The feasibility of in-transit roadworthiness tests on the national roads of South Africa.

by

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Acknowledgements

This project would not have been possible without the following people:

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Executive Summary

Globally, it is estimated that a fatal or serious car accident happens every six seconds; thus, declaring car accidents as a global epidemic. These car accidents are classified as either: driver related, vehicle related or environmentally related. Vehicle related factors are those that are concerned with the road-fitness of vehicles or otherwise known as the roadworthiness of a vehicle. The poor roadworthiness of vehicles using the South African roads is mainly the cause of four main contributing factors which are: poor visibility of vehicles, poor braking systems, tire failure and over-weight cargo. The ultimate goal of this project is to develop possible solutions to the problem of poor roadworthiness in South Africa, whilst considering the utilization of currently established infrastructure, the financial implications and the overall travelling time of travelers on the national roads of South Africa. The document includes research that was conducted on the testing and evaluation of roadworthiness in the United Kingdom and Japan as well as on local grounds. A possible three solutions were generated and developed that would: be able to solve the poor roadworthiness problem, be able to adjust to the current philosophies of South African road users, as well as add to the global competiveness of the South African National Roads Agency Limited (SANRAL). These solutions were then tested for feasibility, against one another, in a decision matrix where the most feasible solution was determined. The most feasible solution was further investigated, by means of simulation modeling and the utilization of the Queuing Theory, to justify the unconvincing rank of feasible solutions that were identified during the decision matrix evaluation. Safer roads are the responsibility of all South African citizens, and engineers should continuously try to design and developed new solutions to the problem of poor roadworthiness in South Africa and thus, indirectly solve the problem of poor road safety.

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Abbreviations

AE	-	Authorised Examiner
EU	-	European Union
HIV	-	Human Immunodeficiency Virus
IRD	-	International Road Dynamics Ltd
km/h	-	kilometers per hour
m/s	-	meters per second
MOT	-	Ministry of Transport
N1	-	National road connecting Cape Town and Pretoria
NaTIS	-	National Traffic Information System
NT	-	Nominated Tester
OR	-	Operations Research
RTMC	-	Road Traffic Management Corporation
SABS	-	South African Bureau of Standards
SANRAL	-	South African National Road Agency Limited
TELOS	-	Technology and system-, Economic -, Legal -, Operational-, and Schedule
UK	-	United Kingdom
UN	-	United Nations
VOSA	-	Vehicle and Operator Services Agency
VST	-	Vehicle Testing Station
WW	-	World War

Chapter One

1.   Project Proposal

1.1   Introduction and Background

Globally car accidents account for 1.3 million deaths per year, amounting to one death, or serious injury, every six seconds. This is a shocking realization since Tuberculosis and Malaria were responsible for only about 881 000 deaths respectively during 2010; thus, classifying car accidents together with HIV, Malaria and Tuberculosis as a global epidemic (Make Roads Safe: The campaign for global road safety 2011).

The global campaign for "Make Roads Safe", estimates that nine in every ten fatal road accidents occur in developing countries like South Africa. Taking a closer look at our country; around 12, 454 fatal car accidents were reported during 2006 alone. Not only is this an increase of 718 since 2005 (Road Traffic Management Corporation 2007), but when considering that during 2006 there were 8, 544, 902 driver licenses issued in South Africa (Road Traffic Management Corporation 2007), the statistics indicates that one in every 686, 11 licensed drivers travelling in a vehicle on South African roads was a victim of a fatal car accident.

This ratio does not seem so intimidating at first, but when considering that more than 300, 000 vehicles travel on the N1 stretch of Ben Schoeman on a daily basis (Wikipedia 2011), this ratio indicates that there exists a possibility of 437, 24 fatal accidents on the Ben Schoeman stretch daily.

Picture 1: The Ben Schoeman highway.

During 2009, the South African Government confirmed a death toll of 16,000 people per year due to car accidents, which in turn cost the country more than R14 billion *(Address during funeral of road accident victims by Mr Sibusiso Ndebele, MP Minister of Transport, Queenstown; 4 Oct 2009).*

Keeping this in mind the question arises, how can we as professionally qualified engineers, better the quality of life for ourselves, our families and loved ones when using the national roads of South Africa, when "the continent of Africa was classified as having the most dangerous roads in the world" (Make Roads Safe 2011)? South Africa alone has around seven million licensed drivers, operating over eight million registered vehicles. Seeing as this number has increases annually with around 6% (Road Traffic Management Corporation 2007), how do we develop and sustain a system to operate over this large amount of entities? What about the large sum of money involved, which in turn would be funded by the tax payers of our country?
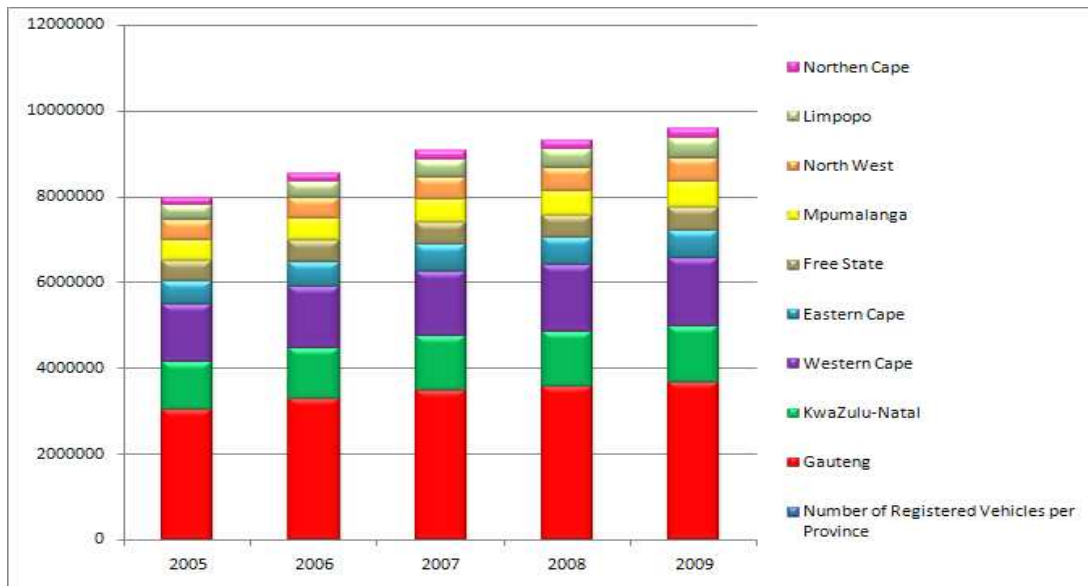
Figure 1: Vehicle number statistics of South Africa, according to the Road Traffic report for the calendar year 2009.

During recent research it was determined that the three major factors that lead to car accidents were driver related factors (80-90%), vehicle related factors (10-30%) and road environmental factors (5-15%) (Ministry of Transport: Republic of South Africa; 2001). Driver related factors like drunkenness, tiredness and the everlasting human factors are unfortunately the factors that we as engineers have little control or authority over. We try to decrease this element through consideration of the ergonomical science of human factors in our designs of cars and their operations, but we can merely design with the human operator in mind, and not drive the vehicles ourselves. Road environment factors include: the quality of the roads in South Africa and the effectiveness of road designs and

implementation thereof; civil engineers continuously try to design and develop better and sustainable road structures.

Vehicle related factors offer a great opportunity for industrial engineers to improve and develop the systems already in use. Seeing as this factor deals with ever-changing entities on a continuous basis consuming a number of resources; almost the same as a manufactured product through a factory floor. The major contributor towards this factor of car accidents is the roadworthiness of vehicles using the national roads of South Africa. During November 2010, a number of 1, 493, 574 vehicles were inspected on the national roads, 10, 282 of which were discontinued from use (Arrive Alive 2010). That is almost 1% of vehicles travelling on the roads that are not fit for driving. These statistics do not include the vehicles that were merely fined for non-roadworthy elements.

The greatest challenge now exists, how to test vehicles using the roads of South Africa for the correct roadworthiness whilst not significantly disrupting the journey of travelers.

The major national roads of South Africa are: the N1, which connects Johannesburg to Cape Town via Bloemfontein, the N2, which connects Johannesburg to Cape Town via the coastal towns of Port Elizabeth and Durban, the N7, which connects Namibia to Cape Town via Springbok and the N12, which connects Johannesburg to the Garden Route, to name a few.
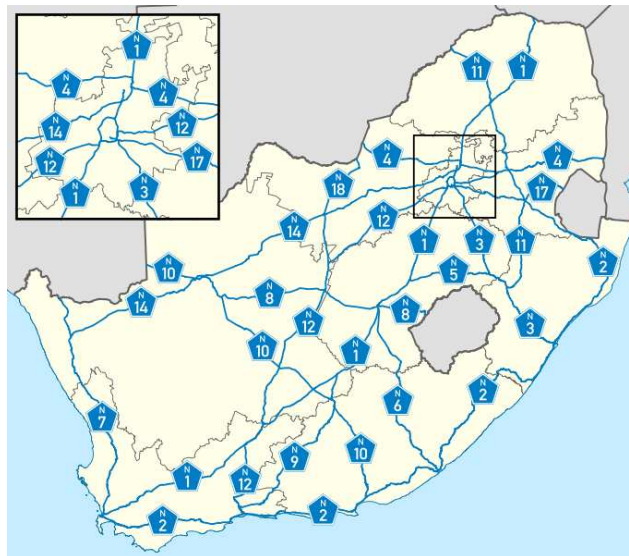
Picture 2: The National roads of South Africa.

The N1 alone manifests around 300,000 vehicles per day, thus with the journey from Johannesburg to Cape Town being an average of a 12 hour route, as little time as possible should be wasted on tests and evaluations. The safety of these travelers as well

as the safety of fellow travelers needs to be top-notch to ensure that all parties arrive safe at their destination.

1.2   South African road safety statistics

- The total number of un-roadworthy and un-licensed vehicles decreased during 2008-2009 by 11, 79%, but the total number of un-roadworthy and licensed vehicles increased during the same period with 13, 69%.

- At the end of December 2009, there were a percentage of 12, 66% of all drivers licenses that were recorded expired on the National Traffic Information System (NaTIS).

- The human factor contributed 82, 85% towards the fatal car accidents reported during 2009, the vehicle factor, 9, 13%, and the environmental factor contributed 8, 02%.

- During 2004, an average of 58, 1% of the weekly fatal crashes occurred on Fridays, Saturdays and Sundays, of which 23, 9% happened on Saturdays.

- An average of 25, 81% of the daily fatalities reported during 2004 were recorded during the early evening hours of 18:00 to 21:00.

- Almost 40% of the daily fatalities that were reported during 2004 were recorded for the hours of 18:00 to midnight.

- Every day an average of 36 lives are lost on the roads of South Africa; of these 15 are pedestrians related, and 3 are killed in taxi-related incidents.

- An average of 20 people is permanently disabled on SA roads every day.

- An average of 100 people is seriously injured on SA roads each day.

Sources: Interim Road Traffic and Fatal Crash Report for the Year 2006 (RTMC), Road Traffic and Fatal Crash Statistics 2003 – 2004, Road Traffic Report for the year 2009 (RTMC).

1.3   Project Aim

The primary aim of this project report is to investigate the feasibility of in-transit roadworthiness tests on vehicles using the national roads of South Africa.

The major objectives forming the basis for this report include:

- Thorough understanding of roadworthiness requirements on South African roads.

- Identification of major contributing factors to the poor roadworthiness of vehicles.

- Constructing solutions to the problem of roadworthiness in South Africa.

- Retrieving the best possible and most feasible solution to the problem of poor roadworthiness in South Africa.

1.4   Project Scope

1. The first part of the project will be an in-depth research study, which will investigate the technologies and methodologies used in various countries abroad. The study will aid in showcasing where South Africa is lacking in terms of authorization and integration of various up-to-date technologies. The study will also investigate the major contributing factors that are responsible for the poor roadworthiness of South African vehicles and roads. Identification and an understanding of the roadworthiness philosophies of vehicle users in our country will clearly provide useful insight into the possibility of low-cost solutions and technologies.

2. The next part of the project will be concerned with possible solutions to the major contributors and problems identified during the research phase, and if foreign technologies that were investigated, during the literature review, are possible solutions to these problems.

3. These solutions would have to be evaluated against a criterion of standards and legislations to uphold as feasible solutions to the problem of roadworthiness in South Africa. The feasibility study will be conducted during this phase of the project.

4. The feasibility test would identify the possible solutions to the problem statement. These solutions would be further investigated to estimate the cost, and impact of implementation of the solution, though practical implementation is not included in the scope of the project.

1.5   Deliverables of the project

Some of the deliverables to be generated by the project will include:

- A comprehensive and detailed summary of the roadworthiness requirements and legislation in South Africa.

- An understandable definition of vehicle roadworthiness in South Africa.

- Statistics on the reality of the situation on the South African roads.

- A detailed summary of international trends and technologies surrounding roadworthiness.

- A study of possible solutions to the problem of poor roadworthiness in South African terms.

- A detailed description of possible solutions.

- A detailed feasibility test conduction of the alternative solutions.

1.6   Anticipated Benefits of the project

The project will generate the following benefits to the stakeholders of the project:

- South African drivers, seeing as all road-users will be liable for un-roadworthy elements to their vehicles.

- South African public, seeing as projects like these will generate a roadworthy conscious public.

- Department of Transport, which will be able to better manage the traffic and car accidents situation in South Africa.

- International media, as to better the quality of life for all road users around the globe.

- Roadworthiness testing stations will provide better services and advice; and thus generate more income.

1.6.1 Advantages of the Project

The project will generate the following advantages:

- South African drivers will be roadworthiness conscious.

- Safer roads.

- Department of Transport will be able to manage the traffic situation on the South African roads better.

- Better quality of life for all road-users.

- Global competitiveness in the road safety techniques and technologies.

- South African drivers will be held liable for their vehicle's conditions.

1.6.2 Disadvantages of the Project

Unfortunately, the project will also be responsible for some disadvantages:

- Large initial capital investments.

- Continuous costs and maintenance.

- Large amount of personnel to be trained.

- South African public's resistance to change.

- Large learning time.

1.7 Chapter One conclusion

The main contributors to car accidents in South Africa are: driver factors, vehicle factors and environmental factors. Vehicle factors are the one element that engineers can control and design for, to ensure a better quality of life for all South African road users. Since the amount of registered vehicles on the roads increase annually with around 6%, the onus is on South African engineers to design solutions to the poor roadworthiness in South Africa that can handle this amount of change annually, while considering the South African public's resistance to change.

1.7 Document Structure

This document will follow the design process as described in by Seyyed Khandani, (Ph.D.) in *Engineering Design Process* (August 2005). Khandani described the engineering design process as follows:

The five steps followed for solving design problems are:

1. Defining the problem at hand.

2. Gather the applicable information for solving the problem.

3. Generate multiple solutions alternative to the problem.

4. Analyzing and selecting the best solution.

5. Testing and implementing the solution.

Define the problem	Gather applicable information	Generate multiple solutions	Analyze and select a solution	Test and implement the solution
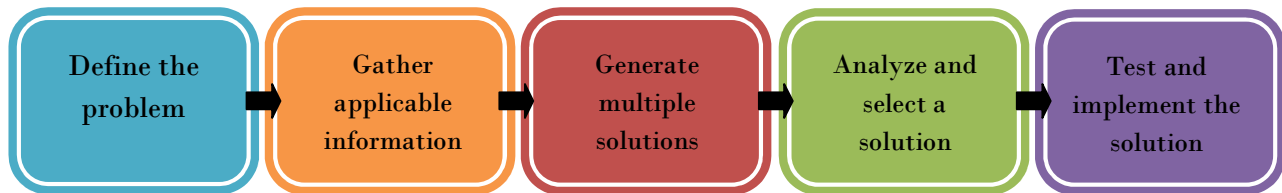
- The first part of the project would be to state the problem of poor roadworthiness in South Africa in terms of statistics and relevant information towards the fatal car accidents occurring on the South African roads.

- The second part of the project will be to try and solve the problem at hand through methodologies and techniques aboard, as well as to identify and analyze the current situation of roadworthiness testing in South Africa.

- The third part of the project will try to develop possible solutions to the problem of poor roadworthiness.

- The fourth part will analyze and conduct feasibility tests on the solutions generated in part three.

- The final part of the project will investigate the feasibility of these solutions in real-life situations and the impact of their implementation (though implementation of the solutions is not within the scope of the project).

Chapter Two

| Define the problem | → | Gather applicable information | → | Generate multiple solutions | → | Analyze and select a solution | → | Test and implement the solution |
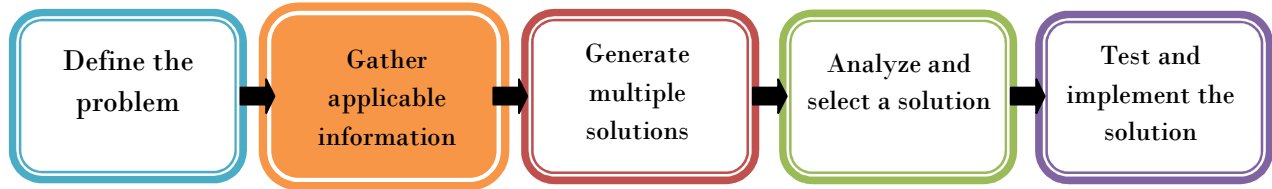
2.   Literature Review

Since 10-30% of all fatal car accidents are the result of vehicle factors like roadworthiness (Ministry of Transport: Republic of South Africa; 2001), the question exists, how are roadworthiness testing conducted in South Africa, and more importantly, how does this method measure up to the methodologies used around the globe.

2.1   Roadworthiness testing in South Africa

The general novelty of roadworthiness testing in South Africa are understood by most drivers as: one's vehicle is tested by car retailers when purchasing a new vehicle and a vehicle should undergo testing once there occurs a change of ownership of any pre-owned vehicle.

In South Africa, roadworthiness testing may only be conducted by an accredited roadworthy testing station. Stations gain their accreditation through registration and evaluation, by complying with the required level of technical competencies as described in the code of practice: SABS 0216's "Vehicle test station evaluation" (Cape Gateway 2009). The manner of evaluating and testing a vehicle should also comply to the code of practice of SABS 047's "The testing of motor vehicles for roadworthiness", as described in the NATIONAL ROAD TRAFFIC ACT, 1996 (ACT No. 93 OF 1996).

Generally a vehicle testing station tests the following entities of a vehicle:

- correct identification and documentation of the vehicle
- electrical systems installed
- fittings and equipment of the vehicle (including mirrors, safety belts etc.)
- braking system efficiency
- wheels (including tyre condition)

- suspension and under-carriage of the vehicle

- steering system

- engine

- exhaust system

- transmission- and drive instruments of the vehicle

- vehicle dimensions (Cape Gateway 2009).

Once the vehicle has been through the testing procedures the station releases a vehicle roadworthiness certificate, as proof that the vehicle passed a roadworthiness inspection and is thus in a good condition and fit to be driving on the road (Cape Gateway 2004). The certificate states the vehicle type, registration number, date of test etc. as can be seen by the example in Appendix A.

Vehicles may also be tested alongside the road once ordered by an official traffic officer. The traffic officer must be registered with the Department of Transport and have the minimum requirements of:

- an appropriate qualification (diploma)

- be a fit and proper person for the occupation

- have successfully undergone training, in relation to the laws applicable to the transportation of dangerous goods (Cape Gateway 2010).

Roadworthiness testing alongside the road must be conducted as described in the SABS 212's "The roadside roadworthiness assessment of motor vehicles" (Cape Gateway 2010).

During September 2010, the minister of transport Mr. Sibusiso Ndebele, released the commitment of South Africa's Department of Transport to the global campaign of "Make Roads Safe". This campaign was initiated in 2006 through the approval from the United Nations (UN) for the 'Decade of Action for Road Safety: 2011-2020' (Make Roads Safe 2011). South Africa showed its support of the campaign by launching the 'million-a-month' target; stating that a million vehicles, travelling on the South African roads, will be stopped and inspected, by traffic law marshals, for law compliance. Since its launching date in October 2010, the campaign has inspected around 6,5 million vehicles around the country, released 2,6 million fines and discontinued over 27 000 un-roadworthy vehicles (The Good News 2011).

Some of the roadworthiness elements that are responsible for the majority of car accidents in South Africa are: smooth and/or damaged tires (36, 30%), faulty steering

systems (25, 04%) and poor braking systems (24, 15%) (Road Traffic Management Corporation 2007).

2.2   Roadworthiness testing around the globe

2.2.1 United Kingdom

In the United Kingdom, vehicles have to undergo an annual testing procedure at their Ministry of Transport (MOT). Up to 1967, only vehicles older than 10 years were required to undergo this annual test, but currently all vehicles older than three years are obligated to undergo these tests (Wikipedia 2011).

Picture 3: The blue 'three triangles' logo display, indicates accredited MOT testing stations.

The test evaluates the vehicle's automobile safety, roadworthiness aspects and exhaust emission. All aspects inspected and tested during a MOT test are indicated by picture 4 (Directgov 2011).

Picture 4: Aspects inspected during the MOT test.

MOT tests can only be conducted by authorized examiners, who have applied to the Vehicle and Operator Services Agency (VOSA) offices and met the requirements as set out by the Department of Transport (United Kingdom). Once authorized, nominated

examiners must undergo the required general training course that interprets the processes applicable to MOT testing, and reinforces the standards as set out in the appropriate inspection manual. Nominated examiners may only test vehicles that they are qualified and received the appropriate training for. There exist two main groups of training: namely Group A and Group B which each has its own types of vehicles and procedures, thus an examiner can be qualified as either a Group A examiner, or Group B examiner or both:

- Group A - for all vehicles in class 1 and 2;
- Group B - for all vehicles in classes 3, 4, 4A, 5, 5A and 7 (Department of Transport: United Kingdom 2009).

To become a Nominated Tester (NT) one must:

- be nominated by the Authorised Examiner (AE) of a registered Vehicle Testing Station
- be at least 20 years of age;
- have a full and unrestricted UK driving licence for the vehicle class(es) that one wishes to test for.
- be a skilled mechanic that has at least four years experience repairing the vehicle types to be tested;
- have no "unspent" convictions, as defined in the Rehabilitation of Offenders Act 1974,
- be otherwise of good repute (Department of Transport: United Kingdom 2009).

In addition to the above mention requirements nominated examiners would also need to demonstrate satisfactory usage and understanding of the Vehicle Testing Station (VTS) device, which is a device used during the testing of a vehicle (Department of Transport: United Kingdom 2009).

Picture 5: VTS device.

Any authorized examiner or police officer may at any time exercise their power of issuing prohibition notices, these notices prohibits the vehicle from public road usage with either immediate effect or an effective date, the vehicle would have to pass a MOT test in order to obtain access to public roads once more (Department of Transport: United Kingdom 2009). Once tested the examiner releases a MOT certificate, stating amongst others the

make of car, date of issue, odometer reading and testing station number. The MOT certificate is valid for one year, from the date of issue, even if the vehicle is sold. Since re-testing is not a prerequisite after a car accident, the vehicle could also suffer a great deal of damage after the initial MOT test and still be valid under the MOT testing validation period (Wikipedia 2011). See Appendix B for an example of a MOT certificate.

2.2.2 Japan

Vehicle roadworthiness testing in Japan is a mandatory test that all vehicles need to undergo bi-yearly (new vehicles only after 3 years of age). The test is called the *"Shaken"* and can be done by any car shop (which will fix the car beforehand, should there be any remotely obvious problems and then test the car) or garage (which is significantly more expensive and charges for every service one receives) in Japan (Wikipedia 2011). The test is fairly simple and can be conducted by a service provider or by the vehicle owner themselves, though the latter method is more time-consuming.

The main reason for the test is to ensure that the vehicles driving on the roads of Japan are fit for the road and are not illegally modified. Should a vehicle be found unfit for road-use the Japan police will issue a red sticker containing the phrase "Illegal Vehicle" (不正改造車) on it as well as the date of issue (Wikipedia 2011).

Picture 6: Illegal vehicle sticker.

A shaken can be obtained by an appointment made at any testing station, and can cost between, ¥100,000 to ¥150 000 (about R 9 175 – R 13 763).

Generally the costs can be broken down into:

- ¥1, 400 towards payment of paperwork and processing,

- ¥25, 200 for the testing procedure,

- ¥29, 780 for 24 months validity of Shaken and

- ¥8, 090 for the "Recycling Department" including additional cost incurred depending on the vehicle and its intended use (business, personal, commercial, etc.)

Should a vehicle be in an overall good condition, the shaken should only cost about ¥60 000, which includes the testing as well as compulsory two year vehicle insurance (Wikipedia 2011).

The test inspects all aspects in- and outside of the car with the procedure as follows:

1. Exterior inspection to ensure the vehicle meets Japanese exterior regulations and ensures that vehicle does not have illegal exterior modifications added (i.e. extreme body kits).
2. A wheel alignment inspection to ensure proper alignment of wheels and turning capability.
3. A speedometer inspection to ensure the vehicle's speedometer is accurate.
4. A headlamp inspection to ensure that the vehicle's headlights are correctly positioned and aligned.
5. A brake inspection to ensure the brakes works correctly to standard.
6. An exhaust gas/muffler inspection which includes testing carbon monoxide and hydrocarbon emissions along with evaluating exhaust noise levels.
7. An under-carriage inspection which including the validation of suspension parts (Wikipedia 2011).

Many Japanese vehicle owners find ways to avoid the high costs involved with the compulsory testing of their vehicle's roadworthiness, these include cleaning the vehicle before testing to hide oil leakages, pumping their vehicle's tires to higher pressures to add to the weight of the car and using tape on the light housings to make their light alignment seem correct (Wikipedia 2011).

Of course as vehicles get older, maintenance and other related features need more attention and thus incur more costs for the owner and higher costs of re-testing for a shaken. It is for this reason that many Japanese vehicle owners decide to export their vehicles to neighboring countries, right before the expiring date of their shaken.


Picture 7: Shaken papers.

2.3   New Technologies in roadworthiness

2.3.1   Tachograph

A tachograph is a device that measures and records a vehicle's speed over a time period. The device is generally installed in heavy weight vehicle behind the speedometer to measure the vehicle's speed and determine whether the vehicle is moving or stationary. The device makes use of a stylus that plots a line on rotating paper disk, where one rotation is equal to one 24-hour period, as seen from Picture 8. As the vehicle's speed increases, the stylus engraving moves farther away from the disk centre (Wikipedia 2011).
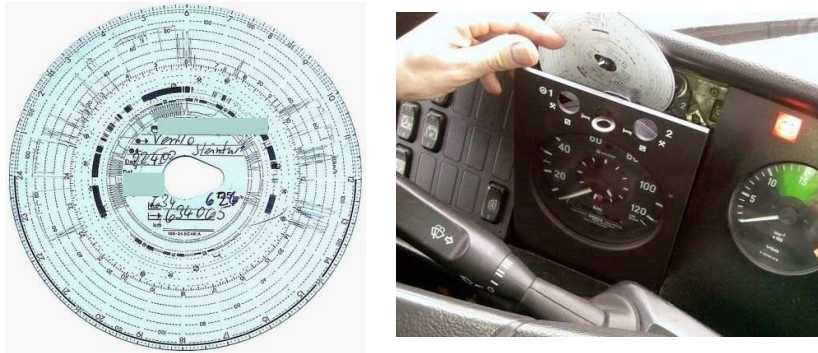
Picture 8: Example of a tachograph and installation.

During the 1990's, Germany's high court approved the usage of tachographs for the regulating of speeding on their roads. The disks are also inspected with microscopes after car accidents for investigations of the accident site (Wikipedia 2011).

Since the mechanical tachographs provides for easy tampering, the digital tachograph replaced its successor. Making use of signals, send in an encrypted manner, the digital device is must more reliable. According to the EU regulation 1360/2002, the installation of the digital tachograph is mandatory for all vehicles manufactured after 1 August 2005 (Wikipedia 2011).

2.3.2   Mobile brake testing

The testing of brakes is one of the most important inspections conducted during a roadworthiness test. The test is simple and can measure the braking system in a matter of seconds. The test is conducted at accredited roadworthiness testing stations, and at the testing station of vehicle manufacturing companies as part of their vehicle post-manufacturing evaluation. The device consists of two platforms; the vehicle is then driven

onto the platforms with one tire on each platform. The tires are the wedged between two opposing rotating rollers as seen by Picture 9 (eGov Monitor 2006).

Picture 9: Brake testing system.

The rollers are then started, turning in opposite directions, to rotate the vehicle's wheels whilst keeping the vehicle stationary. The service brakes of the vehicle are then applied, slowly and evenly until the vehicle starts to slip. This will indicate the effectiveness of the brakes and the stability that they provide to the vehicle.

Though this form of brake testing was only possible in testing stations, the new technology around braking tests is: mobility. The mobile braking testing equipment are now available and easy to operate and can be set-up at any remote site. The mobile brake testing equipment is already used by the VOSA department in the UK for roadside testing and inspection of vehicles brakes (Department of Transport: United Kingdom 2009).
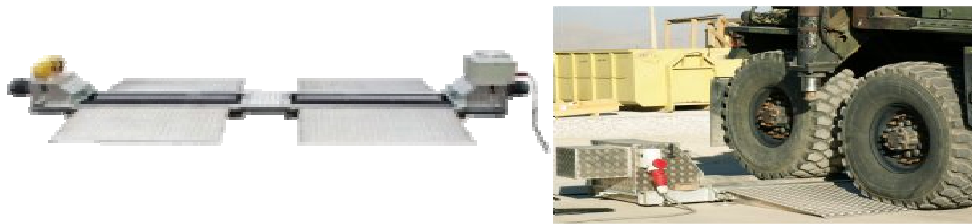
Picture 10: Mobile brake testing system.

2.3.3 Automatic number plate readers

The ability to read the number plates of vehicles with an automatic reader is a method that can read a large amount of information, interpret and store it within a small interval of time. The method makes use of optical character recognition to read the number plates of vehicles and the infra-red lighting allows for the method to be used during any time of the day (Wikipedia 2011). Currently there are two ways of capturing the data, either with the use of on-location data capturing that captures, interprets and stores the information in

real-time (of about 250 milliseconds), or with delayed data interpretation, which captures the data in real-time but transfers it to a remote computer location for delayed interpretation (Wikipedia 2011)..

The technology makes use of a series of image manipulation techniques, to take, manipulate and, thus enhance the image of the number plate. The device then transfers the image to optical character recognition for the extraction of the alpha-numerics of the license plate.

The technology has been made much more efficient and smaller, for the use of police officials in monitoring daily patrols and law enforcing (Wikipedia 2011).

Picture 11: Optical Character recognition preparation and camera.

2.4   Supplementary Methods, Tools and Techniques

2.4.1 Operations Research

The concept of operations research was developed during the course of World War II, in the United Kingdom, for the strategic and tactical problems that existed in the land and air defense operations. The concept of operations research is widely used around the world today, under a number of synonyms namely: Operational Analysis, Quantitative Management, Management Science or Decision Science, but the scientists of WW II named it Operations Research since they did research on the military operations to make it as effective and efficient as possible (Operations Research Society of South Africa 2011). Today, operations research is applied in a variety of industries and applications for the effective manner of decision making, through the use of advanced analytical methods. To achieve the best possible results and outcomes, OR professionals make use of the latest in analytical methods and techniques like simulation, optimization and probability and statistics (Operations Research: The Science of Better 2011).

The main focus of OR is the decision making process, that needs to evaluate and verify a number of decisions or solutions against a criteria of performance indicators, this process is usually done by decision-makers, engineers and analysts (Agrawal, Subramanian and Kapoo 2010). It is mostly the results and solutions generated by OR, that created the need for Industrial and System Engineers, that understand the methodologies, tools and techniques for these kind of decisions. Operations Research underwent it most rapid growth during the last 50 years, with the existence of Industrial Engineers, and established its importance in the fields of economics, mathematics, statistics, engineering and management; making it one of the most multidisciplinary fields to date (Agrawal, Subramanian and Kapoo 2010). According to Sangeeta Agrawal, KR Subramanian and S. Kapoo (2010), operations research can be broadly categorized into three main areas namely: tools, models and methodologies. Tools include: 80:20 rule, break-even analysis and ABC analysis. Models would typically include: blending models and optimized distribution systems to name a few. Whereas methodologies would include: game theory, project management systems etc.

2.4.2 Decision Matrix

One of the most effective tools to use when optimizing decision solutions is the use of a decision matrix (sometimes referred to as decision grid, opportunity analysis or solution matrix). A decision matrix is used by a team of managers, or decisions makers, where decisions are compared and measured against a list of criteria. The criteria are all assigned a relative weight and decisions are then evaluated against each other according to their weight relations. Decision matrixes are usually used in situations where: a list of options or alternatives has to be narrowed to one or when a decision must be evaluated against a list of criteria (Tague 2004).

| ❷ | ❸ | ❶ | Score* | | |
Criteria	Criteria Weight*	Hawaii	Las Vegas	Niagara Falls	Caribbean Cruise
Expense	10	3 ❹	8	9	5
Romantic Potential	10	10	3	7	9
Things To Do	6	8	6	6	10
Travel Time	4	7	3	2	4
Shopping Potential	3	3	7	5	9
Relaxation Potential	8	10	4	6	8
Weather	7	10	7	5	9
❺ **Weighted Score:**		**365**	**260**	**302**	**370** ❻

*1 = Low / 10 = High

Figure 2: Example of a decision matrix.

2.4.3 Feasibility Studies

The viability of an idea or business venture is one of the first aspects that a decision-maker has to address, all efforts and time invested in an idea will be lost if the idea does not proof to be of an advantage to a business (Hofstrand and Holz-Clause 2009). Thus, the development of feasibility studies aims to test decisions and ideas for their validation and viability. One of the primary focuses of feasibility studies is the proposition of a new business venture. Feasibility studies are conducted after a series of business ventures or scenarios have been developed (Hofstrand and Holz-Clause 2009). A feasibility study should be able to provide one with the expected benefits, weaknesses, advantages and risks of a project or venture while providing an in-depth explanation of the methods and responsibilities to be utilized. Though feasibility studies are not a necessity for all new ventures within an industry or business, it should be done under situations like: narrowing business alternatives, identifying reasons to not proceed with a project, providing quality information for decision making etc (Hofstrand and Holz-Clause 2009).

A well executed feasibility study would typically consist of:

- a historical background of the business or project at hand,
- a good description of the product or service that will be offered,
- accounting statements and cost obligations caused by the subject,
- details of the operations and management involved,
- marketing research and policies conducted,
- financial data of the subject,
- legal requirements and tax obligations to be considered (Justis and Kreigsman 1979).

Many Feasibility studies are based on the concept of TELOS project management. TELOS, an acronym for Technology and system-, Economic -, Legal -, Operational-, and Schedule feasibility, originating from the Greek word "Teleology" 'which is the study of objects with a view to their aims, goals and purpose' (Burgess 2009).

A feasibility report is the final product of a feasibility study and is an overview of the findings, reports and conclusions to the study, at this point the validation of the concept is either accepted and implemented or rejected and discarded (Hofstrand and Holz-Clause 2009).

2.4.4 Simulation modeling

Simulation modeling in its simplest form may be described as a model of a real-life or proposed system, with the main purpose of evaluating the system's behavior under a number of circumstances (Rockwell Software Inc. 2005). The simulation modeler or analyst has the ability to construct new systems without the need for real-life implementation, as well as make changes to existing systems, without the cost obligations of real-life situations. Through tools like simulation, the power is in the control of the modeler to create, plan and provide for any situation or condition that a system may encounter before the implementation starts (Rockwell Software Inc. 2005). Simulation modeling can also provide managerial positions with:

- the relationships between resources and entities,
- indicating how key performance indicators change over time,
- identify problem areas within a system, and
- improving the overall effectiveness of a system within its context (Rockwell Software Inc. 2005).

However, it should be noted that simulation has its negatives just as it has positives. Negatives of simulation include:

- all input data needs to be accurate for the model to provide accurate results,
- it cannot solve problems but only has the ability to provide information,
- only modeled characteristics of entities can be modeled, and
- cannot make complex problems simpler, by just simulating it (Rockwell Software Inc. 2005).

The simulation process can be divided into 5 main steps:

1. Define the functional specifications.
2. Formulate the simulation model.
3. Verify/validate the inputs from all contributors.
4. Analyze through statistical evaluation.
5. Recommend alternatives to decision maker(s) (Rockwell Software Inc. 2005).

In any model there are entities that are simulated, these are the items that are being produced, served or acted on during any process (Rockwell Software Inc. 2005). Entities seize resources during process; these resources are an indication of constraints that are placed on entities in a model. When the situation occurs that an entity is waiting for a resource to become available that entity indicates the start of a queue (Rockwell Software Inc. 2005).

In Arena® problems are simulated using process modules, which depict the type of process as it is happening at a specific time-interval, the resource that the process is seizing (if any), as well as the time that the process is utilizing to complete that process. The basic process modules are: seize, delay and release, all which can be modeled in different times and orientation (Rockwell Software Inc. 2005).
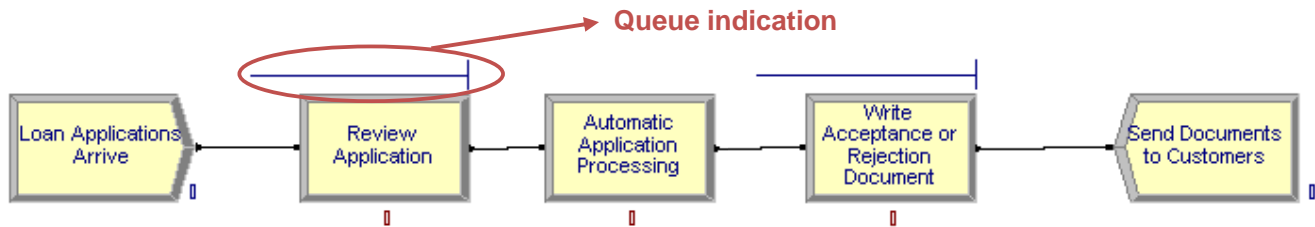

Figure 3: Example of a simulation model.

2.4.5 Queuing Theory

Queuing goes as far back as the history allows Edward Hick painted what some consider one of the earliest and long queues in his interpretation of "Noah's Ark".

Picture 12: "Noah's Ark" by Edward Hick.

The Danish engineer, A.K. Erlang published his first paper on the theory of queuing during 1909, while it is reported that a researcher named: Tore Olaus Engset's early work pre-dates those of Erlang (Hlynka 2011).

The queuing theory makes use of mathematical modeling to estimate if resources are available and adequate to meeting the demand of the system over an interval of time (Business Dictionary 2011).

According to Robert B. Cooper (2000): "Typically, a queuing model represents: (1) the system's physical configuration, by specifying the number and arrangement of the servers, which provide service to the customers, and (2) the stochastic (that is, probabilistic or statistical) nature of the demands, by specifying the variability in the arrival process and in

the service process." The arrival process of entities are denoted by the Greek small letter Lamda (λ), while the service process of the servers are denoted with the Greek small letter Mu (μ) (Winston 2004).

There are a number of queuing models that exist, all designed for different circumstances and reasons. Some of the basic models include:

- **M/M/1/∞/FIFO model:**
  This model is used in events where the arrival and service rates following a Markov chain (stochastic process of exponential distribution), where there is only one available server to utilize, where the capacity of the system is infinitely large and the queue follows a First come, First serve discipline.

- **M/M/s/∞/FIFO model:**
  This model is used where the optimized amount of servers wants to be determined for a specific demand or limitation. The arrival and service rates also follow a Markov chain, the number of available servers is to be determined and the queue follows a First come, First serve discipline.

Refer to Appendix C, for a list of formulas of both of these models.

Finally, "Communicating the Bible in the Context of Religious Pluralism in Indonesia" by E. G. Singgih (Hlynka 2011) described queues as follows:

"When people see arrows, they think of "queuing", and in turn, queuing means "scarcity". In other countries such as Singapore and Malays, queuing means that you are sure to get what you want, even if you have to wait for some time. In Indonesia, queuing means "quick, for there will be nothing left soon". And so you will witness that kind of queuing where people are pressed hard against one another, and where no kind word is heard, and where people sometimes get into blows with one another. Even if they do not relate queuing with scarcity, for many queuing is not a normal way of doing things. They will queue only at the last moment, and feel that this is a regulation which is forced upon them by those who are in power. Arrows that direct people to stand in line, are representatives of the powers that be. But surely arrows are there to help you? And what is queuing except a cultured way of life? Yes, for some, but not for all."

2.5   Chapter Two conclusion

The are many methods and techniques that are used globally to evaluate roadworthiness of vehicles, and South Africa can make use of many of them to increase their roadworthiness and car accident rates. As was seen, both in the UK and Japan roadworthiness testing is a regular testing requirement; where vehicles are tested either annually or bi-yearly and thus ensuring a constant but safer testing environment. Whereas in South Africa a single vehicle can travel on the roads of South Africa for around 40 years with only one valid roadworthiness test conducted.

To evaluate possible solutions to the poor roadworthiness problem there exists many tools and techniques, all which mentioned in the document will used in the final generation and evaluation of final solutions, though industry application of these will not be relevant in certain circumstances within this project.

Chapter Three

Define the problem	→	Gather applicable information	→	Generate multiple solutions	→	Analyze and select a solution	→	Test and implement the solution
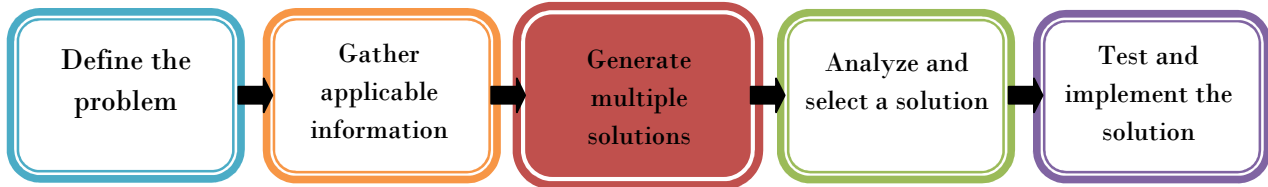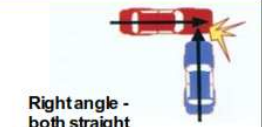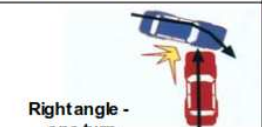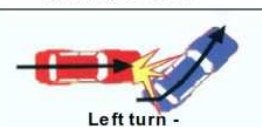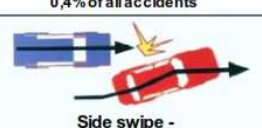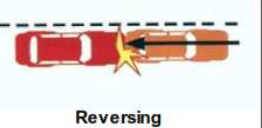
3.   Data Analysis

3.1   The main contributing factors of fatal car accidents

During June of 2004, the Road Traffic Management Corporation (RTMC) released their annual 'Road Traffic and Fatal Crash Statistics'. This document addressed the statistics of fatal car accidents, their causes and an overview of the car accidents over the period of 1999 to 2004. The document included the following sketches to indicate the main types of car accidents as well as their corresponding contributing factors.
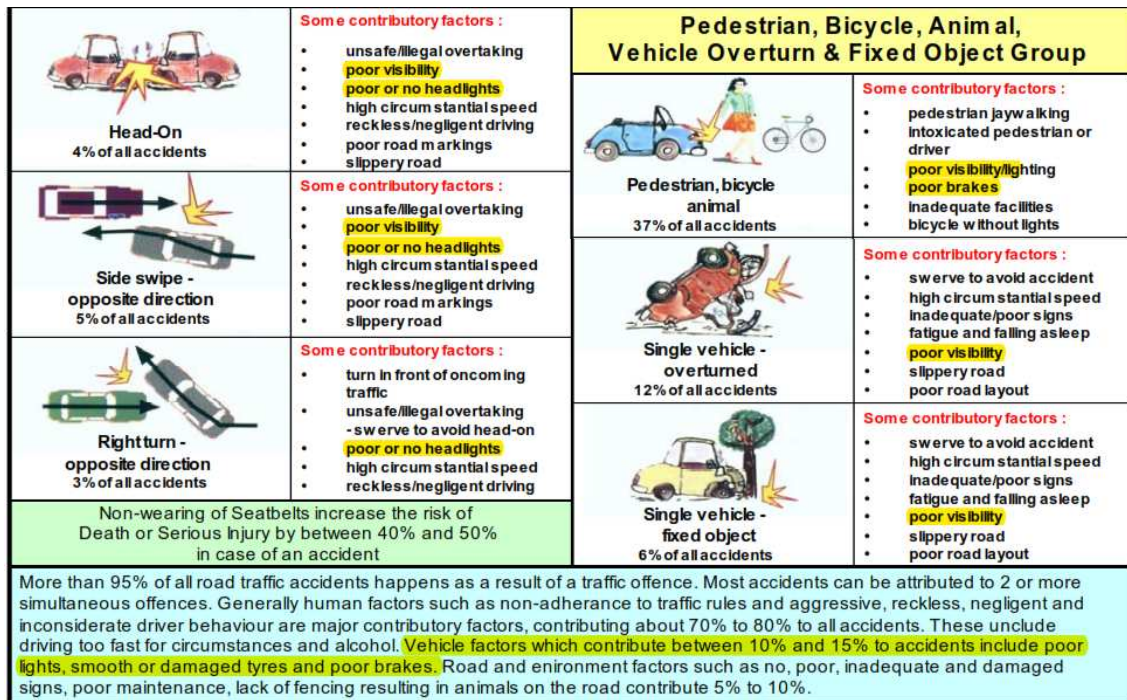
Figure 4: Types and main contributors to car accidents 2004.

The sketches indicate the types and main contributors towards the different types of accidents. The contributing factors that are the results of poor roadworthiness of vehicles are highlighted.

As can be seen by the sketches above, the main contributors to poor roadworthiness are: poor brakes, smooth tires, no or poor brake lights and the visibility of vehicles. The main objective of the project will thus be to understand each of these contributors in the sense of legal requirements, their role in the roadworthiness of a vehicles and how these contributing factors can be addressed to make the vehicles and road safer for all road-users.

3.1.1 Poor visibility

The annual 'Road Traffic and Fatal Crash Statistics' report for 2004 found that 58, 1% of the weekly reported fatal car accidents in South Africa happened during Fridays, Saturdays and Sundays, of these reported accidents 23, 9% happened on Saturdays. The time of accidents were reported to be: 25, 81% of the daily fatal accidents happened between 18:00 and 21:00 in the evening and 40% of all fatal accidents were reported between 18:00 and midnight. This is a clear indication of the severe consequences that poor visibility of vehicles has on the lives of road-users driving in the evenings. Poor visibility can be described as the degree of visibility of a vehicle from an outsider's view whilst driving on the road; this may include headlights, backlights, and brake lights as well

as fog lights. According to the NATIONAL ROAD TRAFFIC ACT, 1996 (ACT No. 93 OF 1996) (see Appendix D for full version):

"No person shall operate on a public road a motor vehicle unless--

a. all lamps fitted to a motor vehicle are undamaged, properly secured, and capable of being lighted at all times; and

b. the head lamps, rear lamps and number plate lamps are kept lighted during the period between sunset and sunrise and at any other time when, due to insufficient light or unfavourable weather conditions, persons and vehicles upon the public road are not clearly discernible at a distance of 150 metres: Provided that the provisions of this paragraph shall not apply to a motor vehicle parked off the roadway of a public road or in a parking place demarcated by appropriate road traffic signs or within a distance of 12 metres from a lighted street lamp illuminating the public road on which such vehicle is parked.

Every lamp required to be fitted or to be used in terms of any of these regulations shall emit a light of sufficient brilliance to be visible from a distance of at least 150 meters to a person of normal eyesight."

In terms of headlights:

"No person shall operate on a public road--

a. motor vehicle, other than a motorcycle, a motor tricycle with one wheel in front or trailer, unless it is equipped in front on each side of its longitudinal centre-line with--

i. one head lamp capable of emitting a main-beam and a dipped-beam;

ii. one head lamp capable of emitting a main-beam and one head lamp capable of emitting a dipped-beam; or

iii. one head lamp contemplated in subparagraph (i) or head lamps contemplated in subparagraph (ii) and an additional head lamp capable of emitting a main-beam;"

The headlights of motorcycles, motor tricycles etc. should be lighted at all times.

"Every head lamp emitting a main-beam of light shall be so adjusted and maintained that--

a. it shall be capable of adequately illuminating an area ahead of the motor vehicle concerned enabling the driver to see any person, vehicle or substantial object at a distance of at least 100 metres ahead; and

b. it can be extinguished by the use of a device which simultaneously shall cause or allow the dipped-beam of light to be emitted or continue to be emitted from a head lamp."

"No person shall operate on a public road, a motor vehicle while any fog lamp fitted to such vehicle is lit, except in conditions of poor visibility caused by snow, fog, mist, dust or smoke."

"No person shall operate a motor vehicle on a public road, excluding a motor vehicle which was first registered before 1 January 1981, a motor cycle or a motor tricycle, unless such motor vehicle is fitted with at least one lamp on each side at the rear--

a. emitting a red light to the rear with a minimum intensity of two candelas;
b. positioned not further than 400 millimetres from the outer edges of the widest part of such motor vehicle; and
c. positioned not lower than 350 millimetres or higher than one and a half metres above ground level, but if it is not practical or impossible due to the structure of the vehicle to position such lamps within one and a half metres above ground level, not higher than two comma one metres above ground level."

3.1.2 Smooth and/or damaged tires

The tires on a vehicle are one of the most important elements within every roadworthiness test. They indirectly affect a vehicle's steering system, vehicle road handling and fuel economy and thus personal finances. Arrive Alive: South Africa states that drivers should regularly inspect their vehicle's tires for slashes and cuts to dismiss the possibilities of tire bursts and failures.

Picture 13: Some tire failure examples.

Arrive Alive released the following sketches and information regarding tires and requirements. The institution states that the most important aspects of vehicle tires are: temperature resistance, traction, tread wear, maximum load capacity per tyre, speed symbol, and manufacturing date. These entities are all readable from the tyre itself as seen by the Figure 5 and explained in Table 1:
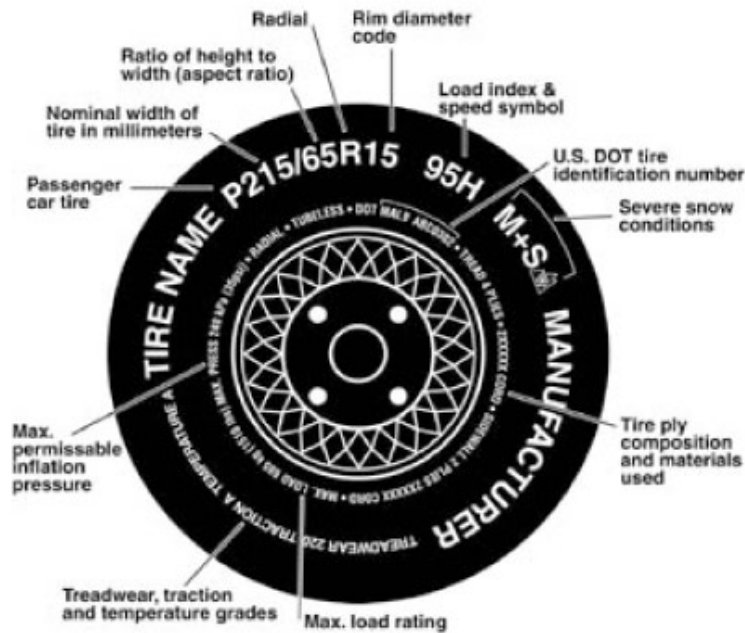

Figure 5: Tire Information.

Tyre Entity:	Information:	Picture:
Temperature Resistance	Indicates the tyre's ability to resist high temperatures. Graded: "A" for hot areas, "B" for normal weather and "C" for cold areas.	
Tread wear Number	Indicating the tyre's wear rate, the higher the number shown on the tyre the longer wear down time.	

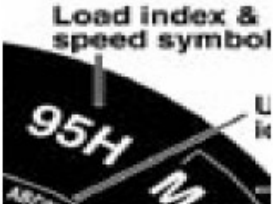|		
Traction	The ability of a tyre to stop on wet pavement. The higher the grade the shorter the distance of stopping. Graded: "AA", "A", "B" or "C".	
Max. Load capacity and tyre speed symbol	Indicating the maximum load that can be carried by the tyre, as well as the designated speed that tyre is to be driven for extended periods of time.	

Table 1: Most important tire information.

According to the NATIONAL ROAD TRAFFIC ACT, 1996 (ACT No. 93 OF 1996):

"No person shall operate on a public road--

a. *a motor vehicle, other than a tractor or trailer, which is equipped with a metal tyre;*

b. *a vehicle which is equipped with a metal tyre unless the whole width of the tread of the tyre is at all times in direct contact with the surface of the road;*

c. *a vehicle which is equipped with a tyre which is in such a state of disrepair or in such a condition that it may cause or is likely to cause damage to the road surface or may be or is likely to be a danger;*

d. *a motor vehicle which is equipped with a pneumatic tyre of which the rubber covering is so worn or damaged that the fabric or cord used in the construction of such tyre is exposed;*

e. *a motor vehicle of which a tyre is so constructed and fitted that the metal part of the wheel to which such tyre is fitted may come into contact with the road surface;*

f. *a motor vehicle which is equipped with a re-grooved tyre having a bead diameter of 430 millimetres or less;*

g. *a motor vehicle--*

  i. *which is fitted with a pneumatic tyre unless such tyre displays throughout, across its breadth and around its entire circumference, a pattern which is clearly visible, and has a tread of at least one millimetre in depth; or*

  ii. *which is fitted with a pneumatic tyre which contains a tyre tread depth indicator, if the tread is level with the tyre tread depth indicator:*

k. a motor vehicle which is equipped with a pneumatic tyre which has a break in its fabric or which has a cut, measured in any direction on the outside of the tyre and of such depth that it reaches the cords used in the construction of such tyre, in excess of 25 millimetres or 10 per cent of the maximum width of the tyre, whichever is the greater; or

l. a motor vehicle which is equipped with a pneumatic tyre which has a lump or bulge caused by the separation of or a partial break in its structure."

3.1.3 Faulty Braking systems

Faulty, or lack of, braking systems in vehicles are one of the major contributing factors to fatal car accidents, and one other factor that walks hand-in-hand to this is speeding. The 2004 annual car accidents report indicated that the average speed of vehicles increased with 9%. Further it was found that over weekends around 9% of vehicles are exceeding the speed limit of 120 km/h, around 14, 1% exceed 130 km/h and around 5,9% are driving faster than 140km/h. The report also indicated the existing conflict within the speed of South African vehicles, where around 5, 9% drive excessively fast, while 15% are driving unreasonably slow, thus resulting in an ugly collision situation.

Making use of the motion equations it can be showed, that for an excessively fast vehicle travelling at 145 km/h (40, 27 m/s) to suddenly brake (decelerate at -10 m/s) to a unreasonably slow speed of 45 km/h (12,5 m/s):

$v = end\ speed$

$u = beginning\ speed$

$a = accelleration$

$s = distance\ travelled$

$$v^2 = u^2 + 2\,a\,s$$

$$12{,}5^2 = 40{,}27^2 + 2(-10)s$$

$$s = 73{,}27\ m$$

Equation 1: Response time and distance.

would require the vehicle to have at least 73, 27 meters road space and about 3 seconds (not including response time). Thus, with an average of around three seconds response time and three seconds braking time, the possibility of a collision is great even if the vehicles are equipped with the best quality braking systems.

But unfortunately a majority of the vehicles on the roads of South Africa are not equipped with the necessary braking system requirements. According to the NATIONAL ROAD TRAFFIC ACT, 1996 (ACT No. 93 OF 1996):

* *all vehicles using a public road of South Africa should be equipped with: service brake (pedal brake), a parking brake (hand brake), and emergency brake, of which the emergency- and parking brake may be one and the same.*

* *No vehicles may operate on the public roads if there is an anti-theft device that is connected (in any way) to the braking system.*

* *All vehicle's braking systems should comply to the provisions of the SABS 1207 "Motor Vehicle Safety Standard Specification for Braking" or the standard specification SABS 1051 "Motor Vehicle Safety Specification for Braking" standard.*

* *The parking brake of a vehicle should be able to keep a vehicles stationary for an indefinite period with the engine disengaged on a gradient of not more than one in 8,33.*

* *The service braking specifications for vehicles which are capable of exceeding a speed of 35 km/h are seen in Table 2:*

	Initial speed in km/h	Maximum stopping distance in m	Minimum deceleration in m/s²	Minimum equivalent braking force in N/kg
Light motor vehicle	35	14	4,4	4,4
Heavy motor vehicle	35	16	4,4	4,4

Table 2: Braking system specifications for >35 km/h.

- *The emergency braking specifications for vehicles which are capable of exceeding a speed of 35 km/h are seen in Table 3:*

	Initial speed in km/h	Maximum stopping distance in m	Minimum deceleration in m/s²	Minimum equivalent braking force in N/kg
Light or heavy motor vehicle	35	30	1,9	1,9

Table 3: Emergency brake system specification >35 km/h.

Source:

DEPARTMENT OF TRANSPORT

NATIONAL ROAD TRAFFIC ACT, 1996 (ACT No. 93 OF 1996)

NATIONAL ROAD TRAFFIC REGULATIONS, 1999.

See Appendix D for a full version of the Act.

3.2   Development of alternative solutions

The development of alternatives to address the problem of poor roadworthiness of vehicles in South Africa is one that requires innovative thinking and analysis. The solutions generated are not the only possible solutions to the problem, but mere options to solutions. The solutions ultimately try to address the four major contributing factors of poor roadworthiness in South Africa, as described in the previous text. The following options are purely for the understanding of the problem and will not include the final implementation phase of the options.

3.2.1 Option 1: Tollgate initiative

There are around 55 tollgates on the national roads of South Africa which can be classified, by means of their toll collection method, in either one of three groups: the traditional toll collection, electronic toll collection or open road tolling.

Most of tollgates in South Africa still make use of the traditional manner of collecting fees through the use of tollgate operators that control the finance collection and opening of boom operation (SANRAL 2011).

Picture 14: Tollgate in South Africa.

a.   Description

Option 1, makes use of this phenomenon within the South African transport system. With a few alterations to the exterior and functioning of traditional tollgate operations, a general tollgate can be transformed into an in-transit roadworthiness testing station.

The main idea behind option 1 is to make use of infrastructure already available, whilst benefiting from a concept that most South African drivers know by heart. Option 1 addresses the four major contributors to poor roadworthiness in South Africa namely: poor visibility, faulty braking systems, overweight vehicles and poor tire quality.

Poor visibility:

The option 1 tollgate will be enhanced with sliding doors instead of the usual boom right of way. Within the sliding doors there will be installed a light intensity system which will measure the headlight intensity and height. The sliding doors thus add to the darkness and effectiveness of the lights. At the same time that the doors close, a boom will be lowered from behind, with the same device as in the sliding doors to check the rear lights.

Faulty braking systems:

The vehicle will be directed to stop with its front and rear wheels on roller brake testing systems. Once the operator gives the instruction, the braking system of the vehicle will be tested against specifications, with the vehicle operator applying the service brakes gradually.

Overweight vehicles:

The tollgate will also be equipped with a weight scale. This will weigh the vehicle as well as measure its weight distribution.

Poor tire quality:

The tires will also be under inspection, from types, to pressures, to tire diameter. This can be conducted by machine operated equipment, but manual operators will be a cheaper option.

Once all elements are tested, all the results will be displayed on a dashboard for the vehicle driver, who will also receive a print-out of the results. Elements that were outside of the requirements or specification (by law) for roadworthiness of vehicles will be penalized by adding to the general tollgate fees. The driver will then pay the general tollgate fee and penalties (if any) and be able to continue its journey. But if a vehicle is found to be unfit to continue its journey it will be directed to a parking bay, for collection and re-pair.

All vehicles will be required to undergo at least one of these testing operations within its journey. Once it underwent and passed one test, it will be able to continue through the rest of the tollgates on its journey, without testing, by payment of the general tollgate fees for those tollgates and by show of its testing print-out as received at their test.

b.   Features

- Ability to test vehicle visibility through a head- and rear light inspection and testing facility.

- Brake testing done on location.

- Inspection of tire safety.

- Weight distribution and safety inspection facility.

- Dashboard and print out of results service.

c.   Illustration
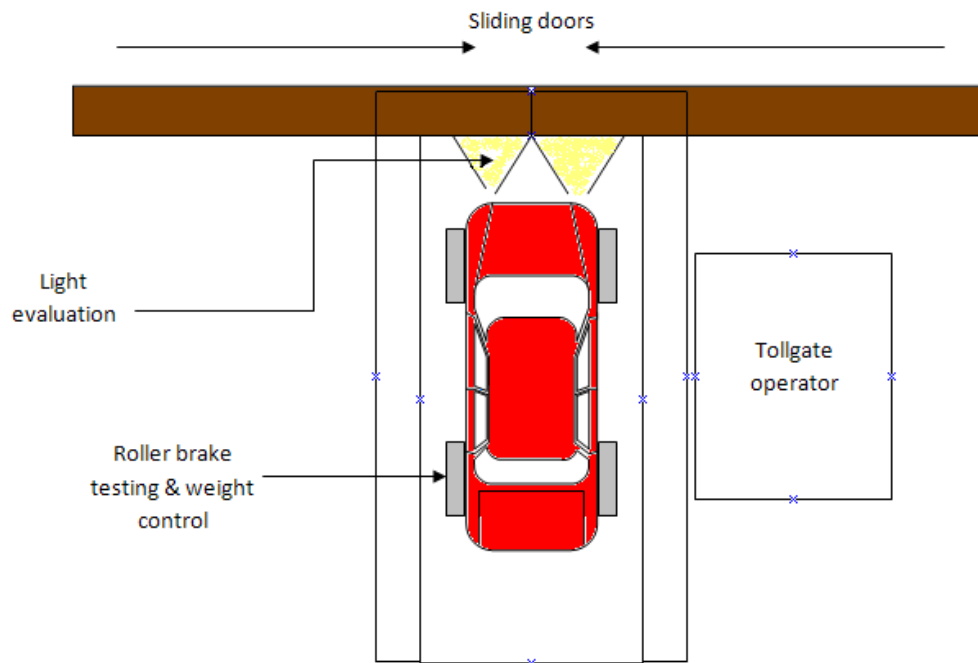
Figure 6: Option 1, overall layout.

d.   General operations and flow

- Vehicle approaches the tollgate.

- Vehicle enters the first available parking bay, while the tollgate operator closes the sliding doors.

- Operator gives first instruction of: switching on head- and rear lights to normal brightness.

- Operator violates light's reflection from the device.

- Operator gives second instruction of: owner to switch off vehicle's engine.

- Operator weights car, and checks for violations.

- Operator gives third instruction of: owner switching vehicle's engine on again and applying service brake pedal.

- Operator violates whether vehicle sways of track, and measures brake-efficiency.

- Operator displays results to vehicle driver on dashboard, and gives print-out to driver.

- Operator collects tollgate fee and penalty fee (if any) from vehicle driver.

- Sliding doors open and vehicle can continue with its journey.

See Appendix E for the flow diagram of option 1 operation.

e.   **Advantages**

➢   Job creation.

➢   Well-trained operators.

➢   Roadworthiness conscious road users.

➢   Testing of most important aspects.

➢   Quick and efficient.

➢   Reliable.

➢   Known concept and environment for drivers.

➢   Cost efficient.

➢   Direct law enforcement.

f.   **Disadvantages**

➢   Can be time-consuming.

➢   Maintenance of equipment and facilities necessity.

➢   Operator reliability and loyalty.

➢   Attitude adjustments.

➢   Large initial capital investment.

➢   Training programs for operators.

3.2.2 Option 2: Roadworthy tunnel

A tunnel can be described as a road that is build through a mountain or hill rather than around or over it; it is thus a way of shortening a road for convenience and travel time. One of the biggest road tunnels in South Africa is the Huguenot tunnel, that extents the N1 toll road between Paarl and Worchester. The tunnel is both shorter and safer than the alternative of the Du Toitskloofs pass that stretches over the mountain.

Picture 15: Huguenot tunnel.

a.   Description

Option 2, requires the building or utilization of tunnels. The main idea behind option 2 is to perform in-transit observations and evaluations as vehicles are driving through the tunnel. Option 2, will validate two elements of the major contributors to car accidents namely: poor visibility and speed as well as weight issues through vehicle dimensions.

Poor visibility:

As with all tunnels, vehicles are required to switch on headlights. Through the use of special devices and equipment, light intensity, height and effectiveness of vehicle lights can be tested as vehicles pass through the tunnel.

Speed:

Generally the speed restrictions remain the same within a tunnel, so speeding above the restricted speed can easily be measured, since speed is be measured between two stationary points – any two points within the tunnel.

Weight issues and dimensions:

A vehicle dimensions controlling element can easily be added to any tunnel. Since all vehicles enter and exits a tunnel through the same size gate, controlling the dimensions of vehicles can be monitored as a vehicle passes through the tunnel.

As with the Huguenot tunnel, most tunnels operate through the use of tollgates. Utilizing the tunnel's tollgate (placed at the end of the tunnel), un-roadworthy elements and other fines can be penalized directly. But otherwise, penalties would have to be reported and directed towards the driver in writing.

b.   Features

- Light intensity measuring devices.

- Speeding cameras and regulating.

- Tollgate operations (if any).

- Weight measures.

- Vehicle dimensions controlling.

c.   Illustration
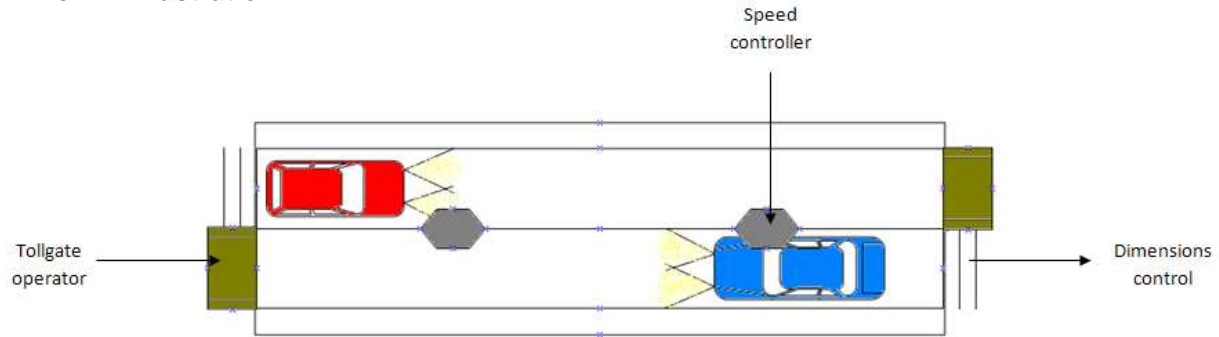
Figure 7: Option 2, illustration.

d.   General operations and flow

- Vehicle approaches tunnel and enters.

- Dimensions control system violates the dimensions of vehicle.

- Vehicle continues through tunnel.

- Speeding control regulates vehicles speed.

- Vehicle approaches end of tunnel (and tollgate if applicable).

- Vehicle pays tollgate fees and penalties for any offences (if applicable).

- Vehicle exits tunnel.

- Driver receives notice of penalties (if no tollgate).

See Appendix F for a flowchart of option 2.

e.   Advantages

- ➢ Makes use of existing infrastructure.

- ➢ Direct penalties for un-roadworthy elements (tollgate).

- ➢ Known operations and activities.

- ➢ No additional training required.

- ➢ Long term investments.

f.   Disadvantages

  ➢ Minimum tunnel infrastructure in provinces where it is needed most.

  ➢ Traffic flow of offenders.

  ➢ Minimum space for outsourcing of technology.

  ➢ Large capital investments.

3.2.3 Option 3: Build-in initiative

Like most things in life, prevention is better than cure; thus, if the problem of poor roadworthiness of vehicles can be solved with gentle and easy solutions, the roads can be much safer in highways and urban roads. International Road Dynamics Ltd (IRD) has brought to the market, a wide range of new technologies and developments that specializes in the road safety market of vehicles. Currently, one of their best selling products is the Weigh-in-motion technologies, which weights vehicles traveling at low speeds. But the even better technologies would be those that can alert the driver that his vehicle is in a state of poor roadworthiness and thus make the correction of these elements the responsibility of the driver.

a.   Description

The idea behind the new technologies of Option 3 requires an intimate relationship with roadworthiness authorities and car manufacturers. The technologies would be developed to specifications of vehicle types and sizes, and then fitted to vehicles at manufacturing phase. These technologies will then be altered to the roadworthiness requirements of the country that the vehicle will be registered and operated in. Once a vehicle is started, the display panel on the speedometer will indicate the state of roadworthiness of the vehicle before the vehicle will be able to continue on its journey. Many technologies are already developed and integrated for certain aspects of roadworthiness, but the ultimate goal of these will be if it could prevent the vehicle from further operation on the road unless these entities are fixed.

b.   Features

  • Up-to-date technologies.

  • Effective utilization and readings.

  • Easy to understand and interpret.

c.   Illustration
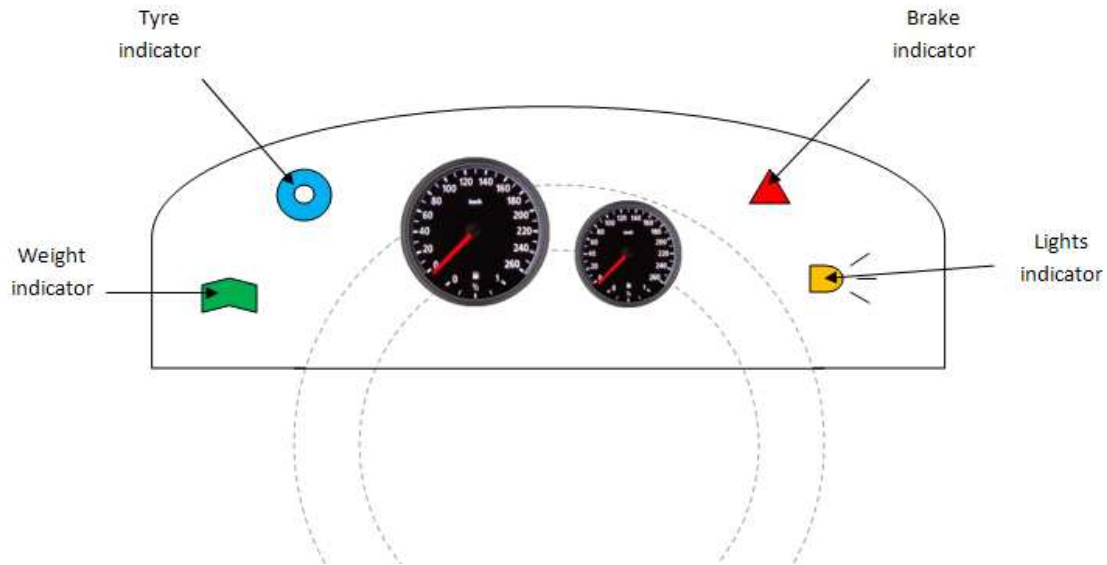
<p align="center">Figure 8: Option 3 illustration dashboard.</p>

d.   Advantages

➢ Roadworthiness consciousness and liability.

➢ Reliable systems.

➢ Directly automated to vehicles types and sizes.

e.   Disadvantages

➢ Higher vehicle prizes.

➢ Higher cost technologies.

3.3   Chapter Three conclusion

Some of the alternative solutions to the problem of poor roadworthiness in South Africa include: Tollgate utilization, Tunnel utilization and build-in technology. Though there are numerous amounts of technologies and tools developed each day, these make use of infrastructure already available, resulting in cost effective plans and savings. The alternatives will be evaluated against the benefits they promise but also against the disadvantages that goes hand-in-hand with each. A feasibility study will be designed in the next section to measure these solutions against one another for the ultimate solution to the problem of poor roadworthiness in South Africa.

Chapter Four

Define the problem	→	Gather applicable information	→	Generate multiple solutions	→	Analyze and select a solution	→	Test and implement the solution
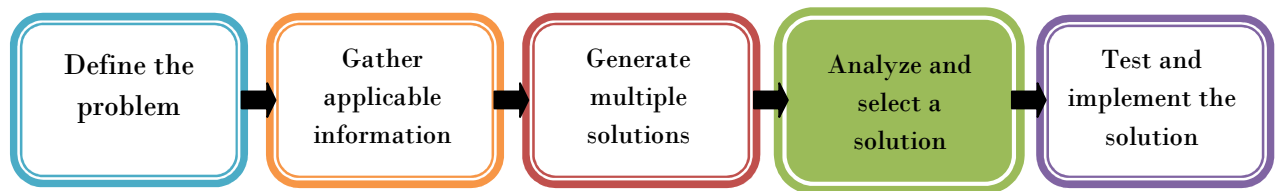
4.   Alternative solutions evaluation

The perfect solution to the problem of poor roadworthiness would have to be measured against criteria of expectations and standards. There exists no room for errors, seeing as the South African public does not favor unresponsive or faulty systems, and thus would eliminate or withstand the system as a whole.

To measure the solutions against the expected standards and cost associated with each, all solutions will be compared to each other by using a decision matrix. Each of the criteria would carry a weight in terms of how best they solve the problem at hand and then the alternative with the highest score in the matrix will thus be the most feasible solution.

The alternatives will be measured against the following criteria:

1. To what degree does it solve the problem of poor roadworthiness?
2. Initial capital investment required.
3. Uniform continuous costs required.
4. Driver satisfaction.
5. Journey time disruption.
6. Maintenance and support required.
7. Safety of vehicles.
8. International competitiveness.
9. Feasibility of alternative.
10. Degree of change from current roadworthiness environment.

Criteria weight distribution will be developed as follows:

5	Excellent (highest quality)
4	Above average
3	Average
2	Below average
1	Poor
0	Not applicable.

Table 4: Weight distributions.

4.1 Decision matrix

The following decision matrix was constructed:

	Option 1 : Tollgate initiative	Option 2: Roadworthy Tunnel	Option 3: Build-in initiative
To what degree does it solve the problem of poor roadworthiness?	5	3	4
Initial capital investment required.	2	1	3
Uniform costs required.	3	3	4
Driver satisfaction.	3	3	4
Journey time disruption.	3	4	5
Maintenance and support required.	2	2	2

Safety of vehicles.	**5**	**3**	**4**
International competitiveness.	**4**	**3**	**5**
Feasibility of alternative.	**4**	**5**	**2**
Degree of change from current roadworthiness environment.	**4**	**5**	**1**
Total:	**35**	**32**	**34**

Table 5: Decision Matrix.

As seen from the matrix, option 1 is the best alternative solution to the problem of poor roadworthiness in South Africa.

Though option 1, is ranked as the number one solution to the problem of poor roadworthiness in South Africa, the winning rank was not as convincing as one would need for the high investment obligation that option 1 requires. Thus, the correct course of action would consider option 1 under a number of tests, evaluations and phases before further development or implementation of not only option 1, but any of the alternative solutions generated.

4.2   Chapter Four conclusion

To correctly estimate the feasibility of a decision, all options would have to be compared in a decision matrix; as was done in chapter four. The matrix elements were first developed before the final comparisons can be done, seeing as all options would have to be compared, against each other, under the same criteria. The comparisons were than conducted against a weight-system. From the matrix it can be concluded that option 1 was ranked as the most feasible, with option 3 and 2 not ranked much lower. Thus, with the results from the matrix not over convincing, careful consideration would have to be taken to ensure that option 1 does indeed rank the highest even when considering the high investment requirements for the solution.

By simulating option 1 in an Arena® model, better insight would be provided about the queues that option 1 would generate thus adding to the journey disruption time of travelers, the model would also indicate where option 1 lacks in terms of execution and required resources. This model would be constructed and interpreted in the following chapter of this document.

Chapter Four

Define the problem		Gather applicable information		Generate multiple solutions		Analyze and select a solution		Test and implement the solution
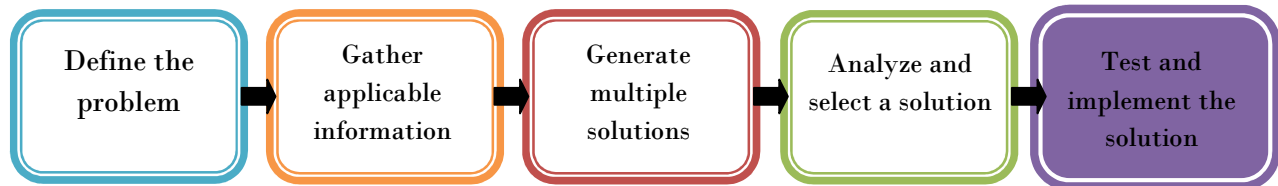
5. Testing and evaluating the best solution

In order for the feasibility study to be properly executed, the solution that ranked the best would have to be considered under a number of events and situations. As was seen in the decision matrix, the best solution would have to be competitive in all of the mentioned criteria listed in Chapter 4.

To properly investigate the criteria of elements like: driver satisfaction, journey time disruption and the feasibility of the alternative, the modeling of the real-life situation is a handful tool in determining the proper effects of these criteria as well as give insight to obstacles and risks that may accompany option 1.

5.1 Arena® simulation

An Arena® simulation model was constructed for the events and processes of option 1. As was described in section 3.2.1.d of this document, option 1 utilizes a number of resources, requires a number of processes and ultimately generates a number of outputs. Thus, the Arena® model would have to be constructed in such a manner as to get as close as possible to a real-life representation of option 1 as possible.

But simulating real-life situations in Arena® of new, non-existing initiatives would bring its own challenges like:

- Simulating models not capable of simulating every possible situation that can occur in real-life.

- Limitations of software and technologies.

- Every modeler would model the venture differently.

- Time-allocations for the processes may differ substantially from real-life situations.

All of these challenges would have to be kept inconsideration to fully and successfully interpret the simulation results. All of these challenges were considered in the development of the Arena® model of this project.

5.2 Arena® model of option 1

The Arena® model for option 1 were interpreted as being under the influence of both a high level model, as well as a lower level sub-model.

The high level model, involves the processes that occur between the vehicle (being tested in the testing station at the tollgate) and the tollgate station itself. It includes no testing procedure processes, thus only utilizing the tollgate resource. The top-level model can be seen in Figure 9.
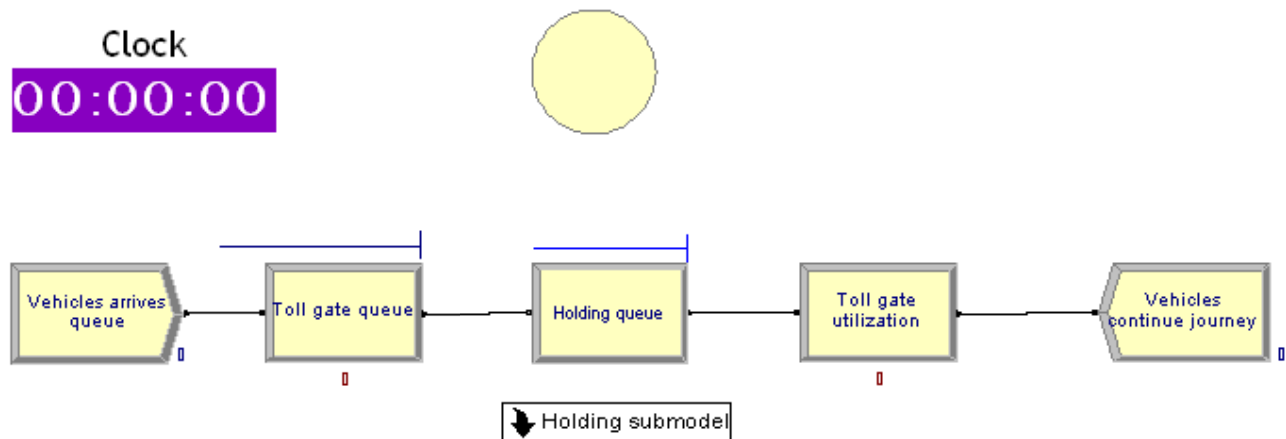
Figure 9: Top-level Arena® model.

The model was initially constructed with the assumption that there is only one tollgate operator available to conduct the roadworthiness testing as was described in section 3.2.1.d, and that the testing can be conducted 24 hours of a day.

The top-level model simulates the following action and processes:

Vehicles approach the tollgate testing bay, in a scheduled manner (assumption), see Appendix G.

Vehicles (other than first arrival) will form a queue at the tollgate resource, waiting for entry into the testing bay.
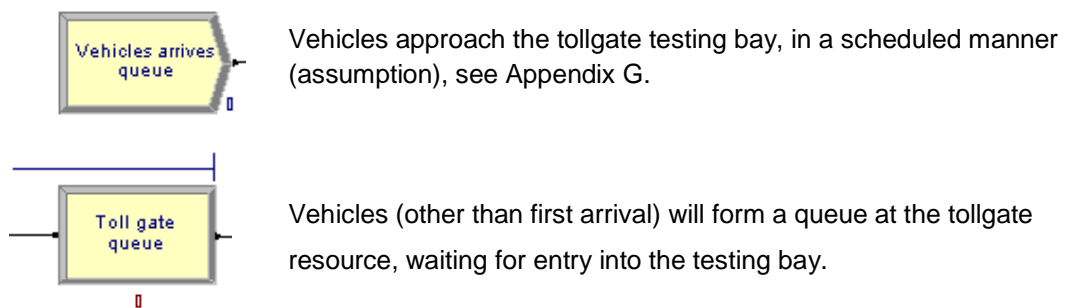
All vehicles (other than first arrival) will be held in queue until the tollgate operator resource gives the signal that it is idling. The hold on the queue will than release one vehicle from the queue.
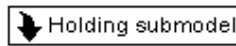
The 'Holding sub-model' includes all the processes that are performed during testing of vehicle's roadworthiness, this process will be discussed in the next section.

Once a vehicle enters the sub-model process, it will thus, utilize the tollgate resource.
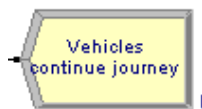
All vehicles that underwent testing will then leave the system, releasing the tollgate resource for next vehicle to utilize.

The top-level model thus, simulated the processes that utilize the tollgate bay itself and not the tollgate operator and its testing procedures. Once the tollgate operator is idle, it will give signal to the 'Holding queue' process to release one vehicle from the queue. This vehicle will then enter the sub-model seen in Figure 10 (see Appendix H for the more detailed model).
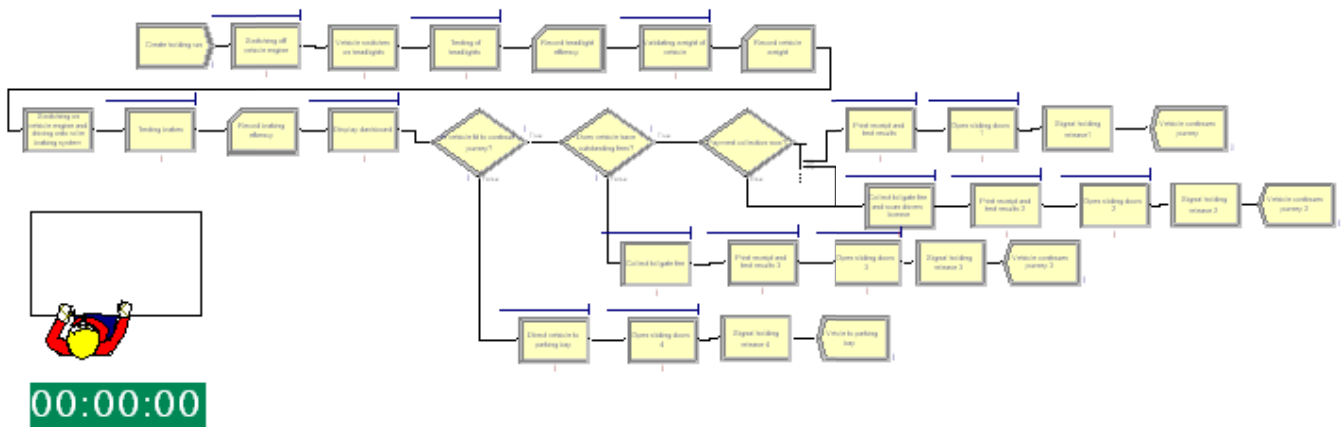
Figure 10: Sub-model of option 1.

Once in the sub-model the vehicle will undergo the following processes in order of simulation (See Appendix H):

1. Enter the sub-model in the same manner as scheduled in the top-level model.

2. Driver will be instructed to stop on a particular area and switch off vehicle's engine, seizing tollgate operator.

3   Driver will be required to switch on the vehicle's headlights; thus, delaying the tollgate operator.

4   The tollgate operator will test the headlight's efficiency, and record the results.

5   The tollgate operator will weigh the vehicle which has stopped on the weight during process 2, and record the results.

6   The driver will be instructed to switch on vehicle's engine and carefully position the vehicle's front wheels on the rollers of the braking tests, delaying the tollgate operator.

7   Tollgate operator will tests the vehicle's front wheel brakes, and then continue to tests rear wheels, by using the same method (model includes time for both wheel positions), the results will be recorded.

8   The tollgate operator will then display the testing results on a dashboard visible to the driver of the vehicle.

9   The results of the tests will indicate whether the vehicle is fit to continue its journey by the use of a decision process, if vehicle is fit to continue journey it will be continue to 11, otherwise:

10   the vehicle will be directed to a parking bay situated at the tollgate, for repairment, or owner collection. No vehicle will be allowed to continue journey if it did not pass a tollgate roadworthiness test.

11   The driver of the vehicle will be penalized and fined for any un-roadworthy elements of its vehicle. If there are no penalties, driver pays the tollgate fee (Pumulani toll gate: Light-weight vehicle - R 7,50) and continue to process 15. Otherwise:

12   The driver should indicate which billing process should be followed:

13   Pay outstanding penalties and tollgate fees immediately, receive receipt of payment and test results print-out to continue journey, or

14   Scan driver's license and invoice the outstanding payments to driver's postal address, collect tollgate fee, receive test results print-out and continue journey.

15   Vehicle will be released from system and tollgate operator will signal for release of queue.

The feasibility of in-transit roadworthiness tests on the national roads of South Africa.

2011

5.2.1 Results obtained from option 1 model

The model as described above was run for one, 24-hour day as seen from Figure 11, and the following results were obtained:
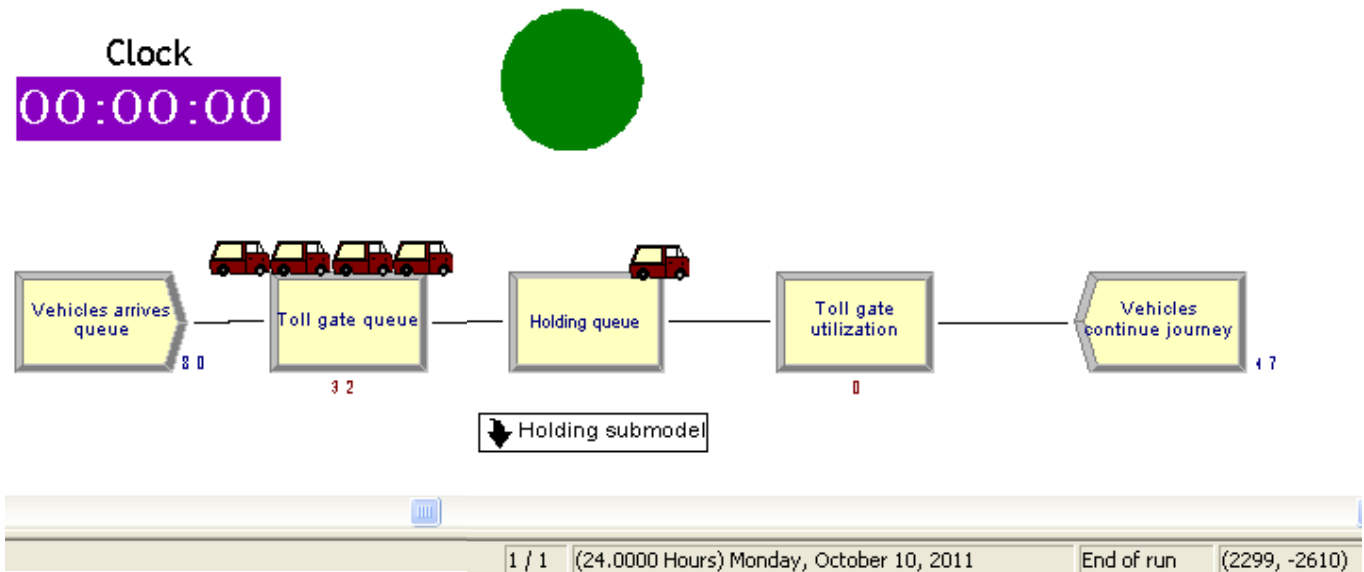
<p align="center">Figure 11: Ran model, option 1 for one, 24- hour day.</p>

- Number of vehicles out of system = 100
- Number of vehicle entering system = 134
- Average waiting time in tollgate queue = 2.5968 hours (155.8 minutes)
- Average number of vehicles in tollgate queue = 13.71 vehicles
- Total number of times that tollgate operator was seized = 425 times

As the results show, the current operation and processes within option 1 is far too time-consuming and labor intensive for one tollgate operator to handle. Thus, the ultimate goal would be to determine the required amount of tollgate operators that would be required to justify this time-consuming alternative.

5.3 Determining the required amount of tollgate operators

The correct determination of the optimized tollgate operator requirement, requires the utilization of queuing theories. Unfortunately, using queuing theories one generally agrees to several assumptions like:

- The arrival rate of entities follows a Markov chain (meaning that they are exponentially distributed, statistically independent in different time intervals).

- The service rate of resources follows Markov chain (meaning that they are exponentially distributed, statistically independent in different time intervals).
- Probability of more than one arrival or service in a small interval of time is zero.

Thus, the current Arena® model for option 1 was altered to fit the assumptions of the M/M/1/∞/FIFO queuing model. From the model is was determined that the process of testing a vehicle once in the system can be at the least 2 minutes and at the most 8 minutes. Thus resulting in:

- Arrival rate (λ) = 10 vehicles per hour (assuming that 240 light-weight vehicles will require roadworthiness testing at a single tollgate)
- Service rate (µ) = 7, 5 vehicles per hour

From these results and the use of the M/M/1/∞/FIFO queuing model equations (Appendix C) the database as seen in Appendix I was generated.

The database indicates that even if the arrival rate (λ) of vehicles were to decrease to 7 per hour, the average time that a vehicle will spend in the system (queue and testing time) will still only be 120 minutes with just one tollgate operator. The results from the database also indicate that should the service rate (µ) of the one tollgate operator increase to 11 vehicles per hour that the system waiting time still amounts to 60 minutes. Thus, the necessity for additional tollgate operators is of utmost importance to the feasibility of option 1 on the N1 freeway of South Africa.

To ultimately determine the required amount of tollgate operators for option 1, the system waiting time would have to be decreased substantially in order to ensure a feasible solution alternative. Currently, the system waiting time, with one operator, according to the Arena® model is estimated to be just over the 300 minutes (5 hour) mark. The database in Appendix I indicates a negative value since no steady-state would be achieved (since arrivals will always exceed service). If one were to limit the system waiting time to 20 minutes, the required amount of tollgate operators can be determined by using the M/M/s/∞/FIFO queuing model, with:

- Arrival rate (λ) = 10 per hour
- Service rate (µ) = 7, 5 per hour.

The results are promising, seeing as the database (see Appendix J) indicates that only one additional tollgate operator would have to be added to the existing operator. The average system waiting time for option 1 would significantly decrease to 14, 336 minutes, making the added financial obligation of an additional tollgate operator worthwhile.

5.4 Adjusting the Arena® model for an additional tollgate operator

The final step in testing the feasibility of option 1 would be to simulate the addition of an additional operator. The additional operator was added to the model constructed in section 5.2 as can be seen from Figure 12 (see Appendix K for detailed model).

Figure 12: Arena® model of additional tollgate operator.

6.   Recommendations and conclusions

The road fitness of vehicles is one of the major contributing factors to many car accidents in South Africa, as well as globally. If the problem of poor roadworthiness of vehicles can be properly addressed, it is believed that vehicle related car accidents can reduce by around 10-30%, indicating a fatal car accident number of around 11 200 deaths instead of the 16 000 reported in South Africa during 2009. A reduction in death rates will also reduce the amount of money that is spent on fatal car accidents annually in South Africa, which was reported to be around R 14 billion in 2009. These costs include damaged road reconstruction, compensation and legal costs.

The global problem of poor roadworthiness of vehicles is dealt with in different ways and legislation. As seen in Chapter 2 of this document, the United Kingdom and Japan require regular investigations and evaluations on the vehicles that use their road-system, either annually or bi-annually; where as in South Africa, a vehicle has the possibility of being tested for roadworthiness only once in its existence. This is due to fact that once ownership of a vehicle in South Africa is changed, the vehicle is required to undergo and pass a roadworthiness evaluation.

Possible solutions to the problem of poor roadworthiness are common and global, and can stretch as high as the heavens, but the feasibility of international trends and solutions in South Africa and other developing countries are of main concern, due to available infrastructure, required resources and finances. Thus, the ultimate goal of the project was to develop possible solutions to the major contributing factors to the poor roadworthiness state of South African vehicles whilst considering the available infrastructure, resources and finances.

Three alternative designs to possible solutions were developed, and finally compared and tested for feasibility in South Africa. The best alternative would have to be internationally competitive, cost-effective and be able to address as many of the contributing factors to poor roadworthiness in South Africa as possible. The decision matrix tool was utilized to conduct this comparison according to a set of standards.

The solution that was ranked as the most feasible and indirectly would satisfy all the specified requirements was Option1: Tollgate initiative. The option strives under the known concept of tollgates in South Africa, whilst not significantly increasing the costs of the solution. A possible four entities of poor roadworthiness in South Africa can be evaluated according to this option; which is a major increase to the current situation within South Africa.

The feasibility study was conducted by using the decision matrix, which ultimately ranks solutions according to their requirement fulfillment. The decision matrix as seen in Chapter 4 highlighted the consideration of the other options through the ranking scores. Option 1 was ranked the number one solution with 35 points, option 3 with 34 and option 2 with 32; these ranks were fairly close and it was recommended that all options be further researched and developed before settlements are made on the final solution, to the problem of poor roadworthiness in South Africa.

Further investigation was conducted on the highest ranked option, namely option 1, to validate the feasibility of the solution. The investigation included in the construction of a simulated model as developed in Arena$^{®}$ Software. The model indicated the existence of long queues and waiting times that would form from the solution. The queues were evaluated through the use of the Queuing Theory models, to determine the required amount of tollgate operators that would ultimately ensure that option 1 would be a feasible solution to the problem of poor roadworthiness. The required number of operators was determined to be only two, which dramatically decreased the waiting time to less than 15 minutes.

The project indicated the feasibility of conducting roadworthiness tests on the national roads of South Africa, but only through full commitment from the South African Department of Transport, can the problem of poor roadworthiness in South Africa be successfully solved.

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8.   Appendices

Appendix A: Roadworthiness certificate

Republic of South Africa   Republiek van Suid-Afrika

Johannesburg

Make   AUDI   Fabrikaat

Vehicle category   Light passenger mv (less than 12 persons)

Driven   Self-propelled / Selfgedrewe

2007-04-25

Vehicle status   Used / Gebruik

Date liable for registration   2010-03-30

TITLE HOLDER   **TITELHOUER**

Type of identification   Reg no certificate / Reg nr sertifikaat

Country of issue   South Africa / Suid-Afrika

OWNER   **EIENAAR**

Type of identification   Reg no certificate / Reg nr sertifikaat

Country of issue   South Africa / Suid-Afrika

Issue number   01

Date of issue   2010-03-10

Johannesburg

RECEIPT   **KWITANSIE**

Transaction   Vehicle registration/Voertuigregistrasie

Total amount received   R92.00

Date   2010-03-30

G DUBE

Method of payment   Cash / Kontant

4024   2010-03-30 13:28:24

T 7239332

ISSUED WITHOUT ANY ALTERATIONS OR ERASURES   UITGEREIK SONDER ENIGE VERANDERINGS OF UITKRAPPINGS

Appendix B: MOT certificate

VT20   MOT Test Certificate   VOSA
Vehicle & Operator Services Agency

This certificate has been issued according to the conditions and notes on the back of this certificate.

Note: If you have doubts as to whether this certificate is valid, please use the service described in note 3 overleaf to check.

MOT test number	Make	Odometer reading
499377061183	PORSCHE	29880 Miles

Registration mark	Model	Test class
WX56YJY	911	IV

Vehicle identification or chassis number	Colour
WP0ZZZ99Z7S720586	GREY

Expiry date	Issue date/time
JUNE 15th 2012 (TWELVE)	JUNE 16th 2011 (ELEVEN) 16:10

Additional Information

To preserve the anniversary of the expiry date the earliest you can present your vehicle for test is 16/05/2012

MOT Text Reminder service now available. For details see www.direct.gov.uk/motreminders

Advisory Notice Issued	NO
Test station number	1ALM00

For all vehicles with more than 8 passenger seats

Seat belt installation checked this test	N/A	Number of seat belts fitted at time of installation check.	N/A	Previous installation check date	N/A

Issuer's name in CAPITALS	Signature of Issuer
A. JONES	

Warning: A test certificate is not evidence that the vehicle is in a satisfactory condition.
Check carefully that the above details are correct.
Do not accept a certificate which has been altered.

Affix sticker to inside of windscreen as a reminder

Reg Mark	WX56YJY
Make	PORSCHE
Test Station	1ALM00
MOT Expiry	JUNE 15th 2012 (TWELVE)

Peel here

Inspection Authority

COACHSTYLE LTD
HORSDOWN GARAGE
NETTLETON
CHIPPENHAM
SN14 7LN   01249783366

SBS40E/01/13

Appendix C: Formulas for M/M/1/∞/FIFO model and M/M/s/∞/FIFO model.

M/M/1/∞/FIFO model:

If $\rho \geq 1$, no steady state exists. For $\rho < 1$,

$$\rho = \frac{\lambda}{\mu} \qquad\qquad W = \frac{1}{\mu - \lambda}$$

$$L = \frac{\lambda}{\mu - \lambda} \qquad\qquad Wq = \frac{\lambda}{\mu(\mu - \lambda)}$$

$$Lq = \frac{\lambda^2}{\mu(\mu - \lambda)} \qquad\qquad Ws = \frac{1}{\mu}$$

$$Ls = \rho \qquad\qquad L = \lambda W \quad (Little's\ Theory)$$

M/M/s/∞/FIFO model:

If $\rho \geq 1$, no steady state exists. For $\rho < 1$,

$$\rho = \frac{\lambda}{s(\mu)} \qquad\qquad Wq = \frac{P(j \geq s)}{s\mu - \lambda}$$

$$\pi_0 = \frac{1}{\sum_{i=0}^{i=s-1} \frac{(s\rho)^i}{i!} + \frac{(s\rho)^s}{s!(1-\rho)}} \qquad\qquad Ls = \frac{\lambda}{\mu}$$

$$P(j \geq s) = \frac{(s\rho)^s \pi_0}{s!\,(1 - \rho)} \qquad\qquad Ws = \frac{1}{\mu}$$

$$Lq = \frac{P(j \geq s)\rho}{1 - \rho} \qquad\qquad L = Lq + \frac{\lambda}{\mu}$$

$$W = \frac{L}{\lambda}$$

Source: Winston (2004), *Introduction to Probability Models*

Appendix D: NATIONAL ROAD TRAFFIC ACT, 1996 (ACT No. 93 OF 1996)

DEPARTMENT OF TRANSPORT

No. R. 1999

NATIONAL ROAD TRAFFIC ACT, 1996 (ACT No. 93 OF 1996)

NATIONAL ROAD TRAFFIC REGULATIONS, 1999

The Minister of Transport has, under section 75 of the National Road Traffic Act, 1996 (Act No. 93 of 1996), made the regulations in the Schedule.

SCHEDULE

Arrangement of regulations

Regulation No.

CHAPTER I

DEFINITIONS

1. Definitions

CHAPTER II

REGISTERING AUTHORITIES AND AUTHORISED OFFICERS

Part I

Matters relating to registering authorities

1A. Procedure in case of dispute in relation to appropriate registering authority

Part II

Authorised Officers

1B. Manner of application for registration as inspector of licences, examiner of vehicles, examiner for driving licences or traffic officer
1C. Manner of registration as inspector of licences, examiner of vehicles, examiner for driving licences or traffic officer
2. Grades of examiner of vehicles and examiner for driving licences
2A. Manner of suspension or cancellation of registration of authorised officer

Part III

Requirements for approval of training centres

2B. Requirements for approval of training centres by Shareholders Committee

CHAPTER III

REGISTRATION AND LICENSING OF MOTOR VEHICLES, AND REGISTRATION OF MANUFACTURERS, BUILDERS AND IMPORTERS, AND MANUFACTURERS OF NUMBER PLATES

Part I

Registration and licensing of motor vehicles

3. Motor vehicle to be registered
4. Motor vehicle deemed to be registered
5. Motor vehicle exempt from registration
6. Date on which registration of motor vehicle becomes null and void
7. Date and conditions on which motor vehicle to be registered
8. Manner of application for registration of motor vehicle
9. Additional requirements for registration of motor vehicle built up from parts
9A. Additional requirements for registration of deregistered motor vehicle
10. Additional requirements for registration of motor vehicle acquired from the estate of deceased person
11. Additional requirements for registration of repossessed motor vehicle
12. Additional requirements for registration of motor vehicle acquired outside borders of Republic
12A. Additional requirements for registration of motor vehicle previously reported as stolen
13. Manner of registration of motor vehicle
14. Application by and appointment of manufacturer or importer as agent of registering authority
15. Introduction of motor vehicles by manufacturer or importer appointed as agent
16. Application for registration certificate in respect of motor vehicle introduced by manufacturer or importer
17. Deregistration of registered motor vehicle which becomes exempt from registration
18. Motor vehicle to be licensed
19. Motor vehicle deemed to be licensed
20. Motor vehicle exempt from licensing
21. Special classification of motor vehicle in relation to motor vehicle licence fees
22. Date on which motor vehicle licence and licence disc of motor vehicle becomes null and void
23. Date on which motor vehicle to be licensed
24. Manner of application for licensing of motor vehicle
25. Manner of licensing of motor vehicle
26. Period of validity of motor vehicle licence and licence disc
27. Licence mark and licence number system
28. Personalised licence number system
29. MEC may change allocated licence number

30. Motor vehicle licence assessment
31. Additional requirements for application for licensing in the case of alteration or reconstruction of registered motor vehicle
32. Procedure on change of appropriate registering authority due to owner moving
33. Procedure on re-defining of area of registering authority
34. Procedure on change of licence mark of registering authority or licence number system of province
35. Display of licence number
36. Display of licence disc or licence and roadworthy certificate disc
37. Procedure for refund of motor vehicle licence fees

Part II

Registration of manufacturers, builders, importers and manufacturers of number plates

38. Certain manufacturers, builders and importers to register
39. Manner of application for registration as manufacturer, builder or importer
40. Manner of registration of manufacturer, builder or importer
41. Conditions for registration of manufacturer, builder or importer
42. Manner of suspension or cancellation of registration of manufacturer, builder or importer
43. Duties of certain manufacturers, builders or importers not required to register
44. Powers and duties of inspectorate of manufacturers, builders and importers
45. Fee to defray expenditure incurred by inspectorate of manufacturers, builders and importers
46. Procedure for change of particulars of manufacturer, builder or importer
47. Manner of change of conditions upon which manufacturer, builder or importer is registered
48. Manufacturers of number plates to register
49. Manner of application for and registration of manufacturers of number plates
50. Conditions for registration as manufacturer of number plates
51. Manner of suspension or cancellation of registration of manufacturer of number plates

Part III

General

52. Procedure for change of particulars of title holder or owner of registered motor vehicle
53. Duty of title holder and owner of motor vehicle where such title holder or owner changes
54. Procedure if motor vehicle is stolen
55. Procedure if motor vehicle becomes permanently unfit for use as motor vehicle
56. Number to be affixed to motor vehicle
57. Penalties for late registration or licensing
58. Registration and licence fees not payable in respect of certain vehicles
59. Arrear fees for licensing of motor vehicle or motor trade number
60. Period of grace
61. Procedure when cheque is dishonoured
62. Duty to furnish information
63. Duty of registering authority in respect of records
64. Confirmation of information in respect of motor vehicle
65. Exporting of motor vehicle

66. Manner in which mass measuring certificate to be obtained
67. Manufacturer, builder or importer to provide certificate
68. Registration certificate to be submitted by owner and title holder under certain circumstances

CHAPTER IV

MOTOR TRADE NUMBERS, TEMPORARY AND SPECIAL PERMITS

Part I

Motor Trade Numbers

69. Motor vehicles may be operated under motor trade number under certain circumstances
70. Manner of application for motor trade number
71. Motor trade number system
72. Manner of issue of motor trade number
73. Motor trade number to be licensed
74. Date on which motor trade number to be licensed
75. Manner of application for a motor trade number licence
76. Manner of licensing of motor trade number
77. Period of validity of motor trade number licence and motor trade number licence disc
78. Motor trade number licence assessment
79. Procedure for change of particulars of holder of motor trade number
80. Cancellation of motor trade number
81. Number issued in prescribed territory
82. Display of motor trade number and motor trade number licence disc
83. Right of appeal to MEC

Part II

Temporary and special permits

84. Circumstances in which motor vehicle may be operated on public road under temporary or special permit
85. Manner of application for temporary or special permit
86. Temporary or special permit number system
87. Manner of issue of temporary or special permit
88. Period of validity of temporary and special permit
89. Display of temporary or special permit
90. Duty of motor dealer in respect of temporary permit

CHAPTER V

FITNESS OF DRIVERS

Part I

Driving licence testing centres

Part II

Learner's and driving licences

Part III

Instructors

Part IV

Professional Driving Permit

CHAPTER VI

FITNESS OF VEHICLES

Part I

Testing stations, roadworthy certificates and certification of roadworthiness

Part II

Equipment on or in respect of vehicles

149. Brakes on motor vehicles
149A. Anti-theft device fitted to brakes prohibited
150. Brakes on motor cycle, motor tricycle or motor quadrucycle
151. Brakes on trailers
152. Brakes on pedal cycles
153. Brakes on unspecified vehicles
154. Specifications for brakes
155. Braking performance of service, emergency and parking brakes
156. Condition and operation of brakes
157. Vehicles to be equipped with certain lamps and times when certain lamps to be lighted
158. Visibility distance of lights
159. Head lamps
160. Main-beam
161. Dipped-beam
161A. Daytime running lamp
162. Lights to be displayed on stationary or parked motor vehicle
163. Fog lamps
164. Parking lamps
165. When parking lamps to be kept lighted
166. Front-position lamps
167. End-outline-marker lamps
168. Rear lamps
169. Stop lamps
170. Number plate lamps
171. Side-marker lamps
172. Interior lamps
173. Lamp illuminating notice on motor vehicle
174. Decorating lamps
175. Reversing lamps
176. Identification lamps
177. Use of spot lamp
178. Lamps on pedal cycle
179. Lamps on animal drawn vehicles
180. Lamps on unspecified vehicles
181. Colour of lights
182. Certain lamps to emit diffused lights
183. Lamps to emit steady light
184. Manner in which lamps to be fitted and maintained
185. Lamps not prescribed or authorised, prohibited
186. White retro-reflectors to be fitted on front of certain vehicles
187. Red retro-reflectors to be fitted on rear of certain vehicles
188. Yellow retro-reflectors to be fitted on sides of certain motor vehicles
189. General requirements for retro-reflectors
190. Rear retro-reflectors on vehicles with certain bodies
191. Warning sign on rear of certain motor vehicles (chevrons)
192. Unlawful use of reflector or reflective material

Part III

Dimensions of vehicles

Part II

Speed limits

292. General speed limits
293. Speed limit for particular class of vehicle
94. Speed limit in relation to tyres
295. Speed limit in relation to braking capability

CHAPTER X

RULES OF THE ROAD AND MATTERS RELATING THERETO

Part I

Rules of the road

296. Vehicle to be driven on left side of roadway
297. Driving on divided public road
298. Passing of vehicle
298A. Prohibition on driving on shoulder of public road, except in certain circumstances
299. Crossing or entering public road or traffic lane
300. Driving signals
301. Right of way at certain road junctions
302. Procedure when turning
303. Towing of vehicles
304. Stopping of vehicles
305. Parking of vehicles
306. Certain vehicles may be stopped and parked at any place where necessary
307. Compulsory stops
308. General duties of driver or passenger of vehicle on public road
308A. Prohibition on use of communication device while driving
309. Duties relating to motor cycle, motor tricycle or motor quadrucycle
310. Vehicle causing excessive noise
310A. Use of hooter
311. Riding on pedal cycles
312. Device running on rails
313. Animal on public road
314. Animal-drawn vehicles
315. Pedestrian's right of way in pedestrian crossing
316. Duties of pedestrians
317. Racing and sport on public roads
318. Convoys on public road
319. Hindering or obstructing traffic on public road
320. Vehicle left or abandoned on public road
321. Damage to public roads
322. Trading on public roads
323. Special provisions relating to freeways

Appendix E: Option 1 flow chart

Vehicle approaches tollgate

Vehicle enters available bay

Operator closes sliding doors

Operator instructs:

Switch on lights

Testing:

Head and rear lights

Operator instructs:

Switch off engine

Testing:

Weight and distribution

Operator instructs:

Stop of rollers

Operator instructs:

Apply service brakes

Appendix F: Option 2 Flow chart

Vehicle approaches tunnel

Vehicle enters tunnel

Dimensions control activated

Vehicle continues through tunnel

Lighting control activated

Vehicle continues through tunnel

Lighting control activated

Vehicle continues through tunnel

```
          │
          ▼
  ┌─────────────────┐
  │ Speeding control│
  │    activated    │
  └─────────────────┘
          │
          ▼
  ┌─────────────────┐
  │ Vehicle approaches│
  │    tollgate*    │
  └─────────────────┘
          │
          ▼
  ┌─────────────────┐
  │ Vehicle driver pays│
  │ fees and penalties│
  │    (if any)*    │
  └─────────────────┘
          │
          ▼
  ┌─────────────────┐
  │ Vehicle exits tunnel│
  │                 │
  └─────────────────┘
```

* Only applicable to tollgate operated tunnels.

Appendix G: Assumed schedule of vehicles arriving

Assumed schedule of vehicles arriving at the tollgate station:

Time-interval	Number of vehicles expected to arrive:
00:00 to 01:00	1
01:00 to 02:00	1
02:00 to 03:00	2
03:00 to 04:00	1
04:00 to 05:00	2
05:00 to 06:00	4
06:00 to 07:00	4
07:00 to 08:00	5
08:00 to 09:00	5
09:00 to 10:00	5
10:00 to 11:00	4
11:00 to 12:00	4
12:00 to 13:00	4
13:00 to 14:00	5
14:00 to 15:00	3
15:00 to 16:00	4
16:00 to 17:00	3
17:00 to 18:00	3
18:00 to 19:00	2
19:00 to 20:00	2
20:00 to 21:00	3
21:00 to 22:00	2
22:00 to 23:00	1
23:00 to 24:00	1

Assumptions:

- Based on the Pumulani tollgate, that functions under a 6-lane free way from Pretoria to Zambesi off ramp and then as a 4-lane freeway from Zambesi to Bela-Bela off ramp.
- Arrivals assumed in a public school holiday period.
- Arrivals only simulated for light-weight vehicles.

Please note that arrivals as tabulated in table above are only indications of what the student predicted the arrivals would be given the assumptions above.

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Appendix H: Detailed Arena® model for option 1

00:00:00
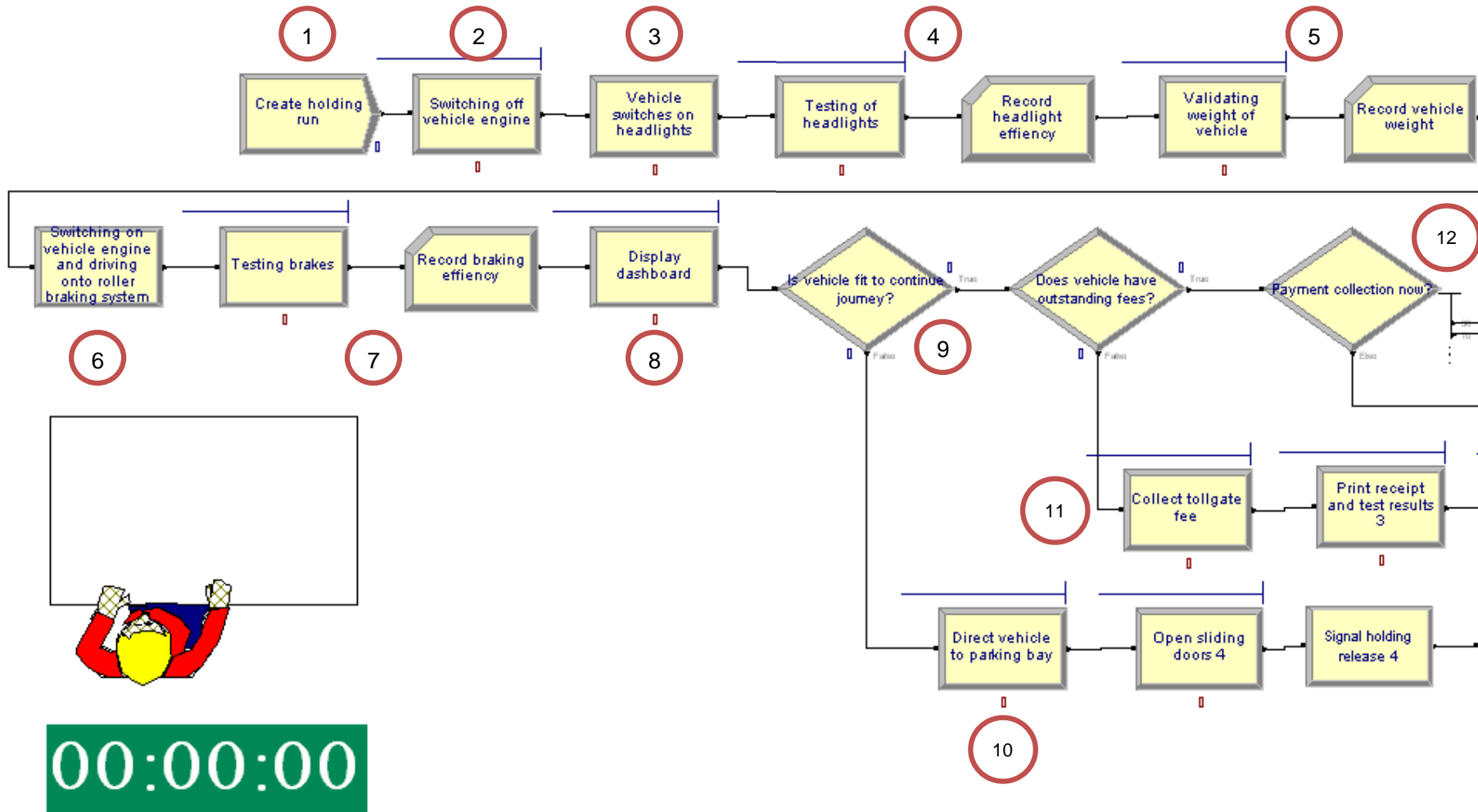
See next page for connecting part of model.

See next page for connecting part of model.

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Print receipt and test results

Open sliding doors 1

Signal holding release1

Vehicle continues journey

14

Collect tollgate fee and scan drivers license

Print receipt and test results 2

Open sliding doors 2

Signal holding release 2

Vehicle continues journey 2

15

Open sliding doors 3

Signal holding release 3

Vehicle continues journey 3

Vehicle to parking bay

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Appendix I: Queuing theory database

Queuing theory entities as arrival rates change:

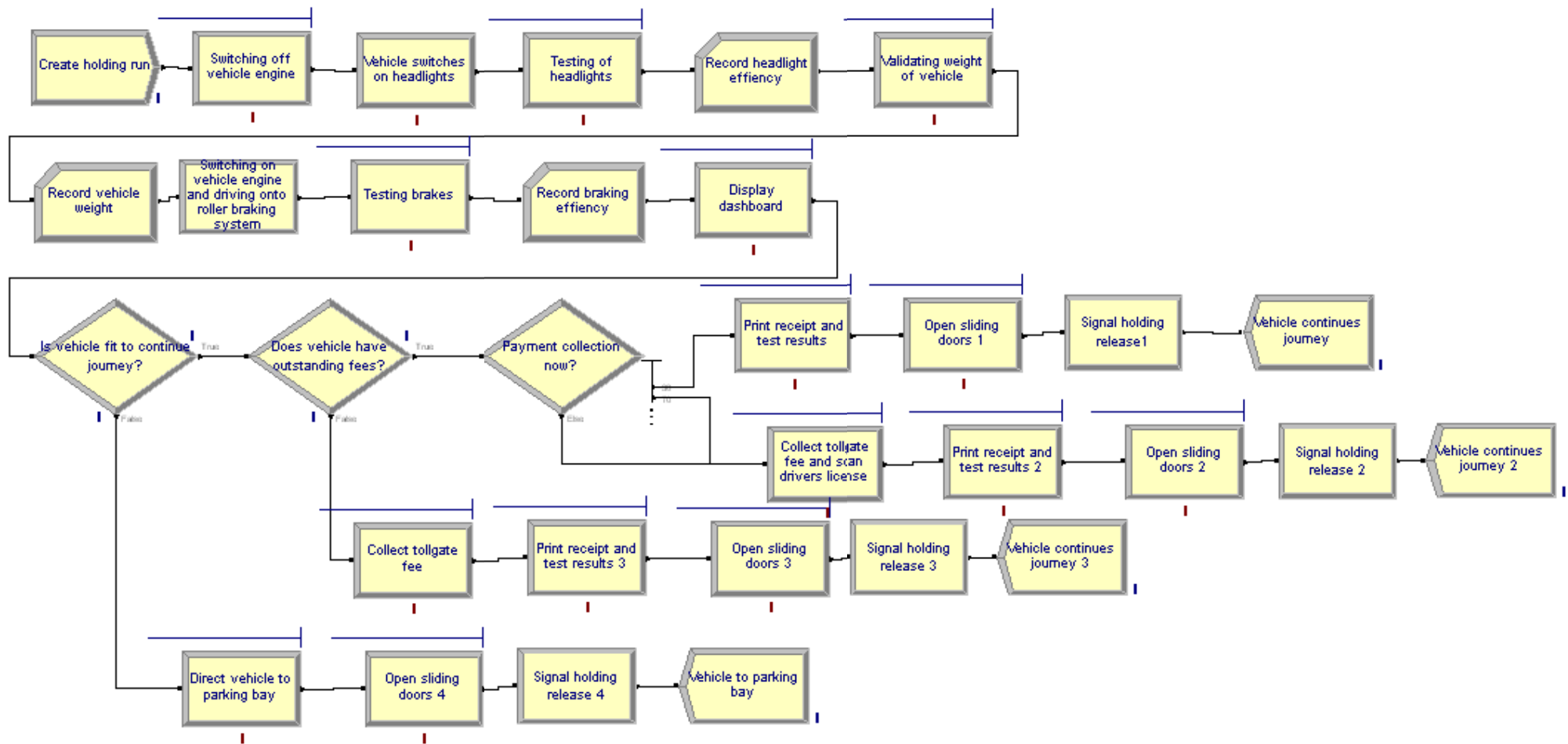| Average number of vehicles entering the system per unit time (λ)	Average number of vehicles being serviced per unit time (μ)	Utilization parameter (ρ)	Average number of vehicles present in the queuing system (L)	Average number of vehicles waiting in the queue (Lq)	Average number of vehicles in service (Ls)	Average time a vehicle spends in the system per unit time(W)	Time in minutes	Average time a vehicle spends in the queue (Wq)	Time in minutes	Average time a vehicle spends in service (Ws)	Time in minutes
7.00	7.50	0.93	14.00	13.07	0.93	2.00	120.00	1.87	112.00	0.13	8.00
7.50	7.50	1.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.13	8.00
8.00	7.50	1.07	-16.00	-17.07	1.07	-2.00	-120.00	-2.13	-128.00	0.13	8.00
9.00	7.50	1.20	-6.00	-7.20	1.20	-0.67	-40.00	-0.80	-48.00	0.13	8.00
10.00	7.50	1.33	-4.00	-5.33	1.33	-0.40	-24.00	-0.53	-32.00	0.13	8.00
11.00	7.50	1.47	-3.14	-4.61	1.47	-0.29	-17.14	-0.42	-25.14	0.13	8.00
12.00	7.50	1.60	-2.67	-4.27	1.60	-0.22	-13.33	-0.36	-21.33	0.13	8.00
13.00	7.50	1.73	-2.36	-4.10	1.73	-0.18	-10.91	-0.32	-18.91	0.13	8.00

Queuing theory entities as service rates change:

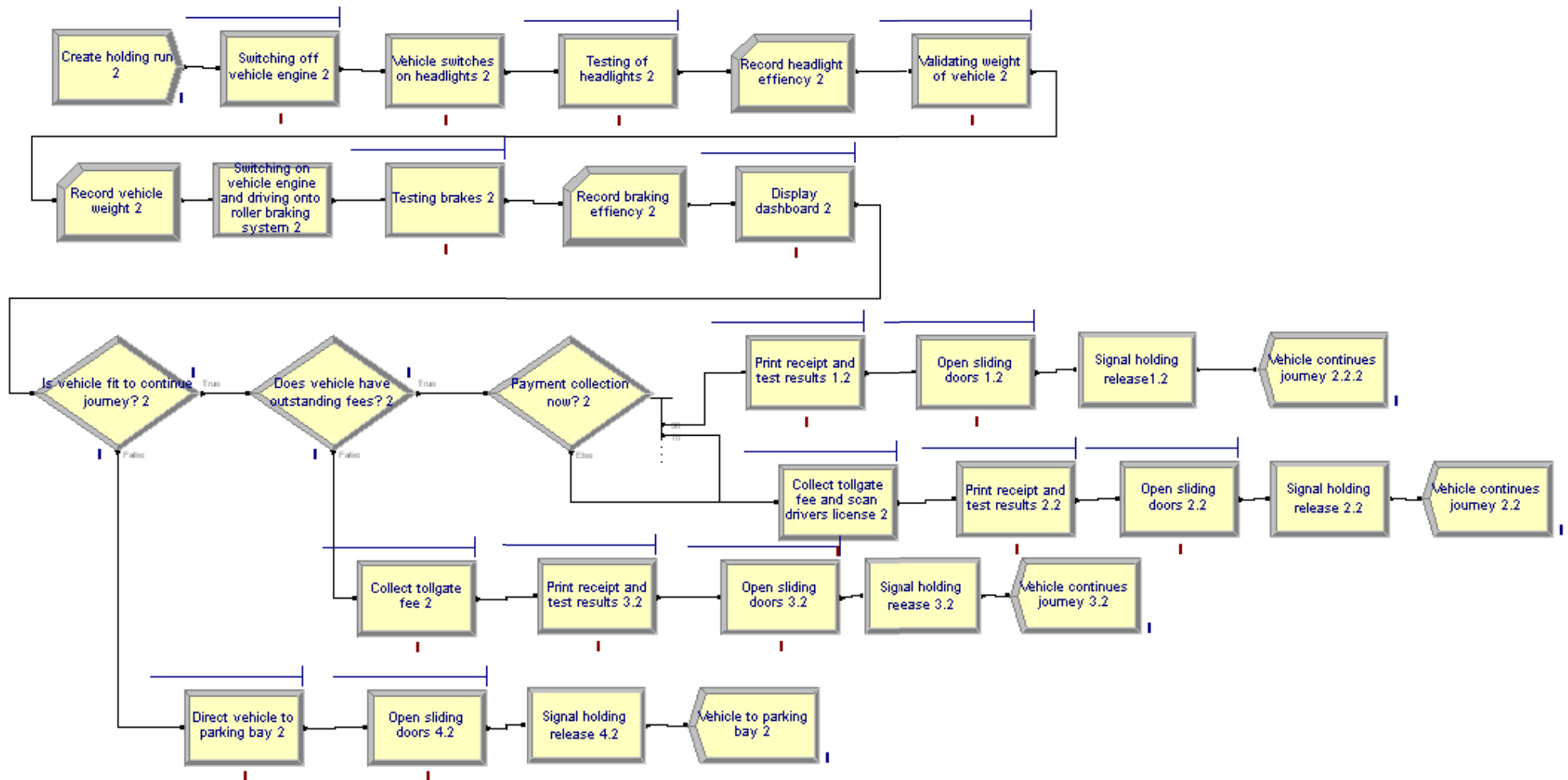| Average number of vehicles entering the system per unit time (λ)	Average number of vehicles being serviced per unit time (μ)	Utilization parameter (ρ)	Average number of vehicles present in the queuing system (L)	Average number of vehicles waiting in the queue (Lq)	Average number of vehicles in service (Ls)	Average time a vehicle spends in the system (W)	Time in minutes	Average time a vehicle spends in the queue (Wq)	Time in minutes	Average time a vehicle spends in service (Ws)	Time in minutes
10.00	5.00	2.00	-2.00	-4.00	2.00	-0.20	-12.00	-0.40	-24.00	0.20	12.00
10.00	6.00	1.67	-2.50	-4.17	1.67	-0.25	-15.00	-0.42	-25.00	0.17	10.00
10.00	7.00	1.43	-3.33	-4.76	1.43	-0.33	-20.00	-0.48	-28.57	0.14	8.57
10.00	7.50	1.33	-4.00	-5.33	1.33	-0.40	-24.00	-0.53	-32.00	0.13	8.00
10.00	8.00	1.25	-5.00	-6.25	1.25	-0.50	-30.00	-0.63	-37.50	0.13	7.50
10.00	9.00	1.11	-10.00	-11.11	1.11	-1.00	-60.00	-1.11	-66.67	0.11	6.67
10.00	10.00	1.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.10	6.00
10.00	11.00	0.91	10.00	9.09	0.91	1.00	60.00	0.91	54.55	0.09	5.45

Appendix J: Determination of required number of tollgate operators using the Queuing theory

Determination of required number of service counters

Average number of vehicles entering the system per unit time (λ)	Average number of vehicles being serviced per unit time (μ)	Number of operators (s)	Utilization parameter (ρ)	Probability of no vehicles waiting in queue (π ₒ)	Probability of more vehicles in queue than available servers (P (j ≥ s))	Average number of vehicles waiting in the queue (Lq)	Average number of vehicles present in the queuing system (L)	Average time a vehicle spends in the system per unit time(W)	Time in minutes
10	7.5	1	1.333333333	No steady state	No steady state	No steady state	No steady state	No steady state	No steady state
10	7.5	2	0.666666667	0.198	0.528	1.056	2.389333333	0.238933333	14.336
10	7.5	3	0.444444444	0.265	0.141333333	0.113066667	1.4464	0.14464	8.6784
10	7.5	4	0.333333333	0.267	0.029666667	0.014833333	1.348166667	0.134816667	8.089

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Appendix K: Arena® model of additional tollgate operator to option 1

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The End