.15	0.50	-	0.15	0.50	0.50
Truck or Tractor drivers ability and care taken during transport	no effect on produce	0.50	0.50	-	0.50	0.35	0.35
	detrimental effect on produce	0.50	0.15	-	0.50	0.50	0.15
Cleanliness of the packhouse	Clean	0.35	0.50	-	0.50	0.35	0.50
	Not Clean	0.65	0.20	0.65	0.65	0.65	-

The relevant agreement degree and resulting crisp value was calculated and is summarised in Table 8-4 the defuzzification technique used for this study is the weighted average technique. No weighting was assigned to the experts in this study so as to not introduce any bias in the results.

Table 8-4: Relevant Agreement degree and crisp value

Node	State	Agreement degree						Crisp Value
		$\widetilde{R}_1$	$\widetilde{R}_2$	$\widetilde{R}_3$	$\widetilde{R}_4$	$\widetilde{R}_5$	$\widetilde{R}_6$	
Avocado plant condition	Healthy	0.20	0.20	0.20	-	0.20	0.20	1.00
	Not healthy	-	0.30	0.30	0.30	-	0.10	4.90
Picking technique	Full hand	0.17	0.17	0.17	0.17	0.17	0.17	1.50
	Partial hand	0.16	0.24	0.22	0.22	-	0.16	1.31
	other detrimental method	0.24	0.11	0.11	0.24	0.24	0.08	2.71
	Full sun	0.21	0.08	0.08	0.21	0.21	0.21	3.00

Node	State	Agreement degree						Crisp Value
		$\tilde{R}_1$	$\tilde{R}_2$	$\tilde{R}_3$	$\tilde{R}_4$	$\tilde{R}_5$	$\tilde{R}_6$	
Sunlight exposure	Partial sun	0.12	0.12	0.21	0.21	0.21	0.12	1.60
Truck Maintenance and condition	Often Maintained	0.19	0.19	0.19	0.19	0.11	0.11	1.22
	Rarely Maintained	0.19	0.12	0.19	0.19	0.12	0.19	3.50
Truck tyre pressure	High	0.12	0.26	0.26	0.03	0.26	0.06	4.68
	Correct	-	0.23	0.23	0.23	0.16	0.16	1.32
	Low	0.11	0.28	0.06	0.17	0.11	0.28	1.94
Tractor Maintenance and condition	Often Maintained	0.02	0.22	0.22	0.22	0.22	0.09	1.12
	Rarely Maintained	0.10	0.15	0.05	0.30	0.10	0.30	2.40
Tractor tyre pressure	High	0.24	0.11	0.11	0.24	0.08	0.24	3.34
	Correct	0.04	0.21	0.21	0.21	0.17	0.17	1.42
	Low	0.07	0.21	0.21	0.25	0.25	-	1.64
Delay in Transportation	No delay	0.23	0.23	-	0.23	0.23	0.07	1.07
	Significant delay	0.08	0.28	-	0.08	0.28	0.28	4.00
Truck or Tractor drivers ability and care taken during transport	no effect on produce	0.23	0.23	-	0.23	0.16	0.16	1.32
	detrimental effect on produce	0.28	0.08	-	0.28	0.28	0.08	4.00
Cleanliness of the packhouse	Clean	0.16	0.23	-	0.23	0.16	0.23	1.32
	Not Clean	0.23	0.07	0.23	0.23	0.23	-	4.07

In addition to the effect on the shelf life of the produce, the experts were asked to estimate what the probability of occurrence of the specific scenarios were. In order to remain consistent with the weighting applied the fuzzy logic approach, the same weighting factors were applied to the probabilities as seen in Table 8-5.

Table 8-5: Probability of occurrence

Node	State	Probability (%)
Avocado plant condition	Healthy	92
	Not healthy	8
Picking technique	Full hand	33
	Partial hand	20
	other detrimental method	47
Sunlight exposure	Full sun	16

Node	State	Probability (%)
	Partial sun	84
Truck Maintenance and condition	Often Maintained	84
	Rarely Maintained	16
Truck tyre pressure	High	19
	Correct	72
	Low	9
Tractor Maintenance and condition	Often Maintained	79
	Rarely Maintained	21
Tractor tyre pressure	High	11
	Correct	76
	Low	13
Delay in Transportation	No delay	58
	Significant delay	42
Truck or Tractor drivers ability and care taken during transport	no effect on produce	49
	detrimental effect on produce	51
Cleanliness of the packhouse	Clean	93
	Not Clean	7

APPENDIX C

Conditional Probability Tables

Conditional Probability tables

The conditional probability tables indicate the effect of each state as well as the conditional probabilities used in analysis.

Tractor Environment

Precipitation		Humidity		Temperature		Damaging	Not damaging
No Precipitation	1	<85	1	≤ 13 C	1	1%	99%
				13 to 27 C	2	2%	98%
				>27 C	3	2%	98%
		≥ 85	3	≤ 13 C	1	2%	98%
				13 to 27 C	2	5%	95%
				>27 C	3	7%	93%
Light	2	<85	1	≤ 13 C	1	2%	98%
				13 to 27 C	2	3%	97%
				>27 C	3	5%	95%
		≥ 85	3	≤ 13 C	1	5%	95%
				13 to 27 C	2	10%	90%
				>27 C	3	14%	86%
Heavy	3	<85	1	≤ 13 C	1	2%	98%
				13 to 27 C	2	5%	95%
				>27 C	3	7%	93%
		≥ 85	3	≤ 13 C	1	7%	93%
				13 to 27 C	2	14%	86%
				>27 C	3	22%	78%

Farm Transportation Effect

IRI farm Road		Sunlight		Tractor driver		Environmental		Damaged	Not Damaged
< 3 m/km	1	full sun	1.09	good	1	damaging	1	0.2%	100%
						not damaging	3	0.5%	99%
				poor	4.5	damaging	1	0.8%	99%
						not damaging	3	2.4%	98%
		partial sun	3	good	1	damaging	1	0.5%	100%
						not damaging	3	1.4%	99%
				poor	4.5	damaging	1	2.2%	98%
						not damaging	3	6.5%	94%
3 to 8 m/km	2	full sun	1.09	good	1	damaging	1	0.3%	100%
						not damaging	3	1.0%	99%
				poor	4.5	damaging	1	1.6%	98%

IRI farm Road		Sunlight		Tractor driver		Environmental		Damaged	Not Damaged
						not damaging	3	4.7%	95%
		partial sun	3	good	1	damaging	1	1.0%	99%
						not damaging	3	2.9%	97%
				poor	4.5	damaging	1	4.3%	96%
						not damaging	3	13.0%	87%
> 8 m/km	3		1.09	good	1	damaging	1	0.5%	99%
						not damaging	3	1.6%	98%
				poor	4.5	damaging	1	2.4%	98%
						not damaging	3	7.1%	93%
		partial sun	3	good	1	damaging	1	1.4%	99%
						not damaging	3	4.3%	96%
				poor	4.5	damaging	1	6.5%	94%
						not damaging	3	19.4%	81%

Environmental Factors

Precipitation		Humidity		Temperature		Damaging	Not Damaging
No Precipitation	1	<85	1	≤ 13 C	1	1%	99%
				13 to 27 C	2	2%	98%
				>27 C	3	2%	98%
		≥ 85	3	≤ 13 C	1	2%	98%
				13 to 27 C	2	5%	95%
				>27 C	3	7%	93%
Light	2	<85	1	≤ 13 C	1	2%	98%
				13 to 27 C	2	3%	97%
				>27 C	3	5%	95%
		≥ 85	3	≤ 13 C	1	5%	95%
				13 to 27 C	2	10%	90%
				>27 C	3	14%	86%
Heavy	3	<85	1	≤ 13 C	1	2%	98%
				13 to 27 C	2	5%	95%
				>27 C	3	7%	93%
		≥ 85	3	≤ 13 C	1	7%	93%
				13 to 27 C	2	14%	86%
				>27 C	3	22%	78%

Harvest

Picking technique		Environmental		Avo plant health		Damaging	Not Damaging
Full hand	1.5	Damaging	3	healthy	1.0	4%	96%
			3	not healthy	4.9	18%	82%
		Not damaging	1	healthy	1.0	1%	99%
			1	not healthy	4.9	6%	94%
Partial Hand	1.31	Damaging	3	healthy	1.0	3%	97%
			3	not healthy	4.9	15%	85%
		Not damaging	1	healthy	1.0	1%	99%
			1	not healthy	4.9	5%	95%
Stick	2.71	Damaging	3	healthy	1.0	7%	93%
			3	not healthy	4.9	32%	68%
		Not damaging	1	healthy	1.0	2%	98%
			1	not healthy	4.9	11%	89%

Truck Environment

Truck tyre pressure		Truck maintenance		Truck type		Lateral position		vertical position		Crate type		Crate position		Damaging	Not damaging
high	4.67	often maintained	1.22	Rigid	1	Corner	4.3	top layer	5	Perforated	1	top	1.5	0.24%	99.76%
												bottom	1	0.16%	99.84%
										solid	3	top	1.5	0.71%	99.29%
												bottom	1	0.47%	99.53%
								middle layer	1	Perforated	1	top	1.5	0.05%	99.95%
												bottom	1	0.03%	99.97%
										solid	3	top	1.5	0.14%	99.86%
												bottom	1	0.09%	99.91%
								bottom layer	1	Perforated	1	top	1.5	0.05%	99.95%
												bottom	1	0.03%	99.97%
										solid	3	top	1.5	0.14%	99.86%
												bottom	1	0.09%	99.91%
						Centre	1	top layer	5	Perforated	1	top	1.5	0.05%	99.95%
												bottom	1	0.04%	99.96%
										solid	3	top	1.5	0.16%	99.84%
												bottom	1	0.11%	99.89%
								middle layer	1	Perforated	1	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.03%	99.97%
												bottom	1	0.02%	99.98%
								bottom layer	1	Perforated	1	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%

										solid	3	top	1.5	0.03%	99.97%
												bottom	1	0.02%	99.98%
				Articulated	4.1	Corner	4.3	top layer	5	Perforated	1	top	1.5	0.96%	99.04%
												bottom	1	0.64%	99.36%
										solid	3	top	1.5	2.89%	97.11%
												bottom	1	1.93%	98.07%
								middle layer	1	Perforated	1	top	1.5	0.19%	99.81%
												bottom	1	0.13%	99.87%
										solid	3	top	1.5	0.58%	99.42%
												bottom	1	0.39%	99.61%
								bottom layer	1	Perforated	1	top	1.5	0.19%	99.81%
												bottom	1	0.13%	99.87%
										solid	3	top	1.5	0.58%	99.42%
												bottom	1	0.39%	99.61%
						Centre	1	top layer	5	Perforated	1	top	1.5	0.22%	99.78%
												bottom	1	0.15%	99.85%
										solid	3	top	1.5	0.67%	99.33%
												bottom	1	0.45%	99.55%
								middle layer	1	Perforated	1	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
										solid	3	top	1.5	0.13%	99.87%
												bottom	1	0.09%	99.91%
								bottom layer	1	Perforated	1	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
										solid	3	top	1.5	0.13%	99.87%
												bottom	1	0.09%	99.91%

		rarely maintained	3.5	Rigid	1	Corner	4.3	top layer	5	Perforated	1	top	1.5	0.67%	99.33%
												bottom	1	0.45%	99.55%
										solid	3	top	1.5	2.02%	97.98%
												bottom	1	1.35%	98.65%
								middle layer	1	Perforated	1	top	1.5	0.13%	99.87%
												bottom	1	0.09%	99.91%
										solid	3	top	1.5	0.40%	99.60%
												bottom	1	0.27%	99.73%
								bottom layer	1	Perforated	1	top	1.5	0.13%	99.87%
												bottom	1	0.09%	99.91%
										solid	3	top	1.5	0.40%	99.60%
												bottom	1	0.27%	99.73%
						Centre	1	top layer	5	Perforated	1	top	1.5	0.16%	99.84%
												bottom	1	0.10%	99.90%
										solid	3	top	1.5	0.47%	99.53%
												bottom	1	0.31%	99.69%
								middle layer	1	Perforated	1	top	1.5	0.03%	99.97%
												bottom	1	0.02%	99.98%
										solid	3	top	1.5	0.09%	99.91%
												bottom	1	0.06%	99.94%
								bottom layer	1	Perforated	1	top	1.5	0.03%	99.97%
												bottom	1	0.02%	99.98%
										solid	3	top	1.5	0.09%	99.91%
												bottom	1	0.06%	99.94%
				Articulate d	4. 1	Corner	4.3	top layer	5	Perforated	1	top	1.5	2.77%	97.23%
												bottom	1	1.84%	98.16%

										solid	3	top	1.5	8.30%	91.70%
												bottom	1	5.53%	94.47%
								middle layer	1	Perforated	1	top	1.5	0.55%	99.45%
												bottom	1	0.37%	99.63%
										solid	3	top	1.5	1.66%	98.34%
												bottom	1	1.11%	98.89%
								bottom layer	1	Perforated	1	top	1.5	0.55%	99.45%
												bottom	1	0.37%	99.63%
										solid	3	top	1.5	1.66%	98.34%
												bottom	1	1.11%	98.89%
						Centre	1	top layer	5	Perforated	1	top	1.5	0.64%	99.36%
												bottom	1	0.43%	99.57%
										solid	3	top	1.5	1.93%	98.07%
												bottom	1	1.29%	98.71%
								middle layer	1	Perforated	1	top	1.5	0.13%	99.87%
												bottom	1	0.09%	99.91%
										solid	3	top	1.5	0.39%	99.61%
												bottom	1	0.26%	99.74%
								bottom layer	1	Perforated	1	top	1.5	0.13%	99.87%
												bottom	1	0.09%	99.91%
										solid	3	top	1.5	0.39%	99.61%
												bottom	1	0.26%	99.74%
correct	1.3	often maintained	1.22	Rigid	1	Corner	4.3	top layer	5	Perforated	1	top	1.5	0.07%	99.93%
												bottom	1	0.04%	99.96%
										solid	3	top	1.5	0.20%	99.80%
												bottom	1	0.13%	99.87%

								middle layer	1	Perforated	1	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
								bottom layer	1	Perforated	1	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
						Centre	1	top layer	5	Perforated	1	top	1.5	0.02%	99.98%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.05%	99.95%
												bottom	1	0.03%	99.97%
								middle layer	1	Perforated	1	top	1.5	0.00%	100.00%
												bottom	1	0.00%	100.00%
										solid	3	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
								bottom layer	1	Perforated	1	top	1.5	0.00%	100.00%
												bottom	1	0.00%	100.00%
										solid	3	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
				Articulated	4.1	Corner	4.3	top layer	5	Perforated	1	top	1.5	0.27%	99.73%
												bottom	1	0.18%	99.82%
										solid	3	top	1.5	0.82%	99.18%
												bottom	1	0.54%	99.46%
								middle layer	1	Perforated	1	top	1.5	0.05%	99.95%
												bottom	1	0.04%	99.96%

										solid	3	top	1.5	0.16%	99.84%
												bottom	1	0.11%	99.89%
								bottom layer	1	Perforated	1	top	1.5	0.05%	99.95%
												bottom	1	0.04%	99.96%
										solid	3	top	1.5	0.16%	99.84%
												bottom	1	0.11%	99.89%
						Centre	1	top layer	5	Perforated	1	top	1.5	0.06%	99.94%
												bottom	1	0.04%	99.96%
										solid	3	top	1.5	0.19%	99.81%
												bottom	1	0.13%	99.87%
								middle layer	1	Perforated	1	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
								bottom layer	1	Perforated	1	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
		rarely maintained	3.5	Rigid	1	Corner	4.3	top layer	5	Perforated	1	top	1.5	0.19%	99.81%
												bottom	1	0.13%	99.87%
										solid	3	top	1.5	0.57%	99.43%
												bottom	1	0.38%	99.62%
								middle layer	1	Perforated	1	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
										solid	3	top	1.5	0.11%	99.89%
												bottom	1	0.08%	99.92%

								bottom layer	1	Perforated	1	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
										solid	3	top	1.5	0.11%	99.89%
												bottom	1	0.08%	99.92%
						Centre	1	top layer	5	Perforated	1	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
										solid	3	top	1.5	0.13%	99.87%
												bottom	1	0.09%	99.91%
								middle layer	1	Perforated	1	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.03%	99.97%
												bottom	1	0.02%	99.98%
								bottom layer	1	Perforated	1	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.03%	99.97%
												bottom	1	0.02%	99.98%
				Articulated	4.1	Corner	4.3	top layer	5	Perforated	1	top	1.5	0.78%	99.22%
												bottom	1	0.52%	99.48%
										solid	3	top	1.5	2.34%	97.66%
												bottom	1	1.56%	98.44%
								middle layer	1	Perforated	1	top	1.5	0.16%	99.84%
												bottom	1	0.10%	99.90%
										solid	3	top	1.5	0.47%	99.53%
												bottom	1	0.31%	99.69%
								bottom layer	1	Perforated	1	top	1.5	0.16%	99.84%
												bottom	1	0.10%	99.90%

										solid	3	top	1.5	0.47%	99.53%
												bottom	1	0.31%	99.69%
						Centre	1	top layer	5	Perforated	1	top	1.5	0.18%	99.82%
												bottom	1	0.12%	99.88%
										solid	3	top	1.5	0.54%	99.46%
												bottom	1	0.36%	99.64%
								middle layer	1	Perforated	1	top	1.5	0.04%	99.96%
												bottom	1	0.02%	99.98%
										solid	3	top	1.5	0.11%	99.89%
												bottom	1	0.07%	99.93%
								bottom layer	1	Perforated	1	top	1.5	0.04%	99.96%
												bottom	1	0.02%	99.98%
										solid	3	top	1.5	0.11%	99.89%
												bottom	1	0.07%	99.93%
low	1.9	often maintained	1.22	Rigid	1	Corner	4.3	top layer	5	Perforated	1	top	1.5	0.10%	99.90%
												bottom	1	0.07%	99.93%
										solid	3	top	1.5	0.29%	99.71%
												bottom	1	0.20%	99.80%
								middle layer	1	Perforated	1	top	1.5	0.02%	99.98%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.06%	99.94%
												bottom	1	0.04%	99.96%
								bottom layer	1	Perforated	1	top	1.5	0.02%	99.98%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.06%	99.94%
												bottom	1	0.04%	99.96%

						Centre	1	top layer	5	Perforated	1	top	1.5	0.02%	99.98%
												bottom	1	0.02%	99.98%
										solid	3	top	1.5	0.07%	99.93%
												bottom	1	0.05%	99.95%
								middle layer	1	Perforated	1	top	1.5	0.00%	100.00%
												bottom	1	0.00%	100.00%
										solid	3	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
								bottom layer	1	Perforated	1	top	1.5	0.00%	100.00%
												bottom	1	0.00%	100.00%
										solid	3	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
				Articulated	4.1	Corner	4.3	top layer	5	Perforated	1	top	1.5	0.40%	99.60%
												bottom	1	0.27%	99.73%
										solid	3	top	1.5	1.20%	98.80%
												bottom	1	0.80%	99.20%
								middle layer	1	Perforated	1	top	1.5	0.08%	99.92%
												bottom	1	0.05%	99.95%
										solid	3	top	1.5	0.24%	99.76%
												bottom	1	0.16%	99.84%
								bottom layer	1	Perforated	1	top	1.5	0.08%	99.92%
												bottom	1	0.05%	99.95%
										solid	3	top	1.5	0.24%	99.76%
												bottom	1	0.16%	99.84%
						Centre	1	top layer	5	Perforated	1	top	1.5	0.09%	99.91%
												bottom	1	0.06%	99.94%

										solid	3	top	1.5	0.28%	99.72%
												bottom	1	0.19%	99.81%
								middle layer	1	Perforated	1	top	1.5	0.02%	99.98%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.06%	99.94%
												bottom	1	0.04%	99.96%
								bottom layer	1	Perforated	1	top	1.5	0.02%	99.98%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.06%	99.94%
												bottom	1	0.04%	99.96%
		rarely maintained	3.5	Rigid	1	Corner	4.3	top layer	5	Perforated	1	top	1.5	0.28%	99.72%
												bottom	1	0.19%	99.81%
										solid	3	top	1.5	0.84%	99.16%
												bottom	1	0.56%	99.44%
								middle layer	1	Perforated	1	top	1.5	0.06%	99.94%
												bottom	1	0.04%	99.96%
										solid	3	top	1.5	0.17%	99.83%
												bottom	1	0.11%	99.89%
								bottom layer	1	Perforated	1	top	1.5	0.06%	99.94%
												bottom	1	0.04%	99.96%
										solid	3	top	1.5	0.17%	99.83%
												bottom	1	0.11%	99.89%
						Centre	1	top layer	5	Perforated	1	top	1.5	0.07%	99.93%
												bottom	1	0.04%	99.96%
										solid	3	top	1.5	0.20%	99.80%
												bottom	1	0.13%	99.87%

								middle layer	1	Perforated	1	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
								bottom layer	1	Perforated	1	top	1.5	0.01%	99.99%
												bottom	1	0.01%	99.99%
										solid	3	top	1.5	0.04%	99.96%
												bottom	1	0.03%	99.97%
					Articulated	4.1	Corner	4.3	top layer	5	Perforated	1	top	1.5	1.15%	98.85%
												bottom	1	0.77%	99.23%
										solid	3	top	1.5	3.46%	96.54%
												bottom	1	2.30%	97.70%
								middle layer	1	Perforated	1	top	1.5	0.23%	99.77%
												bottom	1	0.15%	99.85%
										solid	3	top	1.5	0.69%	99.31%
												bottom	1	0.46%	99.54%
								bottom layer	1	Perforated	1	top	1.5	0.23%	99.77%
												bottom	1	0.15%	99.85%
										solid	3	top	1.5	0.69%	99.31%
												bottom	1	0.46%	99.54%
							Centre	1	top layer	5	Perforated	1	top	1.5	0.27%	99.73%
												bottom	1	0.18%	99.82%
										solid	3	top	1.5	0.80%	99.20%
												bottom	1	0.54%	99.46%
								middle layer	1	Perforated	1	top	1.5	0.05%	99.95%
												bottom	1	0.04%	99.96%

										solid	3	top	1.5	0.16%	99.84%
												bottom	1	0.11%	99.89%
								bottom layer	1	Perforated	1	top	1.5	0.05%	99.95%
												bottom	1	0.04%	99.96%
										solid	3	top	1.5	0.16%	99.84%
												bottom	1	0.11%	99.89%

Truck Transportation Effect

Truck driver		Truck environment		Road condition		Delay		Damaging	Not Damaging
Good	1	Damaging	5	Damaging	5	no delay	1.1	6%	94%
						delay	4	21%	79%
				no damaging	1	no delay	1.1	1%	99%
						delay	4	4%	96%
		not damaging	1	Damaging	5	no delay	1.1	1%	99%
						delay	4	4%	96%
				no damaging	1	no delay	1.1	0%	100%
						delay	4	1%	99%
Poor	4	Damaging	5	Damaging	5	no delay	1.1	17%	83%
						delay	4	64%	36%
				no damaging	1	no delay	1.1	3%	97%
						delay	4	13%	87%
		not damaging	1	Damaging	5	no delay	1.1	3%	97%
						delay	4	13%	87%
				no damaging	1	no delay	1.1	1%	99%
						delay	4	3%	97%

Road Condition

IRI gravel farm road		IRI paved		IRI R36		IRI Jachtpad		IRI packhouse		Damaging	Not Damaging
3	1	3	1	3	1	3	1	3	1	0.03%	100%
								3-8	2	0.06%	100%
								8	3	0.10%	100%
						3-8	2	3	1	0.06%	100%
								3-8	2	0.13%	100%
								8	3	0.19%	100%
						8	3	3	1	0.10%	100%
								3-8	2	0.19%	100%
								8	3	0.29%	100%
				3-8	2	3	1	3	1	0.06%	100%
								3-8	2	0.13%	100%
								8	3	0.19%	100%
						3-8	2	3	1	0.13%	100%
								3-8	2	0.26%	100%
								8	3	0.38%	100%
						8	3	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
				8	3	3	1	3	1	0.10%	100%
								3-8	2	0.19%	100%
								8	3	0.29%	100%
						3-8	2	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
						8	3	3	1	0.29%	100%
								3-8	2	0.58%	99%
								8	3	0.86%	99%

		3-8	2	3	1	3	1	3	1	0.06%	100%
								3-8	2	0.13%	100%
								8	3	0.19%	100%
						3-8	2	3	1	0.13%	100%
								3-8	2	0.26%	100%
								8	3	0.38%	100%
						8	3	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
				3-8	2	3	1	3	1	0.13%	100%
								3-8	2	0.26%	100%
								8	3	0.38%	100%
						3-8	2	3	1	0.26%	100%
								3-8	2	0.51%	99%
								8	3	0.77%	99%
						8	3	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%
				8	3	3	1	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
						3-8	2	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%
						8	3	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
		8	3	3	1	3	1	3	1	0.10%	100%
								3-8	2	0.19%	100%
								8	3	0.29%	100%

						3-8	2	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
						8	3	3	1	0.29%	100%
								3-8	2	0.58%	99%
								8	3	0.86%	99%
				3-8	2	3	1	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
						3-8	2	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%
						8	3	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
				8	3	3	1	3	1	0.29%	100%
								3-8	2	0.58%	99%
								8	3	0.86%	99%
						3-8	2	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
						8	3	3	1	0.86%	99%
								3-8	2	1.73%	98%
								8	3	2.59%	97%
3-8	2	3	1	3	1	3	1	3	1	0.06%	100%
								3-8	2	0.13%	100%
								8	3	0.19%	100%
						3-8	2	3	1	0.13%	100%
								3-8	2	0.26%	100%
								8	3	0.38%	100%

						8	3	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
				3-8	2	3	1	3	1	0.13%	100%
								3-8	2	0.26%	100%
								8	3	0.38%	100%
						3-8	2	3	1	0.26%	100%
								3-8	2	0.51%	99%
								8	3	0.77%	99%
						8	3	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%
				8	3	3	1	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
						3-8	2	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%
						8	3	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
		3-8	2	3	1	3	1	3	1	0.13%	100%
								3-8	2	0.26%	100%
								8	3	0.38%	100%
						3-8	2	3	1	0.26%	100%
								3-8	2	0.51%	99%
								8	3	0.77%	99%
						8	3	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%

				3-8	2	3	1	3	1	0.26%	100%
								3-8	2	0.51%	99%
								8	3	0.77%	99%
						3-8	2	3	1	0.51%	99%
								3-8	2	1.02%	99%
								8	3	1.54%	98%
						8	3	3	1	0.77%	99%
								3-8	2	1.54%	98%
								8	3	2.30%	98%
				8	3	3	1	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%
						3-8	2	3	1	0.77%	99%
								3-8	2	1.54%	98%
								8	3	2.30%	98%
						8	3	3	1	1.15%	99%
								3-8	2	2.30%	98%
								8	3	3.46%	97%
		8	3	3	1	3	1	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
						3-8	2	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%
						8	3	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
				3-8	2	3	1	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%

						3-8	2	3	1	0.77%	99%
								3-8	2	1.54%	98%
								8	3	2.30%	98%
						8	3	3	1	1.15%	99%
								3-8	2	2.30%	98%
								8	3	3.46%	97%
				8	3	3	1	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
						3-8	2	3	1	1.15%	99%
								3-8	2	2.30%	98%
								8	3	3.46%	97%
						8	3	3	1	1.73%	98%
								3-8	2	3.46%	97%
								8	3	5.18%	95%
8	3	3	1	3	1	3	1	3	1	0.10%	100%
								3-8	2	0.19%	100%
								8	3	0.29%	100%
						3-8	2	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
						8	3	3	1	0.29%	100%
								3-8	2	0.58%	99%
								8	3	0.86%	99%
				3-8	2	3	1	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
						3-8	2	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%

						8	3	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
				8	3	3	1	3	1	0.29%	100%
								3-8	2	0.58%	99%
								8	3	0.86%	99%
						3-8	2	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
						8	3	3	1	0.86%	99%
								3-8	2	1.73%	98%
								8	3	2.59%	97%
		3-8	2	3	1	3	1	3	1	0.19%	100%
								3-8	2	0.38%	100%
								8	3	0.58%	99%
						3-8	2	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%
						8	3	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
				3-8	2	3	1	3	1	0.38%	100%
								3-8	2	0.77%	99%
								8	3	1.15%	99%
						3-8	2	3	1	0.77%	99%
								3-8	2	1.54%	98%
								8	3	2.30%	98%
						8	3	3	1	1.15%	99%
								3-8	2	2.30%	98%
								8	3	3.46%	97%

				8	3	3	1	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
						3-8	2	3	1	1.15%	99%
								3-8	2	2.30%	98%
								8	3	3.46%	97%
						8	3	3	1	1.73%	98%
								3-8	2	3.46%	97%
								8	3	5.18%	95%
		8	3	3	1	3	1	3	1	0.29%	100%
								3-8	2	0.58%	99%
								8	3	0.86%	99%
						3-8	2	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
						8	3	3	1	0.86%	99%
								3-8	2	1.73%	98%
								8	3	2.59%	97%
				3-8	2	3	1	3	1	0.58%	99%
								3-8	2	1.15%	99%
								8	3	1.73%	98%
						3-8	2	3	1	1.15%	99%
								3-8	2	2.30%	98%
								8	3	3.46%	97%
						8	3	3	1	1.73%	98%
								3-8	2	3.46%	97%
								8	3	5.18%	95%
				8	3	3	1	3	1	0.86%	99%
								3-8	2	1.73%	98%
								8	3	2.59%	97%

						3-8	2	3	1	1.73%	98%
								3-8	2	3.46%	97%
								8	3	5.18%	95%
						8	3	3	1	2.59%	97%
								3-8	2	5.18%	95%
								8	3	7.78%	92%

Packhouse Conditions

Packhouse temperature		Packhouse humidity		Cleaning in packhouse		Impact		Unloading		Damaging	Not Damaging
< 13 C	1	<85	1	Not Clean	4.1	High	5	Damaging	5	3.3%	96.7%
								Not Damaging	1	0.7%	99.3%
						Low	1	Damaging	5	0.7%	99.3%
								Not Damaging	1	0.1%	99.9%
				Clean	1.3	High	5	Damaging	5	1.1%	98.9%
								Not Damaging	1	0.2%	99.8%
						Low	1	Damaging	5	0.2%	99.8%
								Not Damaging	1	0.0%	100.0%
		≥85	3	Not Clean	4.1	High	5	Damaging	5	9.8%	90.2%
								Not Damaging	1	2.0%	98.0%
							1	Damaging	5	2.0%	98.0%
								Not Damaging	1	0.4%	99.6%
				Clean	1.3	High	5	Damaging	5	3.2%	96.8%
								Not Damaging	1	0.6%	99.4%
							1	Damaging	5	0.6%	99.4%
								Not Damaging	1	0.1%	99.9%
	2	<85	1	Not Clean	4.1	High	5	Damaging	5	6.5%	93.5%
								Not Damaging	1	1.3%	98.7%
							1	Damaging	5	1.3%	98.7%
								Not Damaging	1	0.3%	99.7%
				Clean	1.3	High	5	Damaging	5	2.1%	97.9%
								Not Damaging	1	0.4%	99.6%

							1	Damaging	5	0.4%	99.6%
								Not Damaging	1	0.1%	99.9%
		≥85	3	Not Clean	4.1	High	5	Damaging	5	19.5%	80.5%
								Not Damaging	1	3.9%	96.1%
							1	Damaging	5	3.9%	96.1%
								Not Damaging	1	0.8%	99.2%
				Clean	1.3	High	5	Damaging	5	6.3%	93.7%
								Not Damaging	1	1.3%	98.7%
							1	Damaging	5	1.3%	98.7%
								Not Damaging	1	0.3%	99.7%
	3	<85	1	Not Clean	4.1	High	5	Damaging	5	9.8%	90.2%
								Not Damaging	1	2.0%	98.0%
							1	Damaging	5	2.0%	98.0%
								Not Damaging	1	0.4%	99.6%
				Clean	1.3	High	5	Damaging	5	3.2%	96.8%
								Not Damaging	1	0.6%	99.4%
							1	Damaging	5	0.6%	99.4%
								Not Damaging	1	0.1%	99.9%
		≥85	3	Not Clean	4.1	High	5	Damaging	5	29.3%	70.7%
								Not Damaging	1	5.9%	94.1%
							1	Damaging	5	5.9%	94.1%
								Not Damaging	1	1.2%	98.8%
				Clean	1.3	High	5	Damaging	5	9.5%	90.5%
								Not Damaging	1	1.9%	98.1%
							1	Damaging	5	1.9%	98.1%
								Not Damaging	1	0.4%	99.6%

Final Avocado Condition

Harvest		farm transportation		packhouse		truck effect		Damaged	Not Damaged
Damaging	5	Damaging	5	Damaging	5	damaged	5	100%	0%
						not damaged	1	20%	80%
				no damaging	1	damaged	5	20%	80%
						not damaged	1	4%	96%
		not damaging	1	Damaging	5	damaged	5	20%	80%
						not damaged	1	4%	96%
				no damaging	1	damaged	5	4%	96%
						not damaged	1	1%	99%
not damaging	1	Damaging	5	Damaging	5	damaged	5	20%	80%
						not damaged	1	4%	96%
				no damaging	1	damaged	5	4%	96%
						not damaged	1	1%	99%
		not damaging	1	Damaging	5	damaged	5	4%	96%
						not damaged	1	1%	99%
				no damaging	1	damaged	5	1%	99%
						not damaged	1	0%	100%

APPENDIX D

BayesiaLab Optimisation results

Dynamic Profile Final Avo Condition: Probability Minimization (A posteriori)								
Search Method: Numerical Evidence Proportional to: Mean - Fix Mean (MinXEnt)								
Final Avo Condition = Damaged								
Node	**Prior Value/Mean**	**Value/Mean at T**	**Evidence**	**Posterior Probability P(s|E)**	**Marginal Likelihood P(E)**	**Likelihood P(E|s)**	**Bayes Factor BF(s,E)**	**Generalized BF GBF(s,E)**
A priori				3.0000%	6.2062%			
Avo Plant Condition	1.3139	1.3139	1.0000	2.9458%	5.7067%	90.2899%	15.8217	153.6413
Delay in Transportation	2.3019	2.3019	1.0700	2.8663%	3.3074%	50.9157%	15.3947	30.3265
Picking technique	2.0312	2.0311	1.3100	2.7738%	0.6609%	9.8457%	14.8978	16.4156
Unloading	1.5006	1.5006	1.0000	2.7572%	0.5782%	8.5622%	14.8089	16.1019
Truck driver ability	2.6875	2.6871	1.3200	2.7319%	0.2832%	4.1560%	14.6731	15.2660
Packhouse Temperature	1.2901	1.2901	1.0000	2.7245%	0.2011%	2.9426%	14.6334	15.0468
Tractor driver ability	2.6865	2.6867	4.0000	2.7167%	0.1025%	1.4963%	14.5913	14.7977
Cleaning process	3.8773	3.8774	4.0700	2.7135%	0.0954%	1.3898%	14.5739	14.7652
Avo sun exposure	1.8240	1.8240	3.0000	2.7114%	0.0153%	0.2222%	14.5627	14.5929
IRI Farm Road	2.1000	2.1000	1.0000	2.7113%	0.0137%	0.2000%	14.5621	14.5892
IRI R36	1.4000	1.4000	1.0000	2.7111%	0.0082%	0.1200%	14.5614	14.5777
Lateral position in the crate	2.6500	2.6500	1.0000	2.7110%	0.0041%	0.0600%	14.5609	14.5690
IRI packhouse	1.5000	1.5000	1.0000	2.7109%	0.0021%	0.0300%	14.5603	14.5644
IRI paved section	1.5200	1.5200	1.0000	2.7109%	0.0010%	0.0150%	14.5600	14.5620
Tractor Maintenance and Condition	1.3888	1.3888	1.1200	2.7108%	0.0008%	0.0118%	14.5598	14.5614
Tractor Tyre pressure	1.6598	1.6598	1.4200	2.7108%	0.0006%	0.0090%	14.5597	14.5609

Other Nodes		
Node	**Prior Value/Mean**	**Posterior Value/Mean**
Pallet/ Crate Type	2.2000	2.2000
Truck tyre pressure	2.0142	2.0142
Truck Maintenance and Condition	1.5848	1.5848
Truck Type	2.5500	2.5500
Avocado vertical position in the crate	2.3333	2.3333
Crate position in the truck	1.2500	1.2500
IRI Jachtpad road	2.0200	2.0200
IRI gravel farm road	2.1000	2.1000
Avo Stacking height	1.0000	1.0000
Packhouse humidity	1.0000	1.0000
Packhouse Process Impact	5.0000	5.0000