Elevation based, fuel consumption predictions using a gamification model: The South African Truck Simulator

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Abbreviated Title	Elevation based, fuel consumption predictions using a gamification model: The South African Truck Simulator.
Keywords	Elevation; truck simulator; logistics; gamification
Abstract	This project proposes the use of a gamification model to combat high logistics cost in South Africa. The proposed model, the South African Truck Simulator, is a South African version of an existing truck simulation game. For this model to be effective, it should be able to incorporate road grade in its fuel consumption calculations. Accordingly, this project focuses on determining whether the model's fuel consumption output is sensitive to road grade. Also included in this project, is the first draft of the South African map to be used in the gamification model.
Category	Simulation and logistics
Confidentiality	None

Declaration

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Executive summary

South Africa is a transport intensive country. Consequently, transportation costs are extremely high, which further snowballs into high logistics costs. High logistics costs negatively influences the country's ability to compete with developed countries. South Africa must therefore strive to reduce its logistics cost to ensure competitiveness.

From the literature, it was found that fuel costs and truck driver wages are the two leading transportation cost drivers. Unfortunately, reducing fuel cost is not as trivial as reducing the distance travelled. An more likely approach is to reduce the total fuel consumption by combating the common misconception that the shortest route to a destination will always be the most economical. Creating awareness can result in a different mindset in terms of the most economical route. Furthermore, it was found that high truck driver wages are due to the high demand, but short supply of truck drivers in South Africa. Unfortunately, truck driving training is expensive and it is therefore difficult for an interested individual to get exposure to the truck driving profession. Thus, to reduce South Africa's high logistics cost, the following is required:

- Combat the common misconception by creating awareness about the effect of road grade on a heavy vehicle's fuel consumption.
- Attract more people to the truck driving profession and provide inexpensive truck driving training to alleviate the shortage of truck drivers in South Africa, thereby reducing driver wage costs.

This project proposes the creation of a gamification model to address the needs mentioned. In simple terms, gamfication means to turn something into a game, such as the act of truck driving. Gamification adds a sense of enjoyment and is found to be most effective when applied to an educational context. The suggested gamification model is a South African version of Euro Truck Simulator 2 (ETS2), referred to as the South African Truck Simulator (SATS). ETS2 is a truck simulation game where a player must deliver various cargo across a realistic depiction of Europe. In order for SATS to be able to create awareness about the effect of road grade on a truck's fuel consumption, the actual fuel consumption output of the simulation game must be sensitive to road grade. This will require a road grade evaluation study. Accordingly, the project consists of two deliverables:

- An alpha version of SATS. Note that this version will not be fully functional, as the focus is placed on the creation of the South African map.
- A conclusion as to whether or not SATS's fuel consumption output is sensitive to road grade and if the game could therefore be used to create awareness.

The first deliverable, the South African map, was created using ETS2's build-in map editor. The map consists of South Africa's main transportation network as identified in

the literature. Special attention was given to detail to ensure that the construction of each intersection replicates its real life-counterpart as much as possible.

For the road grade evaluation study, a set of arc's with varying slope percentages were mapped in SATS. Afterwards, multiple simulation runs were driven on each arc to obtain various fuel consumption statistics using telemetry. The three most important telemetry outputs identified were the *telemetry fuel consumption* output, the *fuel average consumption* output and the truck's *odometer* reading at the end of the simulated journey. It was later concluded that the *telemetry fuel consumption* output did not incorporate road grade. Fortunately, the *fuel average consumption* output showed a promising trend. Due to the promising trend, an equation was developed to calculate the total fuel consumption using the *fuel average consumption* and *odometer* outputs. The output of this equation was compared with the expected *theoretical fuel consumption* estimates to determine if SATS's fuel consumption outputs does indeed incorporates road grade. The calculations for the *theoretical fuel consumption* estimates were based on a literature study. Fortunately, the road grade evaluation study concluded that the fuel consumption outputs of the simulation game can be used to accurately predict the fuel consumption when road grade is present, using an equation derived in this project. Accordingly, SATS can be used as an educational tool to create awareness about the effect of road grade on a heavy vehicle's fuel consumption. A suggested approach to create awareness using SATS, is to create in-game awards when the player selects the route with minimal road grade.

This project concludes by stating the belief that SATS will be able to address the needs mentioned. This belief is based on the fact that the simulation game is a form of gamification applied to an educational context, as well as the fact that SATS's fuel consumption output is sensitive to road grade.

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Acronyms

SATS	South African Truck Simulator
ETS2	Euro Truck Simulator 2
MSWM	municipal solid waste management
TFC	total fuel consumption
NFFM	National Freight Flow Model
GDP	Gross Domestic Product
LPI	Logistics Performance Indicator

Chapter 1

Introduction

> *"You will not find it difficult to prove that battles, campaigns, and even wars have been won or lost primarily because of logistics."*
>
> — General Dwight D. Eisenhower (Deroussi, 2016)

The importance of logistics can never be emphasized enough. It possesses the means needed to obtain a competitive advantage in a business or even victory in war. For this reason, logistics must be prioritized and handled with extreme caution.

Unfortunately South Africa is currently facing high logistic costs due to country's spatial challenges and accompanying transport intensiveness. Accordingly, a model will be created that can assist in the reduction of South Africa's high logistics cost, using a concept known as *gamification*.

1.1 Background of South Africa's logistics efficiency

In 2016, South Africa ranked 20th overall on the World bank's Logistics Performance Indicator (LPI), a welcoming improvement compared to the country's 34th ranking in 2014 (Arvis et al., 2016). However, despite being ranked in the top 15%, the country is still behind developed countries when comparing logistics efficiency. Havenga et al. (2015) uses a country's logistic cost, expressed as a percentage of Gross Domestic Product (GDP), as a benchmark metric to measure and compare logistics efficiency. South Africa's logistic efficiency was 11.2% in 2014, which is competitive with developing countries, but higher than developed countries, with Finland being the exception. A logistic efficiency comparison of various countries is given in Figure 1.1.

If South Africa wishes to compete with developed countries, special attention must be given to reduce the major logistic cost driver, transportation. In 2014, transportation accounted for 57% of the South Africa's total logistics cost (Havenga et al., 2016). A better understanding of the impact of transport cost is obtained when calculating logistics cost as a percentage of *transportable* GDP. From 2012 onwards, transportation was accountable for 50% of the total logistics cost incurred for *transportable* goods. In simpler terms, the cost of transporting a product in South Africa is equivalent to the product's total manufacturing cost.

Havenga et al. (2016) reported a transport cost of R244 billion for the year 2014, of which 83% was due to road transport. The authors further stated that the leading road transport cost driver is fuel, followed by truck driver wages. The reduction of the two cost drivers will be the main focus of this project.

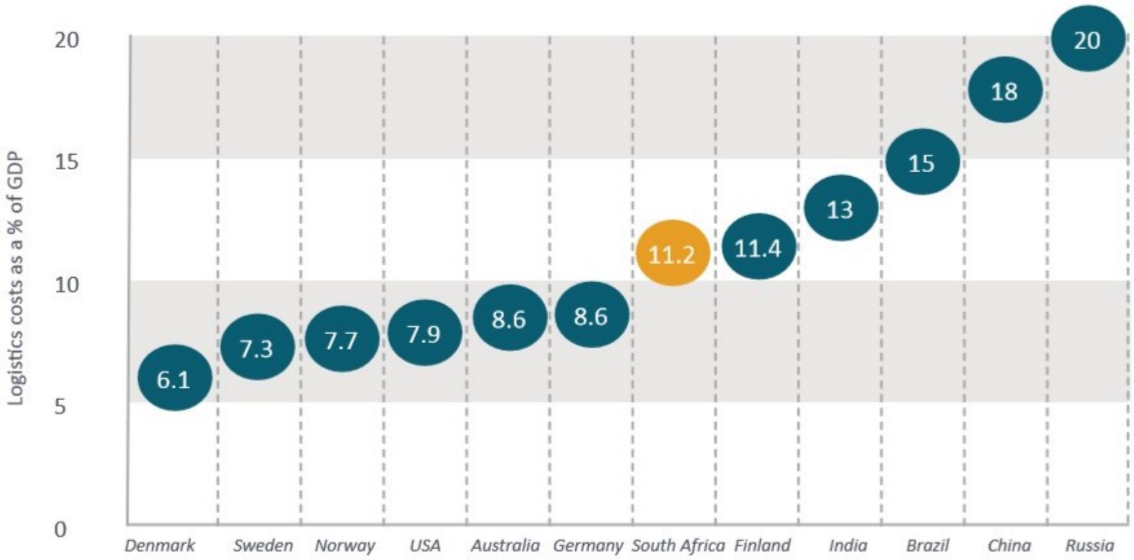


Figure 1.1: Comparison of 2014's logistic efficiencies for various countries (Havenga et al., 2016).

1.2 Gamification

This report proposes the use of one of the latest technology-embracing approaches, *gamification*, as a means of reducing transportation cost. Gamification is the use of game design in a non-game context to encourage positive behaviour changes and can be used as an innovative teaching tool (Fitz-Walter et al., 2017; Yildirim, 2017). The objective of gamification is to encourage users to engage with an application by creating a sense of enjoyment (Deterding, 2011). A notable benefit of gamification is the ability to provide real-time, and possibly continuous, user performance information which can be used instantaneously to guide near-future performance (Cardador et al., 2017).

To answer the research question, *'Does gamification work?'*, Hamari et al. (2014) reviewed 24 empirical studies on gamification and determined three main components of gamification:

Motivational affordance According to Deterding (2011), motivational affordance is linked to the Self-Determination Theory (SDT). This theory states that people will complete certain tasks if these tasks will satisfy motivational needs, including the need for achievement. Motivational affordances are therefore any form of incentives that encourage specific actions. Hamari et al. (2014) created 10 categories of motivational affordance for gamification, of which the most common are points, leader boards, achievements, badges and levels.

Behavioural outcomes Changes in user behaviour as a result of gamification.

Psychological outcomes Includes aspects such as motivation, attitude and enjoyment of user.

The three components will be discussed further in section 1.3, using an example of an existing gamification model known as Euro Truck Simulator 2 (ETS2).

1.3 Euro Truck Simulator 2

ETS2 is a heavy vehicle simulation game developed by SCS Software. The main objective of the game is to deliver various cargo across a realistic depiction of Europe using a heavy vehicle, as shown in Figure 1.2. The game has an additional business component in which the player can expand his truck business by purchasing additional garages and hiring extra truck drivers to earn more profit.

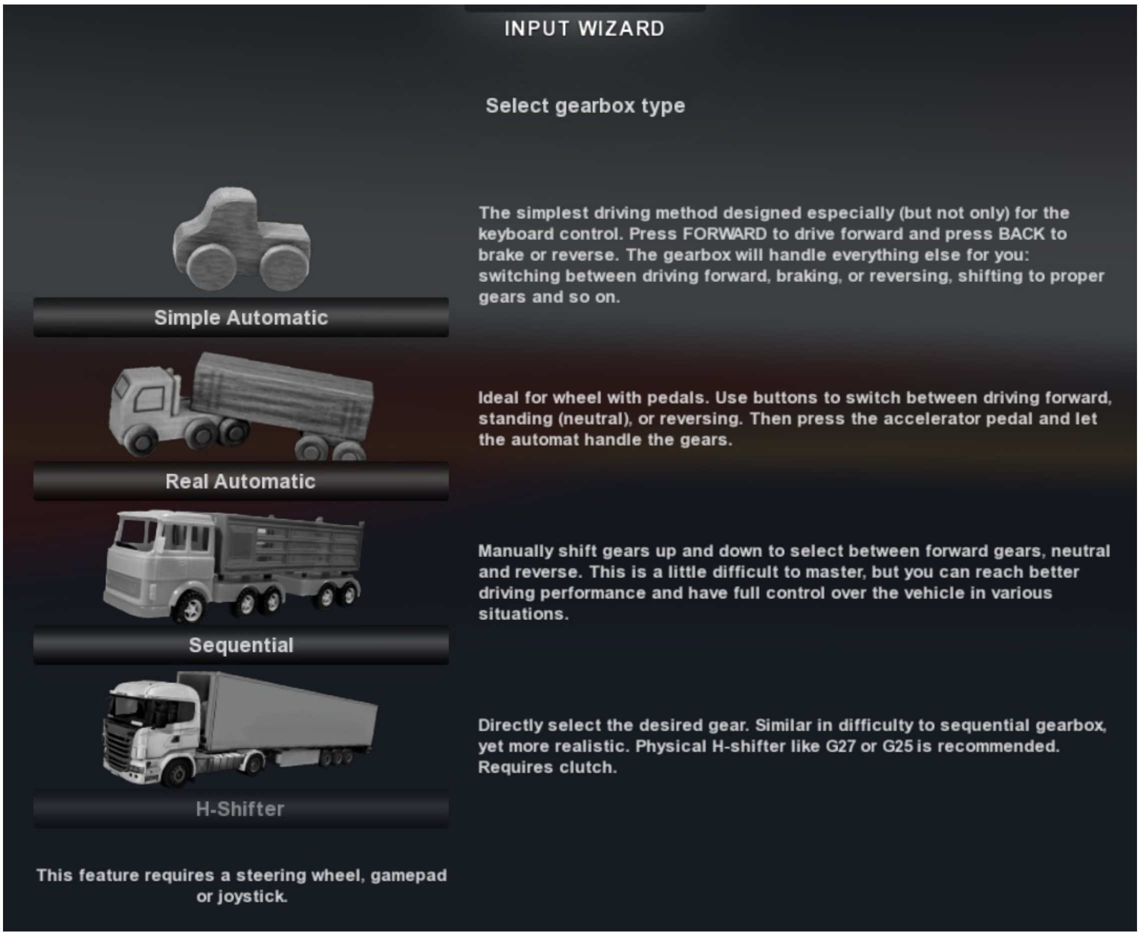
```
Creating save-game file (/home/profiles/53412054727563682053696D20/save/autosave_drive_3/game.sii) ...
Game has been auto-saved.
screenshot
Screenshot written: '/screenshot/ets2_00009.png'.
screenshot
```

Figure 1.2: In-game picture from Euro Truck Simulator 2

Depending on the player's gaming equipment and driving competence, the player can choose from three types of control methods to steer the truck. The simplest method is to steer the truck using a keyboard. The second method uses the mouse for steering. This method is more precise and sensitive compared to the keyboard method. For the most realistic experience, a player must have a computer steering wheel, a joystick and a gas pedal controller to replicate a truck's cabin. The player is also able to select the type of truck gearbox preferred. The gearbox choices, along with a description of each, are shown in Figure 1.3. Being able to select the type of control method and truck gearbox allows the player to select the level of realism that he or she prefers.

The map used in the simulation game consist of various cities across Europe, which in turn consist of various delivery points. Each delivery point offers a unique selection of possible delivery jobs that differ in travel distance, location, profit earnings, truck requirements and so on. The cargo is classified into 5 types: fragile, high value, long distance, urgent and abnormally heavy cargo. A player can specialise in the delivery of certain cargo types by allocating skill points to the specific category, which increases a player's profit and experience points obtained when completing a specialised delivery.

After each delivery, a player is paid a certain amount of money, which can be used for upgrades, to purchase new or additional trucks, to expand the business to other regions in Europe or to obtain various licences. The amount of money received is however dependent on the success of the delivery as any damage to the cargo will lead to profit deduction in order to account for the damage incurred, or even the replacement of the cargo. The same


INPUT WIZARD

Select gearbox type

Simple Automatic

The simplest driving method designed especially (but not only) for the keyboard control. Press FORWARD to drive forward and press BACK to brake or reverse. The gearbox will handle everything else for you: switching between driving forward, braking, or reversing, shifting to proper gears and so on.

Real Automatic

Ideal for wheel with pedals. Use buttons to switch between driving forward, standing (neutral), or reversing. Then press the accelerator pedal and let the automat handle the gears.

Sequential

Manually shift gears up and down to select between forward gears, neutral and reverse. This is a little difficult to master, but you can reach better driving performance and have full control over the vehicle in various situations.

H-Shifter

Directly select the desired gear. Similar in difficulty to sequential gearbox, yet more realistic. Physical H-shifter like G27 or G25 is recommended. Requires clutch.

This feature requires a steering wheel, gamepad or joystick.

Figure 1.3: The four types of gearboxes available for selection in ETS2 (version 1.31).

holds true for late deliveries. Incompetent or careless driving is also penalized through fines for violations, such as speeding, inadequate resting, crashing into surroundings, headlights not turned on and running a red light. These fines and profit deductions contribute to the realism of the simulator and encourages better driving.

ETS2 tries to encapsulate all the aspects related to truck driving and presents it in the form of an enjoyable game. Consequently, ETS2 is a form of gamification, satisfying the three components as follow:

Motivational affordance The main motivation affordances used in the game are experience points, skills, levels, player rating and personal awards. Experience points are obtained by completing various deliveries and is used to unlock better paying, yet more challenging jobs. A player's level is indicative of the amount of experience points earned. As a player progresses in level, skills points are unlocked that can be used to specialize in various skills. Personal awards are achieved through the completion of various activities, such as utilizing a boat or completing a delivery that was greater than 2000 km. With the current version of ETS2, version 1.32, a player can aspire to achieve 60 awards when all of the other expansions are included.

Behavioural outcomes The most desired behavioural outcome of ETS2 is increased truck driving competence and knowledge of the player. The player will also be more aware of truck logistics and the consequences of late deliveries, reckless driving, damaged cargo and inadequate resting periods, to name a few. The addition of the business aspect in the game could result in a business-oriented mindset where the player strives to minimize cost and maximize profit in real-life situations.

Psychological outcomes ETS2 has a variety of attractions that could motivate a person to play the game, the most obvious of which is the desire to drive a heavy vehicle. Additional motivations include an interest to explore Europe, the business aspect of the game, the mentioned motivational affordances and lastly, the overall game enjoyment.

Steam is a online distribution platform for video games, including ETS2. In 2016, ETS2 won two Steam Awards, titled *'I thought this game was cool before it won an award'* and *'Sit back and relax'*. It is therefore no surprise that Steam lists ETS2 as a top seller in 2018. According to Steam, the overall user reviews for the simulation game is *'overwhelmingly positive'*. ETS2 is therefore well perceived and successful in the gaming community worldwide.

1.4 Project description

This project's *objective* is to identify and complete the fist few steps towards the creation of a gamification model. This model should be able to assist in the reduction of South Africa's high logistics cost by focusing on the two main transportation cost drivers, fuel cost and truck driver wages. The purpose of this model will be:

- To investigate and create awareness about the impact of road grade on a heavy vehicle's fuel consumption and how it can lead to fuel cost savings.
- To attract more people to the truck driving profession and to provide inexpensive truck driving training to combat the shortage of truck drivers in South Africa.

Seemingly independent, the common connection between the two purposes is to increase truck driving competence, not only through driving skills, but also through truck knowledge. For instance, knowledge about the effect of road grade on a truck's fuel consumption.

The *proposed solution* is to develop South African Truck Simulator (SATS), a South African version of ETS2. SATS, as a form of gamification, will package the truck driving profession in South Africa as an enjoyable game. This will improve the learning experience and will motivate a player to continue playing the game and thereby continuing to improve his or her truck driving competence. Also, due to the success of ETS2, it is believed that SATS will be welcomed in the gaming community.

1.4.1 Research design

Completion of this project will result in two deliverables:

Alpha version of SATS : In this context, the alpha version of SATS does not refer to a fully functional simulation game. Instead, it refers to the completion of some of the first steps required to create the functional simulator. Accordingly, this deliverable will consist of the basic South African map, as well as a few personal award suggestions relevant to South Africa. The main techniques required for this deliverable include ETS2 map editing skills, logistic research, soft skills, knowledge about South Africa and reasoning.

A Description of the accuracy of SATS's fuel consumption output : This deliverable will be in the form of a conclusion as to whether or not SATS is sensitive to road grade. If sensitive, this deliverable should include an equation that can be used to determine the fuel consumption within the game. The main techniques required for this deliverable include conducting an experimental simulation study, data handling, programming in R, data correlation study, telemetry and various mathematical calculations.

1.4.2 Research methodology

This section describes the research methodology, developed by Manson (2006), that will be followed during the execution of the project. As stated, this project aims to address high transportation cost in South Africa through the implementation of a gamification model.

The *suggested approach* is to develop SATS, a South African version of ETS2. SATS is seen as a means for improving various skills through game-play and exposing more people, especially females, to the truck driving profession. It is also believed that SATS can be used to educate player's on the effect of road grade on a truck's fuel consumption. From the literature review completed in chapter 2, positive results are expected from the simulation game. For clarity, the project is divided into two parts.

The first part of the project, *development*, is concerned with the development of an alpha version of SATS. The key component of the alpha version of SATS is the South African map, which will be created using ETS2's build-in map editor. Since the map will be based on the country's main transportation network, an analysis of South Africa's freight flow will also be conducted to ensure the proper selection of the main road network to include in the simulation game. An additional requirement for this part of the project is to list a few motivational affordance suggestions relevant to South Africa. The model for the development of SATS is given in subsection 3.1.

Part two focuses on the effect of road grade on fuel consumption within SATS, as discussed in subsection 3.2. A simulation experiment will be conducted where the telemetry output for various road inclination segments will be compared with the theoretical fuel consumption estimates. The theoretical fuel consumption estimates will be calculated based on a study preformed by Tavares et al. (2009), as described in the literature. The goal is to determine if the simulation game is sensitive to road grade and if it can be used to accurately determine the fuel consumption of real life scenario's.

The project *evaluation* will take place in chapter 4. The first part of the project, the development of the South African map, will be evaluated based on the overall accuracy of the map's road network and the relevance of the personal award suggestions to South Africa. The second part of the project will be evaluated based on the credibility of the theoretical fuel consumption estimates and the accuracy of SATS telemetry fuel consumption output.

On project completion, a *conclusion* will be made based on the evaluation of the results. The conclusion, given in chapter 6, will be aimed at stating if SATS is capable of addressing the mentioned transportation costs drivers. Any deviations from the listed criteria will be discussed, as well as any improvement opportunities or suggestions for further improvements.

Chapter 2

Literature review

In 2016, South Africa ranked 20th, out of 160 countries, on the World bank's Logistics Performance Indicator (LPI). According to Arvis et al. (2016), a country's LPI rating is based on five criteria, of which *'the competency and quality of the country's logistic services'* is of most importance to this project. For this specific criteria, South Africa ranked 22nd, indicating that this criteria is preventing the country from placing better on the overall LPI ranking. That being so, South Africa must improve its logistic services in order to surpass its current ranking, especially if the country wishes to compete with developed countries.

Knowing that transportation cost is the most expensive logistic service, accounting for 57% of the total logistics cost in 2014, the first section of this literature review will explore the leading transportation cost drivers. Afterwards, the suggested approach of using gamification to address these cost drivers will be discussed, followed by a brief motivation for the expected success of the suggested project when using gamification. The literature review will conclude with an analysis of South African's transportation network and freight flow.

2.1 South Africa's transportation cost drivers

The most influential cost components for road transport in South Africa is shown in Figure 2.1. Since the objective of the project is to reduce South Africa's high logistic cost, the two leading cost drivers will be investigated. Section 2.1.1 focuses on the impact of road grade on fuel consumption. Section 2.1.2 identifies the cause of high driver wage cost and explains the link between driver competence, driver wages and other cost, including maintenance and repair, insurance and tyre cost.

2.1.1 Fuel consumption

South Africa is a transport intensive country due the country's spatial challenges: Gauteng, the country's main demand center, is positioned approximately 600 km from its nearest port in Durban. It is therefore no surprise that fuel is the leading driver of transportation cost.

A common misconception exist where it is believed that the shortest route to a destination will always be the most economical. This misconception is due to factors such as road roughness and road grade that result in varying engine power requirements. Viljoen (2013) states that fuel consumption of a heavy vehicle increases with approximately 1% when the

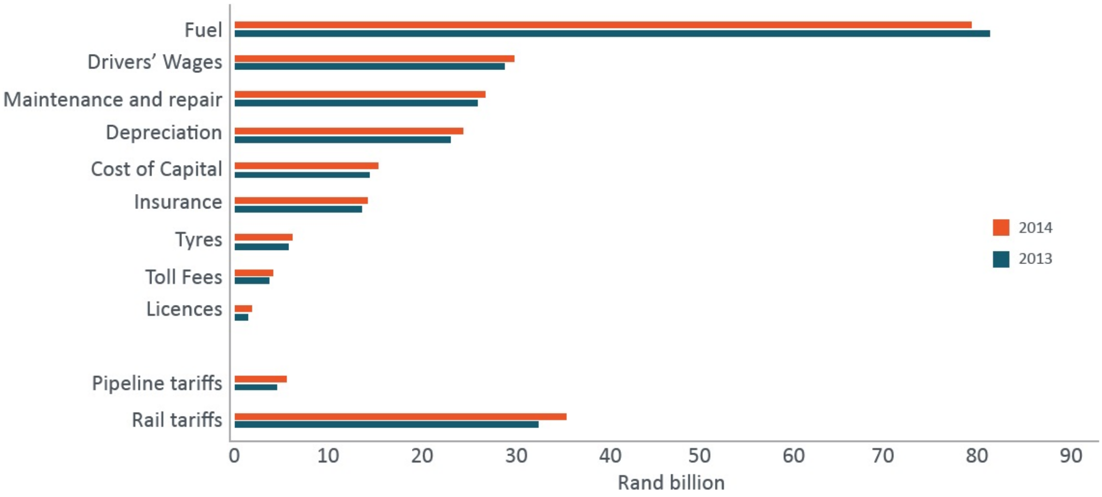


Figure 2.1: Leading cost components per transport mode (Havenga et al., 2016).

vehicle travels at 96 km/h, and approximately 2% when travelling at 56 km/h on a rough road. This report will however focus on the effect of road grade on fuel consumption.

A case study completed by Tavares et al. (2009) highlights the effect of road grade. In their study, a model was developed to determine an optimal routing network that minimized fuel consumption for Santiago's municipal solid waste management (MSWM) system. Santiago is a *mountainous* island of the Republic of Cape Verde and has 6 municipalities that are divide into two zones: the capital Praia and the remaining zones that will be referred to as Santiago for the remainder of the report. The authors used the following three step methodology for the execution of their study:

1. *Create a realistic 3D model of Santiago's road network:* The 3D model created consisted of *m-amounts* geographical polyline objects defined as arcs. An arc is simply the representation of a road in the 3D model and consists of an array of vertices and segments. Vertices are points on the arc indicating a change in direction or road inclination and a segment is the straight line connecting two neighbouring vertices. The amount of segments in an arc will vary depending on the road being represented. Thus, the k^{th} arc will contain n_k amount of segments. Creating a new segment when a change in gradient occurs, allows the incorporation of road inclination in the fuel consumption calculation to obtain a more accurate representation of reality.

2. *Calculate each road's fuel consumption*: The authors used the method and data of Ntziachristos and Samaras (2000) to calculate the fuel consumption for each road in the 3D model. The category of data used was for *heavy vehicles between 7.5 to 16 tonnes*, with a mean speed of 20 km/h.

   Let:

$\mathbf{K}$	be the set of all arcs included in the 3D model, such that $\mathbf{K} = \{1, 2, ..., m\}$, where m represents to the total arc count.
$\mathbf{A}_k$	be the set of all n_k sequential segments constituting arc k, such that $\mathbf{A}_k = \{1, 2, ..., n_k\}$, where n_k represents the number of sequential segments of arc k and $k \in \mathbf{K}$.
$fc_{ki} \triangleq$	Calculated fuel consumption rate (grams/km) for the i^{th} segment of arc k, where $i \in \mathbf{A}_k$ and $k \in \mathbf{K}$.
$fc_k \triangleq$	Calculated fuel consumption (grams) for arc k, where $k \in \mathbf{K}$.

$GrCf_{ki} \triangleq$ Road gradient correction factor for the i^{th} segment of arc k, where $i \in \mathbf{A}_k$ and $k \in \mathbf{K}$.

$L_{ki} \triangleq$ Length (km) of the i^{th} segment of arc k, where $i \in \mathbf{A}_k$ and $k \in \mathbf{K}$.

$LCF_{ki} \triangleq$ The dimensionless load correction factor used to compensate for truck engine operating under different loads when travelling on the i^{th} segment of arc k, where $i \in \mathbf{A}_k$ and $k \in \mathbf{K}$.

$TFC \triangleq$ The minimum total fuel consumption required to travel from the origin to the destination.

$V_{ki} \triangleq$ Average truck speed (km/h) when travelling on the i^{th} segment of arc k, where $i \in \mathbf{A}_k$ and $k \in \mathbf{K}$.

$x_{ki} \triangleq$ Slope of the i^{th} segment of arc k, where $i \in \mathbf{A}_k$ and $k \in \mathbf{K}$. Note that x_{ki} is restricted to be in the range (-15%; 15%), exclusive of bounds.

Each segment's total fuel consumption rate, fc_{ki}, is calculated using (2.1). This equation incorporates vehicle load and road gradient along with the basic fuel consumed, FCS_{ki}, when travelling at 20 km/h. The total fuel consumption rate for heavy vehicles weighing between 7.5 to 16 tonnes is shown in (2.2).

$$
\begin{aligned}
fc_{ki} &= FCS_{ki} \times LCF_{ki} \times GrCF_{ki} && (2.1)\\
&= \left[1068.4V_{ki}^{-0.4905}\right] \times \left[1 + 0.36\frac{LP - 50}{100}\right] \times \left[0.41e^{0.18x_{ki}}\right], \quad \forall k \in \mathbf{K}, i \in \mathbf{A}_k && (2.2)
\end{aligned}
$$

Heavier loads place more strain on a vehicle's engine when compared with lighter loads, resulting in the inclusion of the dimensionless load correction factor, LCF_i, in the fuel consumption calculation. LP is the actual load divided by the maximum load of the truck and is mostly kept constant due to the truck load not varying when travelling on an arc. The LP calculation is shown in (2.3).

$$
LP = \frac{Load_{actual}}{Load_{maximum}} \tag{2.3}
$$

The road gradient correlation factor, $GrCf_{ki}$, accounts for the additional power required by a heavy duty vehicle's engine, due to the increase or decrease of the truck's resistance to traction (Ntziachristos and Samaras, 2000). It is important to mention that the road gradient correction factor formula, $GrCF = 0.41e^{0.18x}$, was derived by the authors of this study. Ntziachristos and Samaras (2000)'s data lists only four gradient correction factor classes with slope percentage range restriction of [-6%, 6%], inclusive of bounds. Tavares et al. (2009) used these classes to obtain four data points. The $GrCF$ formula was then derived by fitting an exponential distribution on the four data points. The advantage of doing so was that $GrCF$ values could be calculated for slope percentages exceeding the [-6%, 6%] slope percentage restriction. The fitted line, along with the four data points, is shown in Figure 2.2. Due to the exponential relationship between the $GrCF$ and the slope percentages, it can be expected that drastic slopes will have a significant impact on fuel consumption.

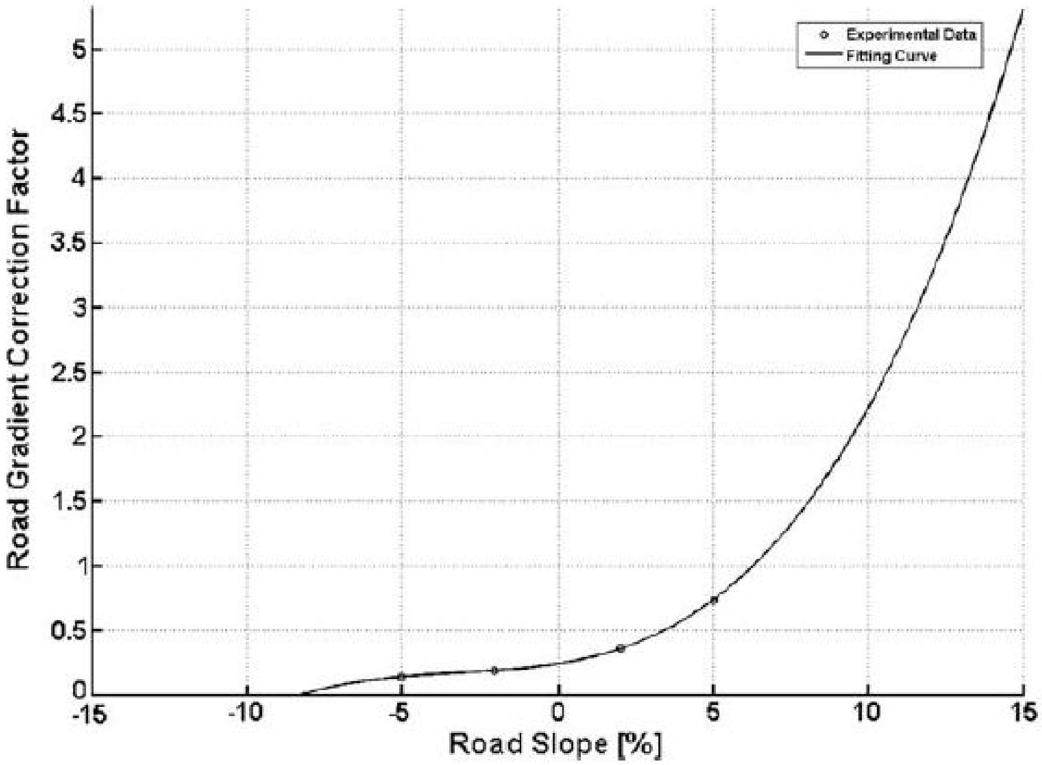


Figure 2.2: Road gradient correction factor for a road segment with slope percentage, x, when travelled by a heavy vehicle weighing between 7.5 to 16 tonnes (Tavares et al., 2009).

As stated, each arc consist of n_k segments, where a segment is separated due to change in road inclination. The total fuel consumption for each arc, fc_k, is simply the sum of its composing segments' total fuel consumption rates multpiplied by the length of each segment, as shown in (2.4).

$$fc_k = \sum_{i=1}^{n_k} (L_{ki} \cdot fc_{ki}), \forall k \in \mathbf{K} \tag{2.4}$$

3. *Optimise vehicle route:* The optimal route is determined using (2.5). The optimal route is the route with the lowest total fuel consumption (TFC) while ensuring that each required collection point is visited when travelling the route.

$$TFC = \min(\sum_{k=1}^{m} fc_k) \tag{2.5}$$

To showcase the importance of the incorporation of road inclination in fuel consumption calculations, an additional route was determined that minimised the total three dimensional (3D) distance travelled. With 3D distance, the ascending and descending distances are also taken into account due to the inclusion of road grade. Accordingly, the 3D distance will always be greater than or equal to the 2D distance of a given route. Note, for clarification on the parameters used, refer to Table 2.1.

Table 2.1: Parameter definintions

Parameter	Description
Distance 2D (m)	Route distance in the absence of elevation (no ascending and descending road segments)
Distance 3D (m)	Road grade is incorporated. Consequently, ascending and descending segments contribute to route distance.
Ascending 3D distance (m)	Total distance of route going uphill as a result of road grade.
Descending 3D distance (m)	Total distance of route going downhill as a result of road grade.
Horizontal distance (m)	Total distance of route with a zero road grade.
Fuel consumption 2D (g)	The calculated fuel consumption when the route is travelled, assuming road grade is zero.
Fuel consumption 3D (g)	The calculated fuel consumption when road grade is included in calculations.
Difference in distance travelled (3D-2D)(m)	The extra distance calculated when incoporating road grade into calculations.
Difference in fuel consumption (3D-2D)(g)	The extra amount of fuel consumed when including road grade in the calculations.

Thus a total of two optimal routes were calculated for the Santiago MSWM system using the methodology as described above: one that minimises the total distance travelled in 3D and another that minimises the total fuel consumption. It is interesting to note that the *minimal distance route*, can be travelled in any direction, since it has no effect on the total distance travelled. In other words, travelling from point A to point B and vice versa will give the same results. However, the route that *minimizes fuel consumption* is dependent on direction of travel as it gives strong preference to routes that minimizes vehicle elevation gain, as seen in Figure 2.3. The elevation and fuel consumption profiles for both routes are given in this figure.

Quantitative results for these two routes are tabulated in Table 2.2 with the parameter explanation given in Table 2.1. When using a 2D model, the *minimal distance route*'s fuel consumption is calculated to be 17.021 grams of fuel. However, when using the 3D model, the minimal distance route's fuel consumption increased to 30.67 grams. This 80% fuel consumption increase is due to the improved accuracy when incorporating road grade in the fuel consumption calculations. Consequently, when a 2D model is used, fuel consumption can be significantly underestimated which could have dire consequences. This emphasises the importance of including road grade. Similarly, a 57% increase was calculated for the *minimal fuel consumption* route when using a 3D model instead of a 2D model.

Most people believe that the shortest route is the most economical. This is proven wrong when considering the fuel savings between the two optimal routes: the route that *minimises fuel consumption* results in a 12.19% fuel savings (from 30,670 to 26,930 grams), even though the route is 0.4 km longer than the *minimal distance route* (62.1 km compared to 62.5 km in 3D distance). This fuel savings is mostly due to a 46% increase in horizontal distance travelled (from 11,735 m to 17,115 m) and a 2.3% reduction in ascending distance travelled (from 25,422 to 24,843) when using the *minimal fuel consumption* route. Consequently, this study demonstrates that the shortest route might not be the

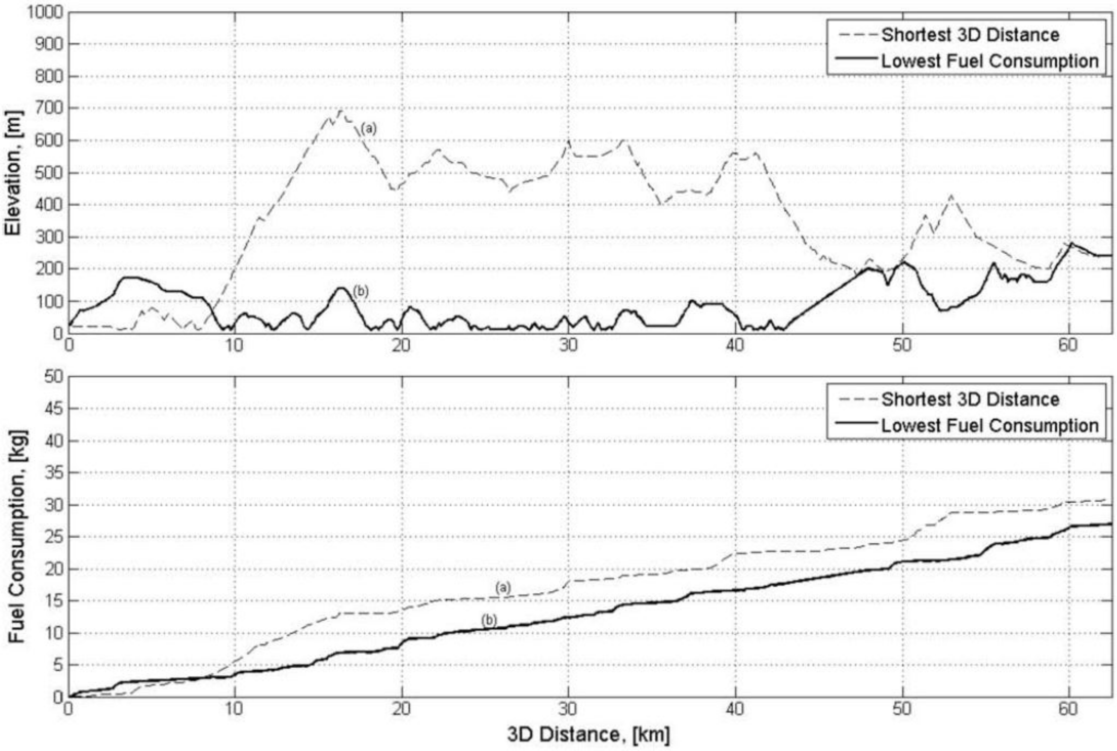


Figure 2.3: Fuel consumption and elevation profiles of optimal MSW transportation routes in Santiago (Tavares et al., 2009).

most economical route due to road inclination. Li et al. (2014) obtained similar results in a comparable study.

In an independent study, Joubert (2017) created an agent-based simulation model to indicate the effect of road grade on route choices. The author concluded that preference was given to routes with long down-hills and short, steep up-hills. This conclusion supports the results shown in Figure 2.3, where the *minimal fuel consumption route* avoided the `long` uphill between approximately 8 km to 18 km from the starting position.

Because of the misconception, a need exists to educate the public about the effect of elevation on fuel consumption. Encouraging companies to incorporate road inclination in their route choice selection proses can lead to vast reductions in transportation cost.

2.1.2 Truck driver wages and skills

The Department of Higher Education and Training (2016) released a list of occupations in high demand which include general truck drivers. Why this profession is in high demand is a result of a variety of reasons, including the growth of road freight movement, unattractive long working hours of truck drivers and HIV/AIDS affecting approximately 50% of truck drivers (Ramjee et al., 2002).

The cause of most significance for this report is however the lack of sufficiently trained and experienced truck drivers, aged 24 to 40, as stated in the chapter 7 of the *National Transport Master Plan 2050 Synopsis report*, listed by the *Department of Transport*. In 2002, the mean age of South African truck drivers was 37 years (Ramjee et al., 2002). A more recent study completed by Lalla-Edward et al. (2017), suggests the mean truck age to be 39 years. Consequently, the mean truck driver age is too high and increasing,

Table 2.2: Santiago's route optimization results (Tavares et al., 2009)

Calculated parameters	**Minimal distance route**	**Fuel minimisation route**
Distance 2D (m)	61,942	62,408
Distance 3D (m)	62,102	62,528
Ascending 3D distance (m)	25,422	24,843
Descending 3D distance (m)	24.945	20.570
Horizontal distance (m)	11,735	17,115
Fuel consumption 2D (g)	17,021	17,149
Fuel consumption 3D (g)	30.670	26,930
Difference in distance travelled (3D-2D)(m)	160	120
Difference in fuel consumption (3D-2D)(g)	13,649	9,781

thereby creating a need for new, young replacements. When considering South Africa's high youth unemployment rate of approximately 50% for 2017, as reported by *Trading Economics*, the country definitely has the youth to supply the need.

However, the *National Transport Master Plan 2050 Synopsis report* expressed major concern regarding the incompetence of the training programs and institutions for truck drivers in South Africa. Many competent driving schools do however exist, but the high price tag accompanying Code EC training can scare off potential individuals. Consequently, well trained and mature Code EC drivers are in short supply, resulting in a wage increase for truck drivers and ultimately higher transportation cost.

As explained by the authors, lowering the hiring standards is not an option to increase the workforce as this will result in higher externality costs due to more accidents and, accordingly, increased insurance premiums . The only solution is to train more competent truck drivers. Viljoen (2013) proposed that the supply chain industry should invest more in training opportunities available outside of tertiary institutions.

A need therefore exist to attract a younger generation to the profession of truck driving and a means of improving truck driving competence through inexpensive training. Not only will this lower truck driver wages, but increasing the competence of truck drivers will also lead to additional cost reductions. Competent drivers have improved knowledge about truck operations and how to protect the truck to reduce maintenance and tyre cost. They are also less prone to cause accidents, resulting in less repair and insurance cost.

2.2 Suggested approach

Section 2.1 found fuel cost and truck driver wages to be the leading transportation cost drivers in South Africa. It was concluded that the inclusion of road grade in fuel consumption calculations is extremely important as this significantly influences the most economical route. Furthermore, it was found that truck driver wages are costly due to a high demand, but inadequate supply of competent truck drivers, which also affects other transportation costs.

Accordingly, two needs were identified from the literature that, if addressed properly, could lead to transportation cost savings. The two needs that should be addressed are:

- A way to create awareness about the impact of road inclination on a heavy vehicle's fuel consumption and how it can lead to fuel cost savings.
- A way to attract more young people to the truck driving profession and to provide inexpensive truck driving training to combat the shortage of truck drivers in South Africa.

The *suggested approach* is to use gamifcation as a means to address the above-mentioned educational needs. This can be done by creating a South African version of Euro Truck Simulator 2 (ETS2), referred to as South African Truck Simulator (SATS).

Seeing that there are two needs, the project will be divided into to main parts. These two parts will be discussed in the remainder of this section, but before that, an imporant question is answered in section 2.2.1, namely, *'Why develope SATS when ETS2 and other simulators already exist?'*.

2.2.1 ETS2 versus SATS and existing truck simulators

One might wonder why time and effort would be spent to develop SATS when ETS2 is already available. An obvious reason is the direction of traffic that differs between these two countries. The most important reason for the development of the South African version is however the belief that it will help South African truck driver's to become more familiar with the country's road network and provide a sense of familiarity. In turn, this can reduce the driver's confusion and impulsive driving as the driver knows which route to take, thereby improving the driver's competence. Additionally, the creation of a South African version might also attract players that are specifically interested in South Africa and its landscapes.

One might also wonder why SATS would be developed if actual truck simulators, that are specifically designed and equipped for training, already exist. An example of such a simulator is owned by Stefanutti Stocks, a dynamic company that delivers construction and contracting solutions. The company owns two mobile operator-training simulator sets, which consists of two containers each, as shown in Figure 2.4. Note that these simulator sets are mobile and can therefore be used to train newcomers and test the competency of qualified operators of heavy vehicles throughout South Africa, as well as across the border.

Figure 2.4: Stefanutti Stocks' simulator set consisting of two containers.
Source: www.miningreview.com

One of the containers consist of six computer workstations which are used for theory and pre-simulator training. The other container contains a heavy vehicle console that can be surrounded by up to four full-screen monitors, replicating a heavy vehicle's cabin. This container also includes an additional computer workstation. At this works station a supervisor can view various instantaneous statistics about the trainee operating the simulator and can control and change the training scenarios. These scenarios range in difficulty levels and teaches the trainee how to operate the vehicle for day-to-day operations, as well as a variety of emergency situations. The inside of this container is shown in Figure 2.5, with the console at the back and the computer workstation in front. Note that the fourth screen, located between the console and workstation, is not pulled down in this picture.

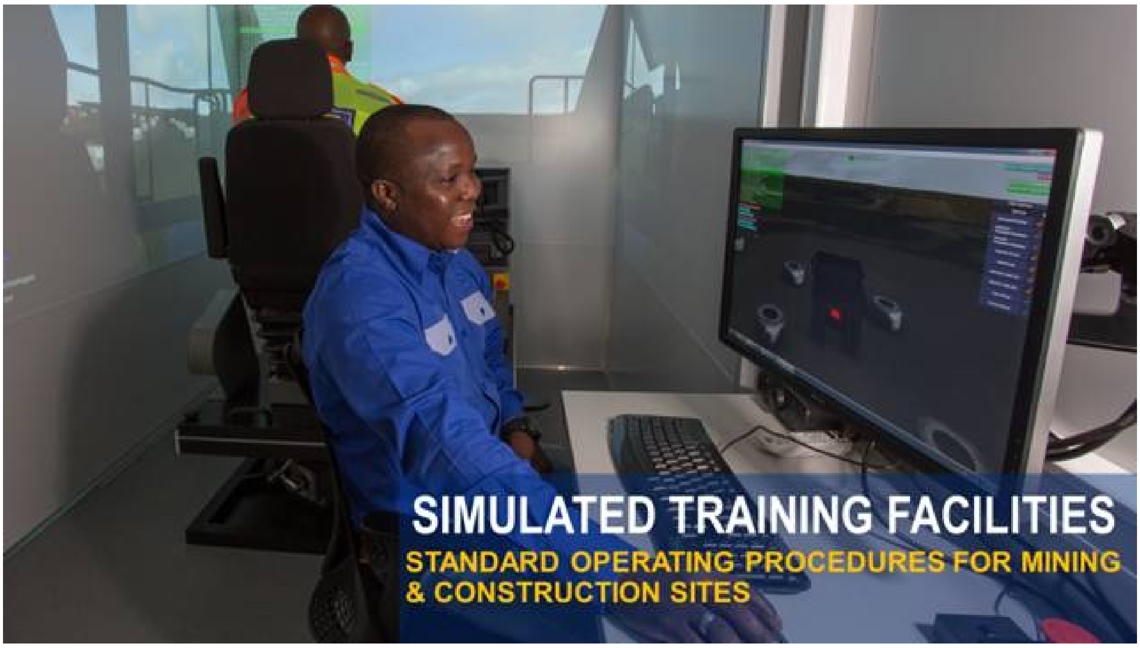


Figure 2.5: Interior of Stefanutti Stock's simulator container.

Source: Thulani Ngobeni, a training manager at Stefanutti Stocks

These simulator sets are extremely versatile as they can accommodate at least nine different equipment consoles, each of which is an exact replica of the real machine. Accordingly, they can provide simulated training for a variety of machines, including a truck. The truck console is shown in Figure 2.6.

Unfortunately, these simulator sets are extremely expensive. According to an online article published in September 2014 by *Mining Review*, titled '*Stefanutti Stocks' launches Roads, Pipelines and Mining Services training centre*', the cost to build such a simulator set was about R18-million (South African Rand) back in 2014. And, stated by Thulani Ngobeni, a training manager at Stefanutti Stocks, the software maintenance cost is around R28 000 per month. Consequently, obtaining and maintaining these simulator sets require capital investments which most companies, let alone individuals, cannot afford. This emphasises the opportunity for SATS, an inexpensive truck driving simulation game where an individual can learn the basics of truck driving in the comfort of the player's home. Depending on the player's commitment towards the game, the player might be required to buy a steering wheel, paddles and additional accessories in order to replicate the truck's cabin. However, SATS will still be more affordable, accessible and convenient for most individuals, when compared with Stefanutti Stocks' simulator sets.

Figure 2.6: Truck console used in Stefanutti Stock's simulator.

2.2.2 Part 1: Development of SATS

The first part of the suggested approach is concerned with the first few steps towards the development of SATS. This simulation game will strongly be based on ETS2, but with the exception of the South African context. This will require the creation of a South African map that can be added to the existing ETS2 simulation game in the form of a *mod*. A *mod* is a term used in video gaming as an abbreviation for *modification*. The new mod will be created using ETS2's build-in map editor and will be based on South Africa's main road network.

Creating a South African version of ETS2 requires more than South African scenery and road infrastructure, it also requires the South African experience. Most South African's would probably think that this would mean the addition of taxi's, but this is actually where the importance of motivational affordances comes to light.

Motivational affordances motivate a user to behave in a desired way, and according to Hamari et al. (2014), it is one of the key components of gamification. This is considered to be true in the case of SATS, where motivational affordances can be used to evaluate a player's truck driving competence. Specific focus will be placed on *personal awards* which can be achieved when completing specific achievements, as this is considered to be indicative of a player's experience and competence. Currently, a player can strive to achieve 60 personal awards in ETS2, many of which are Europe specific. Accordingly, the development of SATS should also include suggestions for motivational affordances, in the form of personal awards, relevant to South Africa.

The end-vision is that SATS will be able to attract a young generation to the truck driving profession, help build the player's truck and related knowledge and provide initial, inexpensive truck driving training in South Africa. To satisfy the second need mentioned, awareness of road inclination on fuel consumption should be included in the knowledge learned when playing the simulation game. This will however strongly depend on wheter or not SATS fuel consumption calculation takes road inclination into account. Consequently, the second part of this project will conduct a road grade evaluation study to determine if SATS's output is influenced by road grade. This will be discussed in subsection 2.2.3

2.2.3 Part 2: Road grade evaluation study

The suggested approach is to use SATS as a means for educating the general public about the influence of road inclination on fuel consumption. This requires an analysis to determine if the simulation game is sensitive to road grade. If sensitive, various features can be included in SATS to make the player more aware of the effect of road grade. This can include, for example, in-game notifications of the existence of a more economical route or various motivational affordances, such as personal awards for completing various uphill deliveries. The analysis will also be aimed at determining the accuracy of SATS's fuel consumption output and whether or not the game can be used for optimal route choice planning using fuel consumption. The analysis will be based on the study preformed by Tavares et al. (2009), as discussed in the literature. It is expected that the results will align with this study, as well as the results reported by Joubert (2017).

The study performed by Tavares et al. (2009) was based on heavy vehicles with masses between 7.5 to 16 tonnes, driving at a speed of 20 km/h. However, the heavy vehicles used in the simulation game are much heavier, weighing between 16 to 32 tonnes and the chosen driving speed, for the purpose of this project, will be 60 km/h. Fuel consumption is heavily dependent on these two factors. Accordingly the fuel consumption equation (2.4) will have to be recalculated for the new vehicle classes, based on the data provided by Ntziachristos and Samaras (2000), as used by Tavares et al. (2009).

In the study performed by Tavares et al. (2009), each road in the 3D model created was represented with an arc. These arcs varied in length, as well as the number of segments depending on the number of road inclination changes. The optimal route was then determined by combining various arcs (roads). However, in the road grade elevation study, the arcs used will be of equal 2D length and consist of the same number of segments with varying inclination. This will ensure comparability between the various arcs. The amount of arcs used will depend on the restriction of the road grade correction factor's variable, x_{ki}, where k refers to a specific arc and i to a specific segment, as defined in the literature.

Also, it is known from the literature that road inclination will lead to higher fuel consumptions and as a result, it is expected for the arcs' fuel consumption to increase accordingly. This means that the optimal arc is expected to be the arc with zero inclination, thereby creating no need for (2.5).

In order to determine if SATS's output is sensitive to road grade, the theoretical fuel consumption for each arc must be compared with the simulation game's fuel consumption output. This will require the mapping of each arc in SATS and afterwards, a truck must be driven on each arc to obtain various in-game output, such as fuel consumption. If found sensitive, SATS could be used to create awareness of the effect of road grade on fuel consumption and how this could lead to fuel cost savings.

It is believed that SATS is an appropriate educational tool and will be successful in addressing the two needs mentioned, due to the implementation and effectiveness of gamification in an educational context. This will be discussed in section 2.3.

2.3 Effectiveness of gamification

A study performed by Fitz-Walter et al. (2017) aimed to determine the effects of gamification on behavioural changes, user motivation and user experience. This study investigated the use of a gamified logbook smartphone application for learner drivers in Queensland, Australia, where learner drivers are obligated to undertake a minimum of 100 hours of supervised driving training. Learners drivers can use this application to record their driving practice with their smartphones, instead of manually completing a logbook after each practice session. In this study, two versions of the application were created: a gamified version, where learner drivers are encouraged to take a virtual road trip through Australia while receiving virtual coins (motivational affordance) when progress is made, and a non-gamified version. Twenty-five participants were selected to take part in the field study and each participant was instructed to use each application version for two weeks. Afterwards, the students completed questionnaires and interviews, which led to the following results:

- The gamified version was perceived to be the most *enjoyable* version, indicating increased positive user experience. Only one student reported a negative experience and the remainder of students were neutral.
- The gamified version was perceived to be more *motivating* by 16 students and demotivating by 3 students.
- A 28.6% increase in the mean time spent practising was obtained when using the gamified version compared with the non-gamified version. This difference was however declared statistically insignificant, meaning that gamification did not result in improved behaviour. The authors state that these results might be due to factors outside the control of the students, such as supervisor availability, cost accompanying driving lessons, available practice time and other external factors. Additional factors could be the short timespan and small sample size used by the study.

The impact of external factors on the statistically insignificant difference in mean time spent practising is unfortunately unknown. Consequently, the study can only be used to conclude that gamification can result in increased psychological outcomes.

The effect on behavioural change is however evident in a case study completed by Yildirim (2017), which aimed to determine the effect of gamification-based teaching practices on student achievements. The author concluded that gamification is most effective in an educational context and can lead to significant academic and behavioural improvements and favourable psychological outcomes.

The results from the above-mentioned studies are not isolated cases as Hamari et al. (2014) investigated 24 empirical studies on gamification and found that the majority reported positive effects and benefits. Accordingly, the author agrees that gamification can provide positive outcomes, but adds that these outcomes are influenced by the context and users of the gamification platform. It is therefore believed that gamification has the potential to contribute significantly to the success of this project with the development of SATS, a simulation game with an educational context. The aimed behavioural outcome of the game is to improve truck driving competence and knowledge while the psychological outcome is to expose and motivate the young generation to participate in the truck driving profession.

Regrettably, concerns about gamification do exist and it is therefore noteworthy to be mindful of the following: the positive outcomes obtained in some of these studies might not be long-term but only due to the novelty effect (Hamari et al., 2014). The *novelty effect* is a term used to explain short-term performance improvements due to the introduction of a new tool or technology. Also, gamification can result in increased player competitiveness that might lead to cheating (Fitz-Walter et al., 2017).

According to Nick Pelling, the person who coined Gamification, there are two aspects that will influence the success of gamification. In his presentation at the Gamification World Congress in May 2014, titled '*Gamification, past and present*', he described these two aspects as follow:

- *Digital content platform*: The distribution of electronic content over the internet, or any other online delivery medium.

- *User experience design*: The ease with which a user can interact with a product and the satisfaction obtained accordingly.

The second aspect indicates the importance of the player's satisfaction for the successful implementation of gamification. Since the simulation game will be based on South Africa, some player's might be dissatisfied if the game does not actually replicate the country's transportation network. For this reason, South Africa's main transportation network will be identified in section 2.4.

2.4 South Africa's transportation network and freight flow

Havenga and Pienaar (2012) developed a National Freight Flow Model (NFFM) for South Africa in 2004, using truck traffic counts obtained from SANRAL. The model used four transport typologies to divided the freight market, as defined in Table 2.3. Note that rail export machines are concerned with rail transport and therefore beyond the scope of this report.

Table 2.3: Transport typologies (Havenga and Pienaar, 2012)

Transport typology	**Distance**	**Traffic type**
Corridor	Long and Short	Mostly manufacturing
Rural	Medium to short	Mostly agriculture
Metropolitan	Short	Mostly final deliver
Rail export machines	Long	Low-value, bulk

According to Havenga (2013), South Africa's surface freight transport had a demand of 178 billion ton/km in 2011, of which 57% was due to road corridor transport. Also, corridor logistics costs accounts for approximately 75% of logistic costs with road corridor transportation contributing to 89% of *total* corridor transportation. It is for this reason and the fact that corridors span across the entire country, that corridors are considered to be extremely important for the backbone of South Africa's transportation network.

Figure 2.7 shows the main corridors, their relative size and expected ton/km growth from 2011 to 2041. The two major corridors are Gauteng–Cape Town and Gauteng–Durban.

Metropolitan areas are also of concern for this report, as it relates to to the major cities in the country. Gauteng is the country's main demand centre and metroplitan area. It is estimated that 82% of the corridor freight travels through this city. The other metropolitan areas identified by Havenga (2013) are Cape Town, Durban, Bloemfontein, Port Elizabeth, Witbank and East London.

To enhance the NFFM model, Havenga (2013) developed a commodity flow model (CFM) that indicates the commodity composition of freight flow in South Africa. In 2011, the commodity demand within South Africa totalled 62 million tons. The truck commodity composition for 2011 and expected growth is shown in Figure 2.8. This figure indicates that almost a quarter of freight transported in South Africa is fast moving consumer goods (FMCG), which include beverages, food, pharmaceuticals, textiles and tobacco. The dominant commodities for specific routes are listed in Table 2.4.

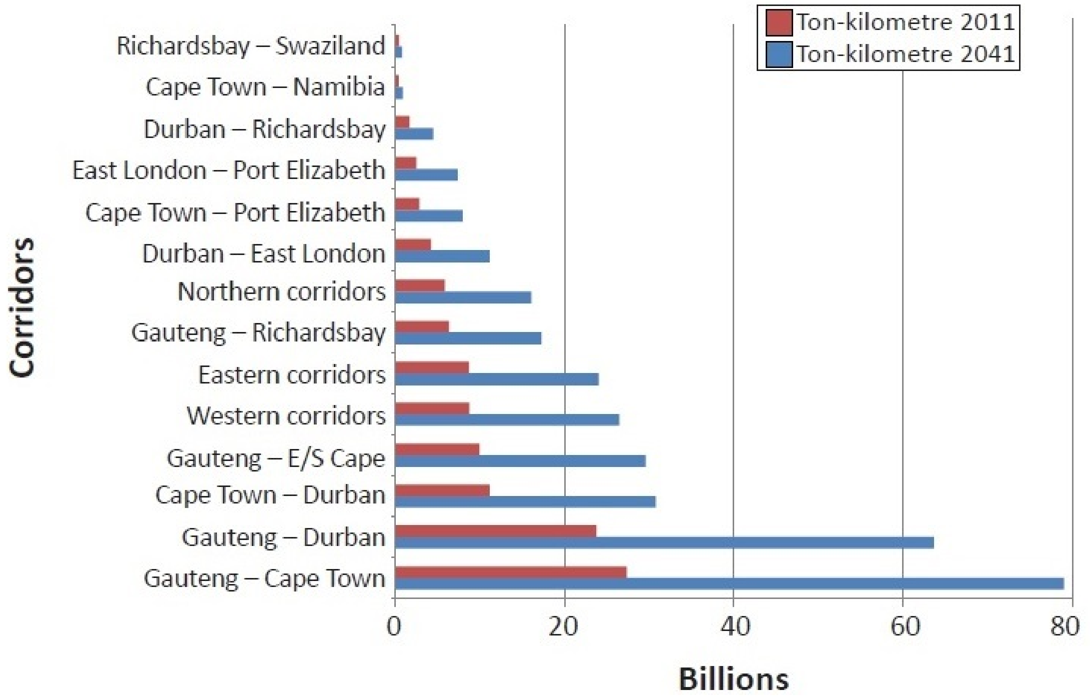


Figure 2.7: Corridor growth and relative current size for 2011 vs. 2041 (Havenga, 2013).

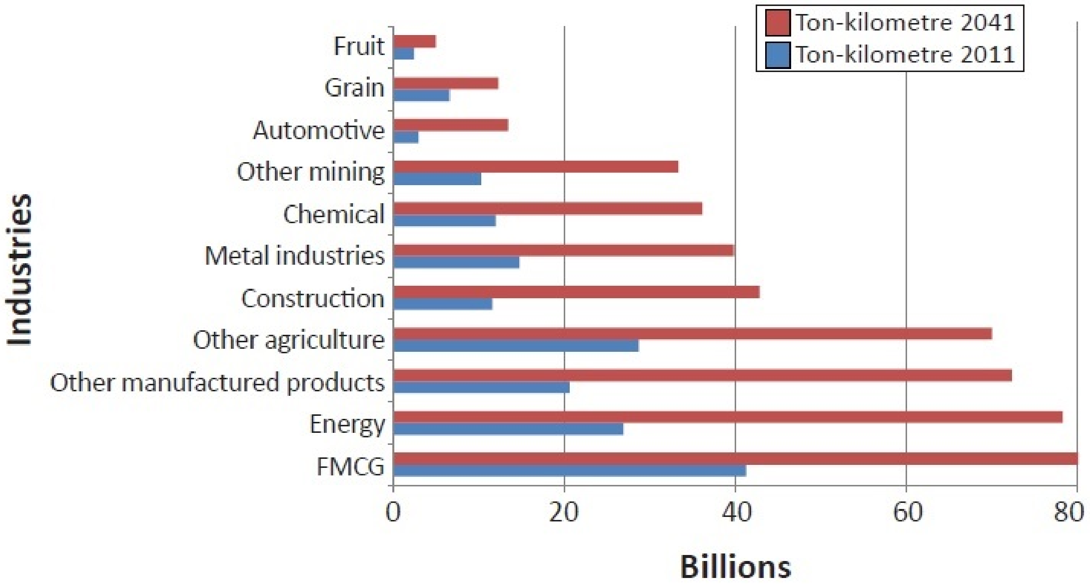


Figure 2.8: South Africa's commodity demand growth for 2011 vs. 2041 (Havenga, 2013).

Table 2.4: Domininant commoditiess for major network sections as obtained from the *National Transport Master Plan 2050 Synopsis report*

Network section	**Freight commodities**
Gauteng–Durban	Containers, steel, cars, coal, manganese, fuels, perishables
Gauteng–Cape Town	cars, grains, containers, perishables, cement, steel
Gauteng–Musina	Foods, fuels, vehicles, cements, perishables, beverages
Gauteng–Tlokweng	Fuels, cement, containers, vehicles, food
Gauteng–Ressano Garcia	Mineral ore, fruit, sugar, timber cars, paper
Cape Town–Namibia	Fish, containers, fertilisers, cement, machinery
Cape Town–Port Elizabeth	Cars, fuels, fruit, perishables, steel, tyres
East London–Durban	Beverages, foods, fuels, vehicles
Durban–Pongola	Containers, fuel, chemicals, timber
Winburg–Harrismith	Maize, livestock, perishables, steel, containers
Gauteng–Upington	Foods, cement, steel, machinery, chemicals, perishables
East London–Bloemfontein	vehicles, steel, grains
George–Colesberg	Fuels, grains, perishables
Britstown–Nakop	Food, cement, steel, machinery, cars, perishables
Gauteng–Swaziland	Beverages, cement, coal, vehicles, grains, sugar
Thaba Nchu–Maseru	Containers, fuel, cement, rains, coal, foods
Ermelo–Richards Bay	Coal, steel, timber, chrome
Sishen–Saldanha	Iron ore, lead

Chapter 3

Model

The development of the South African map in Euro Truck Simulator 2 (ETS2) and related information is given in section 3.1. Afterwards, the road grade evaluation analysis model is explained in section 3.2.

3.1 Part 1: Development of SATS

The key component of the South African Truck Simulator (SATS) is the development of an alpha version of the South African map using ETS2's build-in map editor. The map, or more formally, the model, must be a realistic depiction of the country. This requires attention to detail, such as proper object elevation, recognisable intersections and common South African features and landmarks. But due to the complexity and scale of the SATS map, it is however not possible to include all of South Africa's 535 000 km of proclaimed road network (Viljoen, 2013).

Figure 3.1 depicts the roads network that will be mapped in the alpha version of SATS. This road network consists of all the corridors identified in the literature, as well additional national routes to increase the accessibility of the map. The main cities that should be included in future versions of the map are the metropolitan areas as listed in Table 3.1, along with their respective elevation as obtained from *worldatlas.com*. Note that Pretoria and Johannesburg is included instead of Gauteng.

Table 3.1: Main South African cities and their elevation values (Havenga and Pienaar, 2012)

	City	**Elevation [m]**
1	Pretoria	1,332
2	Johannesburg	1,767
3	Witbank	1,629
4	Bloemfontein	1,396
5	Durban	21
6	East London	48
7	Port Elizabeth	37
8	Cape Town	25

The first step of the map development is to insert a background image of South Africa and important routes as a background image in the South African map. This will provide

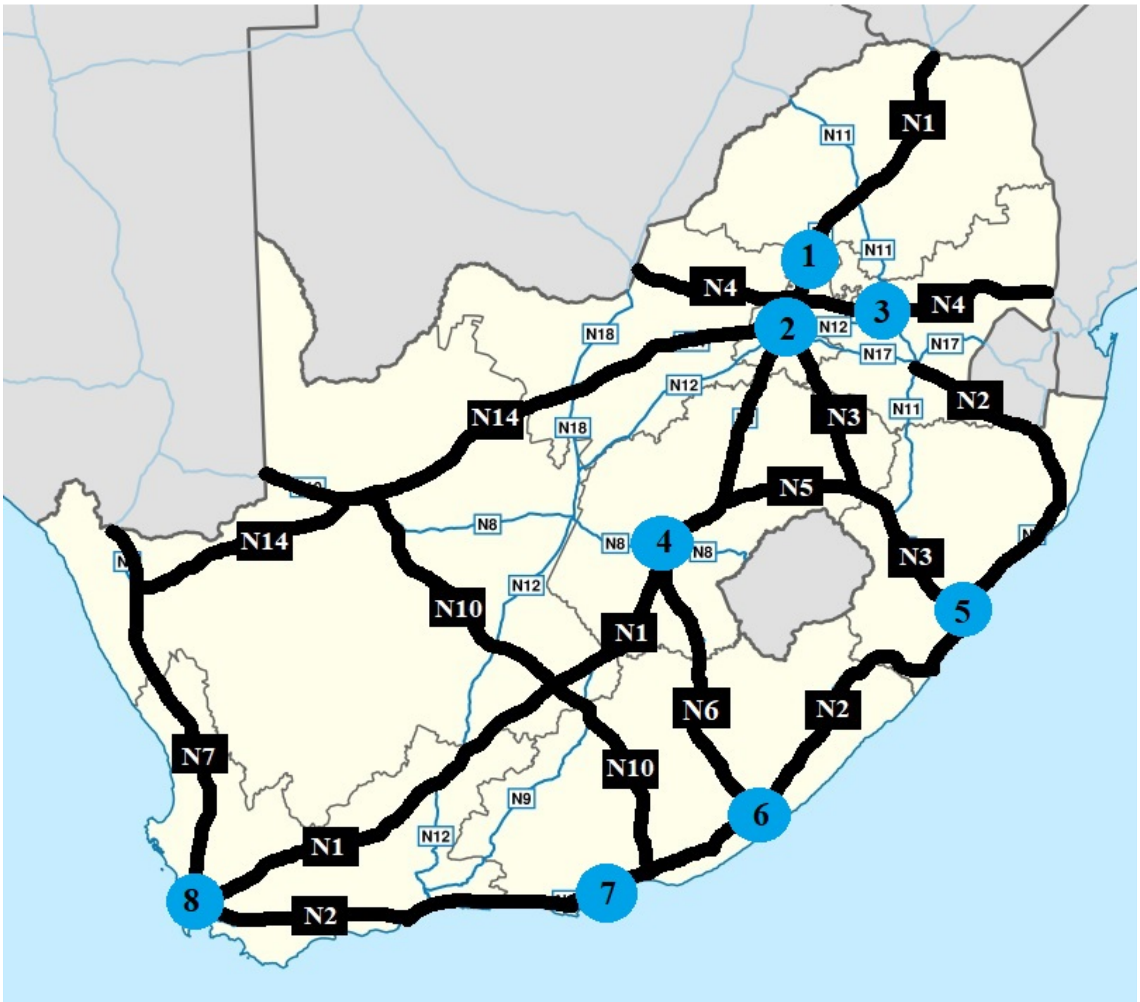


Figure 3.1: Backbone of SATS's road network

ease of mapping, since the background image could be traced to ensure correct road placement and flow. Details regarding the actually mapping and how it works, is captured in the TruckSim Wiki and additional information concerning the development of the model is discussed below in the respective subsections.

3.1.1 Map scale in ETS2

Two scales are used in the ETS2's map editor, a normal-scale and a city-scale. The city-scale applies inside the perimeters of a city and the normal-scale applies for the remainder of the map. The use of two scales allows more detail to be added inside a city. These scales influences the time and total distance travelled. In other words, when a truck travels on a road segment of length 1 km, the truck's odometer will increase with 1 km times the applicable scale value and the time elapsed will also be a function of the applicable scale value. Too maintain consistency between ETS2 and SATS, the default scale values were used, hence the normal scale is 1:19 and the city-scale is 1:3.

Although initially thought to be trivial, the map scale will have a significant impact on the project, especially on fuel consumption calculations. The reason being that the scale does not influence the actual size of the components inside the map, but only the distance travelled by a truck. If an actual road segment is of length 190 km, it should be drawn as a

Figure 3.2: Bridge of height 8 m as mapped in SATS.

road of length 10 km in SATS, when the normal-scale is applicable. Similarly, a city with an elevation of 38 km should be mapped with an elevation value of 2 km. Thus, one would expect a bridge of height 8 metres to be drawn as 0.421 m in SATS, yet this is not the case. The problem is illustrated with the bridge shown in Figure 3.2. Since the components, in this case the two trucks, are not sized according to the applicable scale, the height of the bridge must remain 8 m in order for the trucks to fit underneath. This results in longer road segments leading to the top of a bridge that can impact fuel consumption estimates.

3.1.2 Included Intersections

A variety of intersection typologies can be found when driving on South Africa's national roads, including various deviations from the flying-saucer intersection. Most of these intersections are however unique and distinctive to certain locations in South Africa. For this reason, each intersection should be mapped as correctly as possible. This will help South African truck drivers to familiarise themselves with the actual South African road network, as discussed in section 2.2.1. Care should also be given to ensure that each intersection is mapped at its true elevation level. Not only will this improve the genuineness of SATS, but it will also be valuable when using the simulation game as a means for estimating a route's fuel consumption. The latter is however dependent on the ability of SATS to include road grade in the game's fuel consumption calculations.

Unfortunately, the intersections will be influenced by the scale used. Figure 3.3 illustrates the relative size of an intersection against Cape Town. The actual intersection measures 600 meters in width. The intersection is also drawn at its smallest possible size, with a width of 600 meters inside SATS, but due to the components not being scaled, the intersection will be much larger in-game than reality. This increases the complexity of mapping the South African map, as more planning is required to ensure that all the chosen roads and intersections will be able to fit inside the map without overlap.

Figure 3.3: Top view of a portion of the South African map which highlights the size of an intersection relative to the size of Cape Town.

3.1.3 Personal Award suggestions

Personal awards obtained when completing certain activities is though to be a good indication of a player's truck driving competence. Since most of the existing awards are only relevant to Europe, new awards must be suggested that will aid in measuring the competence of a truck driver in South Africa.

A few of the personal awards already in ETS2, but relevant to South Africa, include the use of automatic parking, using a filling station to fill up the fuel tank and using a rest stop. These awards are aimed at motivating the player to learn the operations of the game. A player can also obtain two other awards by exploring 60%, followed by 100% of the map, which encourages a player to familiarizes him or herself with the routes available. Additional awards that can be seen as incentives for the player to improve his or her (virtual) truck driving competence is given below:

- Complete a delivery that was greater than 2,000 km.
- Complete a perfect delivery (no damage, no fines, in-time) for a job that is at least 1,000 km.
- Complete 5 jobs in a row without taking any damage to cargo and without using

auto-parking.

- Take and complete jobs with at least 30 different cargo.
- Preform jobs for at least 15 different companies.
- Complete a perfect delivery (no damage, no fines, in-time) of 3 consecutive Heavy Cargo Pack jobs.

Personal awards that are only relevant to Europe include the discovery of all Italian cities, entering Rome from all the possible corridors leading to it, completing delivery jobs to all quarries in Scandinavia and discovering a list of landmarks in France. Since these awards do not apply to South Africa, a few suggestion for South African related awards should be given.

3.2 Part 2: Road grade evaluation study

The road grade evaluation study will be used to determine the fuel consumption accuracy of SATS. This will require theoretically calculated fuel consumption estimates and actual game-play fuel consumption outputs for each arc, as explained in subsection 3.2.1 and subsection 3.2.2 respectively. The arcs that will be used in both subsections are described in detail below:

A set of arcs, consisting of three segments each, will be used in this study. Figure 3.4 illustrates the basic structure of an individual arc, arc k. The main focus is to determine the fuel consumption for segment BD only. Segments AB and DE will only be included in subsection 3.2.2, where the fuel consumption is determined using SATS. The reason for the inclusion of these two segments is to ensure that the truck drives the entire BD-segment. This will be explained further in the relevant section.

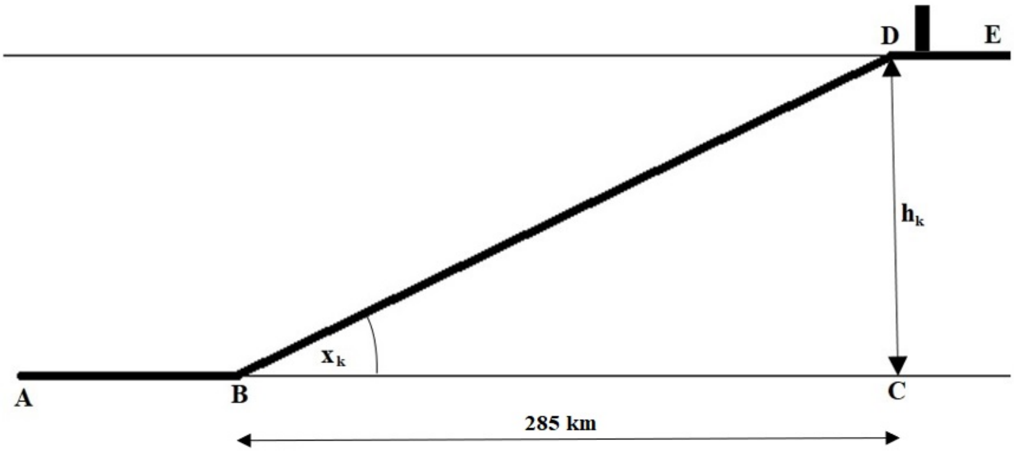


Figure 3.4: Graphical representation of an individual arc.

The length of Segment BC will be kept constant at a distance of 285 km. This distance was chosen to ensure proper opportunity to obtain fuel consumption differences, if any. Accordingly, the actually distance travelled, L_k, represented by segment BD, will vary depending on the slope percentage, x_k, of arc k. The slope percentage, x_k, and therefore the height, h_k are the controlled variables in this study and will be different for every arc. The slope percentage is however restricted to be in the range of (-15% ; 15%), exclusive of bounds. Consequently, h is restricted to be in the range of (-42.75 km; 42.75 km) calculated using 3.1.

$$x_k = \frac{h_k}{\text{Segment } BC} \tag{3.1}$$

It was decided that 9 arcs, with a height difference of 10 km between successive arcs, will be used. Details for each individual arc is given in Table 3.2. It is also necessary to keep the speed, V, and the load factor, LP constant to ensure comparability. A speed of 60 km/h will be used throughout the study. The load factor will be set to zero due to the truck used for simulations runs in SATS not having a trailer.

Table 3.2: Information for each indivual arc of the road grade evaluation study.

	Arc (*k*)								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
x_k **[%]**	-14.0	-10.5	-7.0	-3.5	0	3.5	7.0	10.5	14.0
h_k **[km]**	-40	-30	-20	-10	0	10	20	30	40
L_k **[km]**	287.79	286.57	285.70	285.18	285	285.18	285.70	286.57	287.79

3.2.1 Theoretical fuel consumption estimates

This subsection focuses on creating an equation to estimate the theoretical fuel consumption for each arc, based on Tavares et al. (2009)'s study. Note that segments AB and DE is not required in the calculation, as they have no impact on the fuel consumption calculation for the inclined segment. Accordingly, an arc will only consist of segment BD.

As defined in the literature, (2.1) will be used to calculate the fuel consumption rate for each arc. Since the trucks in the simulator are in a heavier weight class (16 to 32 tonnes), equation (2.2) cannot be used and new formulas must be obtained for the *basic fuel rate* (FCS_k) and *road grade correction factor* ($GrCF$). Also, due to the arcs in this study only consisting of a single segment, (2.1) and (2.4) are combined, as shown in (3.2).

$$fc_k = L_k \times [FCS_k \times LCF_k \times GrCF_k]\,, \forall\ k \in [1;9] \tag{3.2}$$

The *arch length*, L_k, is dependent on the slope percentage of the respective arc, x_k, as well as the length of segment BC. Using Pythagoras, the length of segment BD can be calculated with (3.3).

$$L_k = 285\sqrt{1 + \left(\frac{x_k}{100}\right)^2}, \forall\ k \in [1;9] \tag{3.3}$$

For heavy duty vehicles weighing between 16 to 32 tonnes, the *basic fuel consumption rate* (FCS_k) can be calculated using (3.4), as obtained from Ntziachristos and Samaras (2000). Note that the speed of the vehicle must be between 59 to 100 km/h for this equation to be valid.

$$FCS_k = 0.0382V^2 - 5.1630V + 399.3, \forall\ k \in [1;9] \text{ and } V \in [59;100] \tag{3.4}$$

The equations for the *load correction factor*, LCF_k, and *load percentage*, LP, is the same as used in the literature and is combined to form (3.5).

$$LCF_k = 1 + 0.36\left(\frac{Load_{actual}}{Load_{max}} - 0.50\right),\ \forall\ k \in [1;9] \tag{3.5}$$

The *road gradient correction factor*, $GrCF$, is also dependent on the weight of the truck. Consequently, the $GrCF$ values from Figure 2.2 cannot be used and therefore new values must be calculated for the required weight class. To do so, the same methodology as followed by Tavares et al. (2009) to obtain the $GrCF$ equation used in the literature, will be followed.

Table 3.3 categorizes slope percentages into four categories, along with the respective maximum speed and gradient factor functions. This table, along with (3.6) is then used to determine the $GrCF$ value for each slope percentage category. As stated earlier, a speed of 60 km/h will be used, however, if the chosen speed exceeds the maximum speed of the slope percentage category (V_{max}), the given maximum speed should be used instead.

Table 3.3: Gradient factor function for fuel consumption of heavy duty vehicles weighing between 16t to 32t (Ntziachristos and Samaras, 2000).

x [%]	V_{max}	**A5**	**A4**	**A3**	**A2**	**A1**	**A0**
-6...-4	49.9	-1.22E-07	2.03E-05	-1.3E-03	3.94E-02	-5.70E-01	3.75E+00
-4...0	86.1	8.55E-01	-4.74E-03	5.76E-05	-2.58E-06	2.91E-08	-8.24E-11
0...4	64.7	1.45E+00	-1.96E-02	2.06E-03	-6.74E-05	9.93E-07	-5.25E-09
4...6	36.5	1.07E-01	3.69E-01	-2.31E-02	6.55E-04	-6.69E-06	00+E00

$$GrCF = A_0 + \sum_{j=1}^{5} A_j V^j \tag{3.6}$$

The calculated $GrCF$ values for each category is plotted alongside the category's median slope percentage value, illustrated in Figure 3.5. In order to obtain $GrCF$ values for a wider slope percentage range, a regressions line was fitted to these four data points. The line's equation is represented with (3.7). For slope percentage below approximately -5%, negative $GrCF$ values are obtained, which in turn will result in a negative fuel consumption. Intuitively, this seems impossible. However interpreting the negative sign differently could indicate that driving on a specific *downwards* slope, can result in a fuel consumption greater than zero. Consequently, the absolute values of (3.7) should be used.

$$GrCF_{(x)} = 1.194710 + 0.286847x + 0.00785x^2 \tag{3.7}$$

In the liturater study, Tavares et al. (2009) fitted an exponential function to the four data points. However, in this case, it was found that the quadratic polynomial function was a better fit, resulting in a multiple R-squared value of 0.9932 and a low p-value of 0.08223. When fitting a exponential function, a lower multiple R-squared value of 0.7862 was obtained. Consequently, the quadratic polynomial in (3.7) is the best fit and can explain 99.3% of *road gradient correction factor*'s variance with the controlled variable,

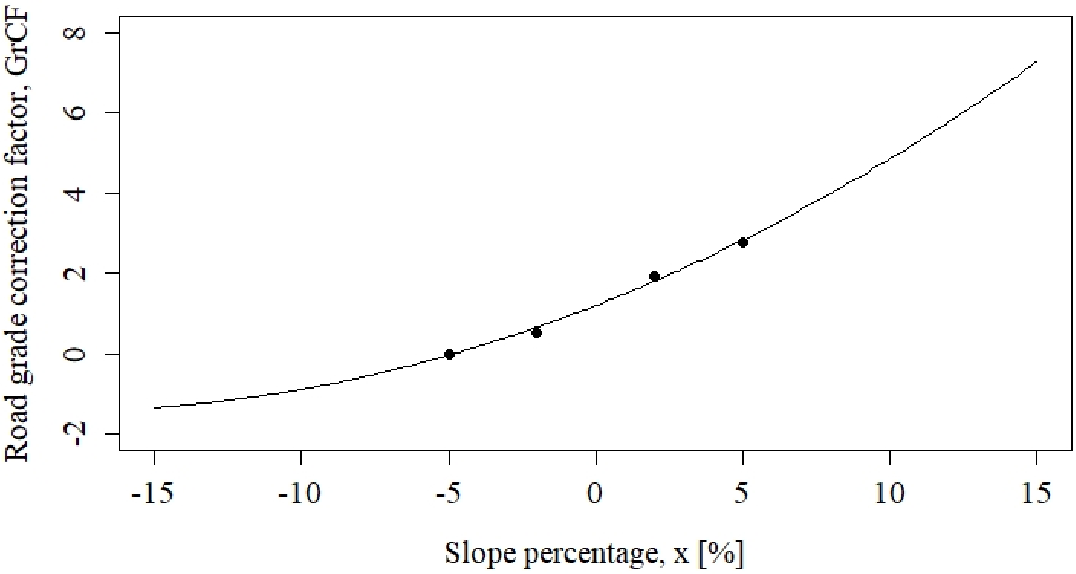


Figure 3.5: Fitted line Road gradient correction factor values for heavy vehicles weighing 16 to 32 tonnes.

x. It should be noted that a linear model and a cubic model was also fitted. The linear model resulted in a slightly less multiple R-squared value. The cubic model's multiple R-squared value was however slightly higher than the quadratic model's value, but, when plotting the cubic function it was found that a slope of 5% had a higher fuel consumption than a slope of 10%, which is highly unlikely.

For simplification, (3.3), (3.5) and (3.7) are combined with (3.2), along with the substituation of constant parameters, to form (3.8). The constant parameters include the speed of the truck, which will be kept constant at 60 km/h, and the LP value. Due to the limitations of the testing capabilities of ETS2's build-in map editor, the truck used in the simulation runs will be without a load, resulting in a LP of zero percent.

$$\begin{aligned} fc_k &= L_k \times FCS_k \times LCF_k \times |GrCF_k| \\ &= 53059.25\sqrt{1+\left(\frac{x_k}{100}\right)^2} \times |1.194710 + 0.286847x_k + 0.00785x_k^2| \end{aligned} \tag{3.8}$$

Although (3.8) can be used to calculate the theoretical fuel consumption for arc k, the result will be given as the total *grams* of diesel consumed. For comparability purposes, the equation should thus be converted to the total *litres* consumed. This is achieved using the density of diesel, 845 kg/m^3, obtained from Ntziachristos and Samaras (2000), which is equivalent to 845 grams/ℓ. The converted equation is shown in (3.9) and the equation output, fcL_k, is the theoretical amount of *litres* of diesel consumed when traversing arc k with a 16 to 32 tonne heavy vehicle.

$$\begin{aligned} fc_k &= L_k \times FCS_k \times LCF_k \times GrCF_k \\ &= 62.79201\sqrt{1 + \left(\frac{x_k}{100}\right)^2} \times \left|1.194710 + 0.286847x_k + 0.00785x_k^2\right| \end{aligned} \tag{3.9}$$

The converted equation will be used to calculate the *theoretical fuel consumption* for each arc. The results will be compared with the results obtained form the SATS's simulation runs in order to determine if the simulation game's output is sensitive to road grade.

3.2.2 SATS's fuel consumption output

To obtain fuel consumption output, each arc is mapped with the correct height and length in SATS. Due to the normal-scale of 1:19 used in the simulation game, each distance must be scaled down. This means that segment BC must measure 15 km in the map editor, but will represent a distance of 285 km on the truck's odometer.

Segments AB and DE will be included to provide a start and end point for the truck in the actual simulation. This ensures that the the truck's entire body completes segment BD, as this could influence the fuel consumption output. The length of these two segments are slightly larger than the length of the truck and the fuel consumption outputs when traversing these two segments are negligible. A wall is placed at the end of segment DE as this will prevent the truck from falling into darkness and will ensure that the truck reaches standstill at the same location for each arc. Without the wall, the truck must be brought to rest manually, which can result in discrepancies and human error.

A screen-shot of some of the arc's mapped in SATS is given in Figure 3.6. The sunflower field represents the start of segment BC of *arc 5*, the arc with 0% inclination. Accordingly, the asphalt terrain before the sunflower field represents segment AB. Note that *arc 6* to *arc 9* are visible in the background, emphasising inclination differences between the arcs. Unfortunately, due to the limitations of ETS2's map editor, the entire arc cannot be captured in a single picture and therefore only parts thereof are visible in the figure, in this case, the starting position.

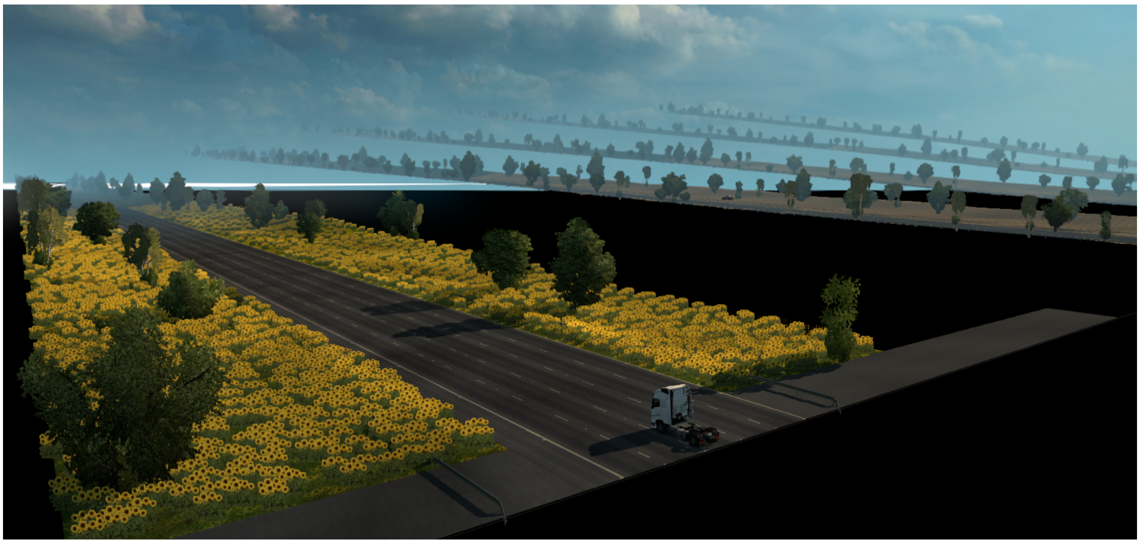


Figure 3.6: View of arc's mapped in SATS

The SATS fuel consumption model consist of the 9 arc's defined earlier and various simulations runs must be preformed to obtain the required fuel consumption output using telemetry. A simulation run is considered to be the act of driving a truck, at a speed of 60 km/h, on a specific arc in SATS and while recording the relevant outputs. For every arc, the simulation must be performed three times. The averages of the simulation runs will be used as the final SATS fuel consumption output for the respective arc.

Unfortunately, ETS2 does not provide access to game-play information other than the limited and unusable information visible on the truck's dashboard. This creates a need for telemetry. In simple terms, telemetry is the automatic collection of data which is not normally accessible. Telemetry can be applied to SATS by adding an additional program to the existing game. Adding telemetry will provide various data outputs such as the truck's odometer, fuel consumed and average fuel consumption for the specific distance travelled, to name a few. The telemetry program stores each variable's output in a `*.csc` file for every time stamp measured and will have to be analysed to obtain the required information. Further detail concerning telemetry is beyond the scope of this report.

Chapter 4

Results and discussion

The results obtained from the two separate parts of the project is given and discussed in the respective section.

4.1 Part 1: Development of SATS

The first part of the project was concerned with the development of an alpha version of the South African Truck Simulator (SATS). This includes the development of the South African map, as well as motivational affordance suggestions related to South Africa.

4.1.1 The South African map

An alpha version of the South African map, in the form of a *mod*, was created using Euro Truck Simulator 2 (ETS2)'s build-in map editor. The goal was to map the backbone of South Africa's main transportation network, as shown in 3.1. The main focus was the road intersections, as they are the connecting nodes of transportation network. Consequently, special attention was given to each intersection in order to ensure that it is a realistic representation of the actual, real-life intersection. A realistic representation requires more than physical resemblances, it also requires proper elevation and placement of each intersection. Unfortunately, the map editor is limited and therefore restricted the ability to ensure 100% resemblance.

ETS2's build-in map editor can be compared with Lego. A Lego builder has a variety of blocks that can be used to build various structures. These blocks are however only available in certain sizes, forms and colours and their usability is restricted in certain ways. For instance, to build two blocks on-top of each other, their connecting interfaces must be complementary and compatible, indicating that only Lego of the same size could be used and only in a *head-to-tail* connection. Additionally, the Lego builder must use innovation and allow certain trade-off's to compensate for the unavailability of certain building blocks. The same holds true for ETS2's build-in map editor. The map editor has a huge selection of roads, terrains, prefabricated road components and decor, which can be used to build a map. Unfortunately, just as in Lego, not all of these components are compatible with the required usage. In the instance of SATS, the components must accommodate left-hand traffic, which is in contrast with Europe's right-hand traffic. Due to this constraint, only a small subset of map components from the ETS2 component library, could actually be used for the South African map. This increased the difficulty to map an intersection to replicate its real-life counterpart as some of the crucial components are not available in the small subset. This resulted in some visual discrepancies between the mapped intersection and its real-life counterpart.

The remainder of this subsections includes various figures to showcase some of the intersections and extra features mapped in SATS. Most of these figures include a picture of the actual intersection as obtained form *Google Maps*, that can be used as reference to evaluate the structural resemblance. Although initially stated that prettifying of the map is beyond the project scope, effort has been given to add decor to the intersections of the N1. This had a significant impact on the aesthetics and genuineness of the N1 and shows the importance of the visual aspect of gamification. Additional, a video containing all the mapped intersections of the N1 and can be viewed on YouTube.

The first intersection when driving from the Cape Town on the N1, is the N1 and N2 intersection. This intersection boasts with two great views, one of which is Cape Town's main feature, Table Mountain. It therefore goes without saying that this famous landmark should be included in the simulation game. Fortunately, the ETS2 component library has a few mountains that can be used for decorative purposes, one of which is used to represent Table Mountain, as seen in Figure 4.1. The second view worth mentioning is shown in Figure 4.2. This figure shows the sea view on the right hand side of the road. Note that Table Mountain is located on the left but not visible in this specific figure.

```
pause
pause
Creating save-game file (/home/preview_profiles/70726576696577/save/autosave_drive/preview.sii) ...
Game has been auto-saved.
```

Figure 4.1: View of Table Mountain when driving on the N1 and N2 intersection in SATS.

The top view of the N1 and N7 intersection is given in 4.3. It is evident from this figure that the mapped intersection has a good structural resemblance of the actual intersection. The horizontal main road does however appear to be thicker than required, but this is due to the components necessary that ensures smooth transitions from two lanes to five lanes, and therefore cannot be avoided. Also, the background terrain of the mapped intersection appears to be too orange, but as seen in the two additional views, the background terrain can be considered realistic. Two additional views of this intersection is included in Figure 4.5 and Figure 4.4. The first figure shows the the actual bridge along with the mapped bridge found at the N1 and N7 intersection. The second figure illustrates some of the decor, in this case houses, added to improve the aesthetics of the intersection.

Figure 4.2: The sea view of the N1 and N2 intersection mapped in SATS.

Figure 4.3: Top view comparison of N1 and N7 intersection.
Source: Google Maps, 33°53′15.4”S18°31′51.7”E, accessed 25 Augustus 2018.

Figure 4.4: Additional view of the N1 and N7 intersection.

Figure 4.5: Bridge view comparison of N1 and N7 intersection.
Source: Google Maps, $33^\circ53'15.4"S18^\circ31'51.7"E$, accessed 25 Augustus 2018.

The top view of the N1 and N10 intersection located in Hanover, is showen in 4.6. A reddish background was considered to be the most accurate choice. Although the actual landscape near this intersection is extremely flat with no prominent mountains, it was decided to add a few mountains for visual appeal, as seen in Figure 4.7.

One of the most complex intersection's mapped is shown in 4.8. The reason for being complex is that this intersection has three roads on top of each other, thereby requiring a bridge on-top of a bridge, visible in Figure 4.9. An additional view of this intersection is included as Figure 4.10.

The remainder of the mapped intersections can be viewed in Appendix A.

Figure 4.6: Top view comparison of the N1 and N10 intersection.
Source: Google Maps, 31°04′30.3”*S*24°25′58.0”*E*, accessed 25 Augustus 2018.

Figure 4.7: Additional view of the N1 and N10 intersection mapped in SATS.

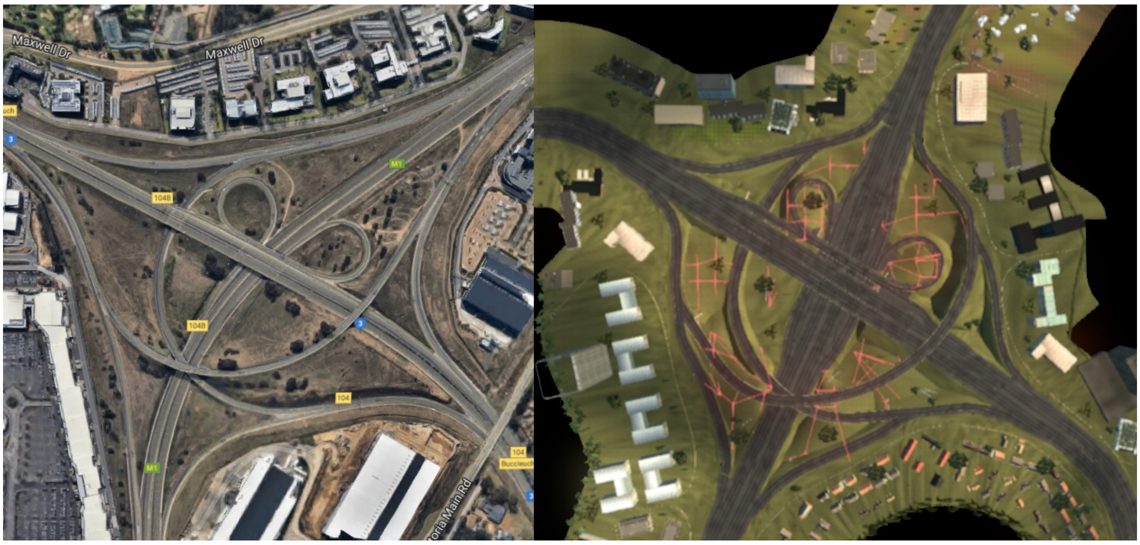


Figure 4.8: Top view comparison of the N1 and N3 intersection.
Source: Google Maps, 26°02′50.5”*S*28°05′42.1”*E*, accessed 25 Augustus 2018.

Figure 4.9: View of the bridge on-top of a bridge complexity of the N1 and N3 intersection.

Figure 4.10: Additional view of the N1 and N3 intersection mapped in SATS.

4.1.2 Personal Award suggestions

As stated, creating a South African version of ETS2 requires more than South African scenery and road infrastructure, it also requires the South African experience. Accordingly, a list of personal awards are listed below that could increase the South African experience when added in the future development of SATS. The suggested awards include:

- Visiting popular landmarks, such as Table Mountain and the Voortrekker Monument.
- Visit all the capital cities of the country.
- Enter the Kruger National Park from all the possible gates leading to it.
- Complete a delivery of each of the Big Five game (lion, leopard, elephant, rhinoceros and the Cape buffalo).
- Complete charcoal deliveries from all the charcoal mines.
- Complete a delivery from Cape Town to Pretoria.
- Complete a perfect delivery while driving on Van Reenen's pass.
- Cross all the main rivers in the country.
- Deliver heavy cargo to farmers such as irrigation equipment, trucks, silo's and other farming equipment.
- Complete a just-in-time delivery of fruits and vegetables from a farmer to a farmer's market.
- Complete a delivery in each of the nine provinces.

Some of these awards are only focused on familiarizing the player with the South African environment, whereas others are aimed at educating the player to drive in a certain why. For instance, the driver must drive slow and extra cautious when transporting an animal or driving on Van Reenen's pass.

However, the most important awards to include should be aimed at educating the player about the effect of road grade. This can be achieved, for example, by awarding the player if he or she has visited the top tree highest points on the map or giving a player various possible route options for a delivery and awarding the player if the most economical route was chosen. Unfortunately, adding these awards will only be possible, if the simulation game is sensitive to road grade, which will be determined in the following section, section 4.2.

4.2 Part 2: Road grade evaluation study

The road grade evaluation study requires two components, the theoretical fuel consumption estimates and the SATS fuel consumption output in order to determine the accuracy of the simulation game's fuel consumption output. The results of these two components are summarized in subsection 4.2.1 and subsection 4.2.2 respectively. Subsection 4.2.3 will conclude on the accuracy of SATS and if it could thus be used as an education tool to educate about the effect of road grade on a truck's fuel consumption.

4.2.1 Theoretical fuel consumption estimates

The *theoretical fuel consumption* estimate, fcL, for a truck traversing a 285 km road segment at a controlled constant incline, x, is graphed in Figure 4.11. This graph is obtained using (3.9), calculated in subsection 3.2.1. This equation was originally derived from slope percentages between -6% and 6% and is now used to predict the estimated fuel consumption for slope percentages in the range of (-15%; 15%). The increased slope percentage range can reduce the accuracy of the fuel consumption estimates. However, the two points listed below can help to validate the output to some extent:

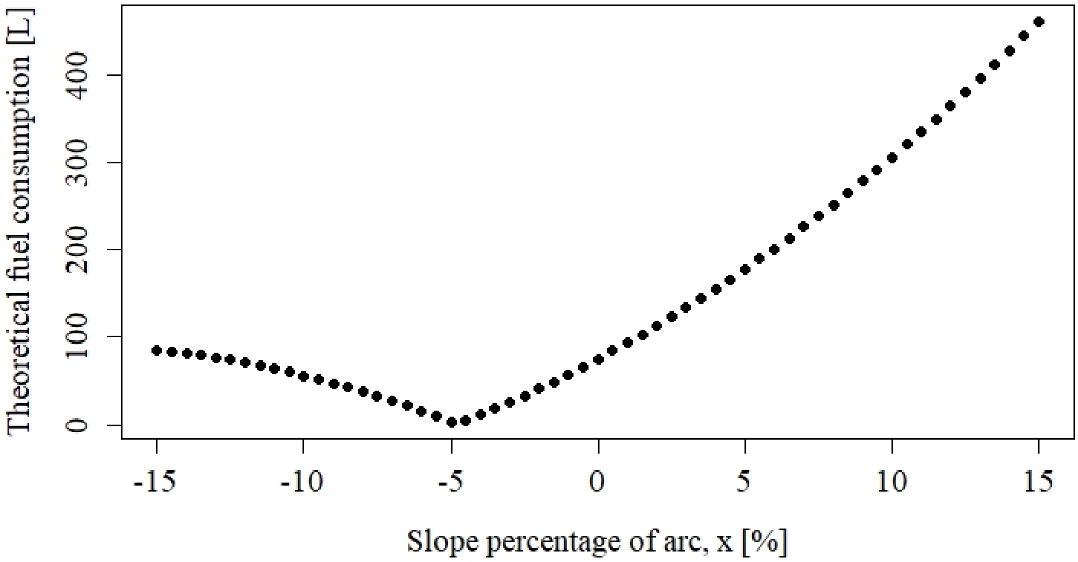


Figure 4.11: The *theoretical fuel consumption* when traversing a 285 km road segment with a constant slope percentage x, at a constant speed of 60 km/h.

- The results obtained from the study performed by Joubert (2017) can be confirmed with this figure. The author stated that when road grade is present, preference will be given to routes with long down-hills and short, steep up-hills. As seen in the figure, down-hills which is represented by negative slope percentages, can lead to fuel savings, resulting in long down-hills being more desirable.
- When manipulating the data given in Figure 4.11, a fuel efficiency of 3.8 km/ℓ is obtained for a loadless truck driving on a 285 km road segment with a slope percentage of 0%. This fuel efficiency is considered to be reasonable for a loadless truck, especially considering that no other factors including driver's skill and tyre wear are incorporated.

An aspect of Figure 4.11 not explained by the literature is the increasing fuel consumption output for slope percentages below approximately -5%. In subsection 3.2.1, it was found that slope percentages below -5% resulted in negative *road gradient correction factor* values, which in turn, would result in negative fuel consumption outputs. Although no formal proof is given in this report, it is believed that this *negative* fuel consumption might be due to the truck driving downhill in a low gear and therefore relying on its engine's gears to combat gravitation, thereby increasing fuel consumption. Consequently, the absolute value of the *road gradient correction factor* values where used when developing (3.9). In doing so, it was found that steeper down-hills can also lead to increased fuel consumption. This is however not a formal conclusion as further study is required to provide more proof for this statement.

4.2.2 SATS fuel consumption output

Each arc, as described in 3.1, was mapped in the simulation game. Afterwards, a truck was driven on each arc to obtain the relevant Telemetry outputs. This was repeated three times in order to obtain an average value for each output. Only three outputs were deemed relevant:

- *Odometer*: The total distance (in km) driven by the truck.
- *Telemetry fuel consumption*: The number of litres of fuel used to drive a distance equal to the truck's odometer.
- *Fuel average consumption*: Intuitively, this output is thought to be the *telemetry fuel consumed* divided by the truck's *odometer*. This is however not the case and will be explained later in this section. Consequently, the actual unit of this output is unknown, but is believed to be ℓ/km.

The *telemetry fuel consumed* output for each arc is shown in Figure 4.12. At first glance, it appears as if road grade does indeed result in higher fuel consumption. However,

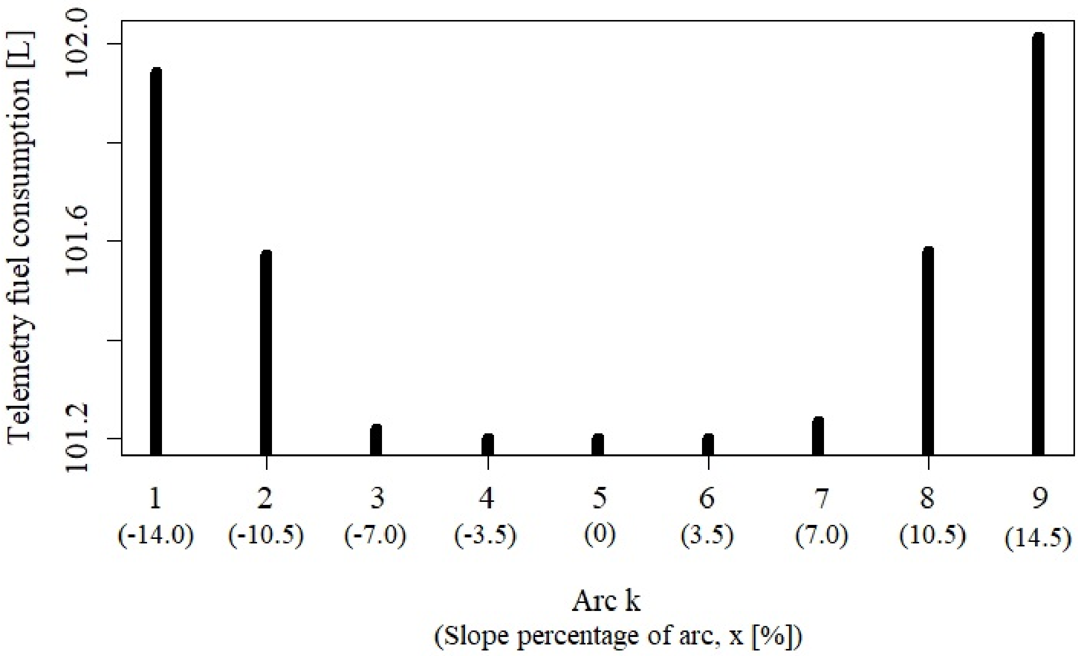


Figure 4.12: *Telemetry fuel consumption* output obtained when simulating a drive on arc k, at a constant speed of 60 km/h in SATS.

when inspecting the results in more detail, it was found that the arc with the highest inclination of 15%, consumed only an additional 0.812 litres of fuel when compared to the arc with 0% inclination. Unfortunately, this small fuel consumption increase might only be due to the additional 2.85 km travelled due to the 15% inclination. Accordingly, the fuel efficiency of each arc was calculated to overcome this dilemma.

The fuel efficiency for each arc is calculated by dividing the arc's *odometer* output by the *telemetry fuel consumption* output. The results are plotted in Figure 4.13. Note that lines were added between observation points for visual aid. From the literature, it is expected that the arc with the highest inclination of 15% (arc 9) will have a lower fuel efficiency compared to the arc with zero inclination (arc 5). Surprisingly, the 0% inclined arc has the lowest fuel efficiency. This led to the conclusion that SATS's *telemetry fuel consumption* output does not consider road grade, but is only dependent on the actual distance travelled by the truck during the simulation run. To confirm this statement, a correlation test was conducted on the *odometer* and the *total fuel consumed* outputs obtained for each arc's simulation runs. It was found that there is a strong linear relationship, with a multiple R-squared value of 0.982, between these two variables and that this relationship is indeed significant with a p-value approximating zero. Therefore, it appears that fuel efficiency is only dependent on the distance travelled, yet *arc 2* and *arc 8* is

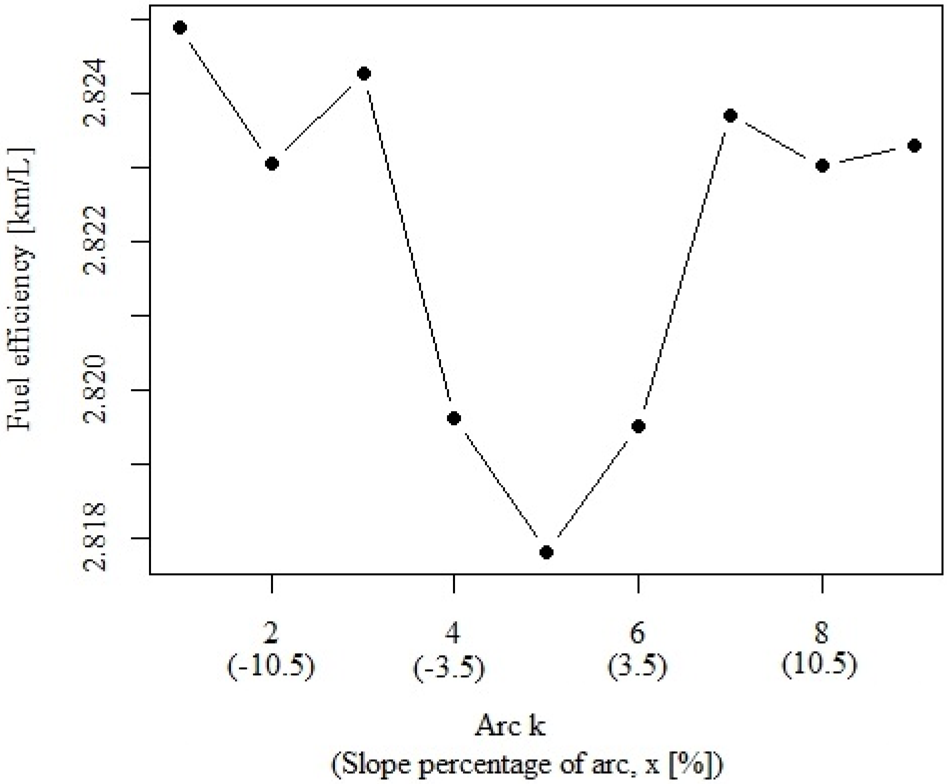


Figure 4.13: Fuel efficiency obtained when simulating a drive on arc k, with a slope percentage x, at a constant speed of 60 km/h in SATS.

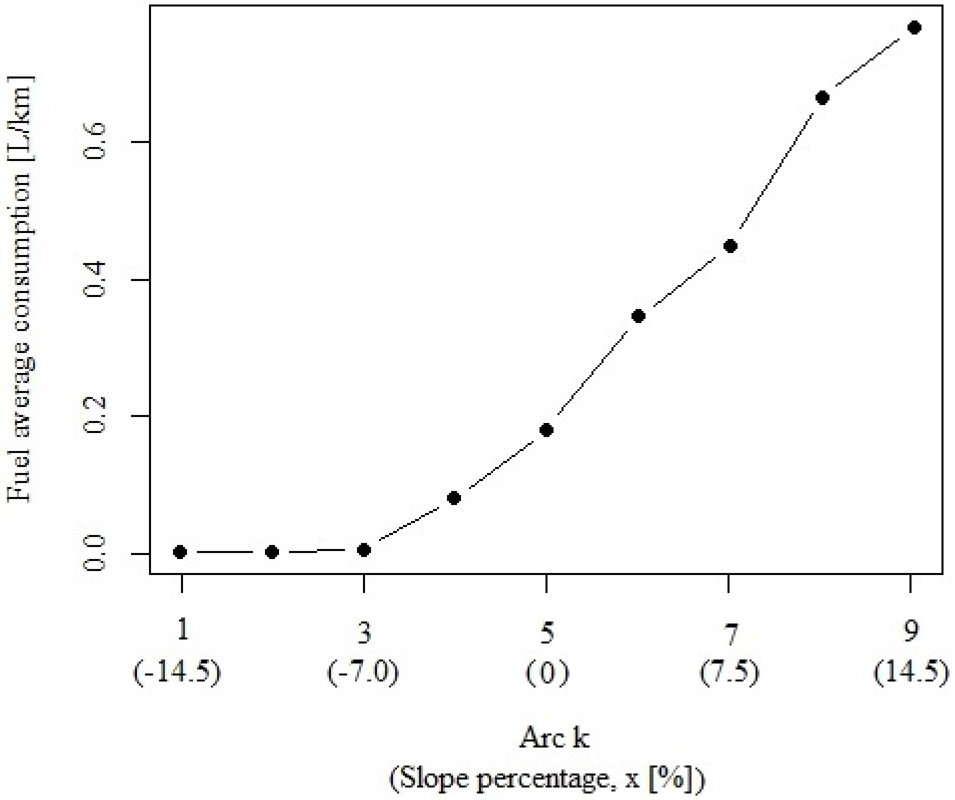


Figure 4.14: *Fuel average consumption* output obtained when simulating a drive on arc k, with a slope percentage x, at a constant speed of 60 km/h in SATS.

deviating from this assumption for reasons unknown.

Fortunately, SATS's telemetry provides an additional output, labelled *fuel average consumption*. When plotting this output for the arc set, a promising trend is obtained, as seen in Figure 4.14. In this trend, it appears as if the output increases along with the increase in the arc's *slope percentages*. Unfortunately, how the *fuel average consumption* output is actually calculated is a mystery, as it is not simply the *total fuel consumed* output divided by the truck's *odometer*. However, after conducting a correlation test between the *slope percentage* and the *fuel average consumption* output of the arc set, a significant multiple R-squared value of 0.9583 was obtained. Consequently, there is a strong possibility that the *fuel average consumption* does take road grade into account.

To obtain a better understanding of the *fuel average consumption* output (FAC), the output was reversed engineered for each arc. In other words, this output was used to derive a new fuel consumption value for arc k, based on the intuitive thought that *fuel average consumption* is simply the amount fuel consumed, divided by the distance travelled. This is illustrated with (4.1).

$$FAC_k = \frac{\text{Derived fuel consumption for arc k}}{\text{Distance travelled on arc k}}, \text{ where } k \in [1;9] \tag{4.1}$$

Telemetry automatically stores each output at periodic time intervals during the simulation run. Accordingly, when completing a simulation run on arc k, a telemetry output dataset is obtained with T_k amounts of timestamps. These timestamps can be used to obtain instantaneous outputs during each point in the simulated truck's journey. The *fuel average consumption* equation for arc k, at timestamp t, is given with (4.2). The distance travelled up until timestamp t is equal to the truck's *odometer* reading at timestamp t. Since the *odometer* and *fuel average consumption* is known for each timestamp, (4.2) can be manipulated to determine the *derived fuel consumed* (DFC) for each timestamp.

$$FAC_{kt} = \frac{DFC_{k1} + DFC_{k2} + DFC_{k3} + ... + DFC_{kt}}{Odometer_t}, \ \forall k \in [1;9] \text{ and } t \in T_k \tag{4.2}$$

The total *derived fuel consumption* for arc k, DFC_k, can then be calculated using (4.3). This equation sums together the *derived fuel consumption* for each timestamp in the arc in order to determine the total number of *litres* of fuel required to travel the simulated journey. The results for the arc set is tabulated in Table 4.1.

$$DFC_k = \sum_{t=1}^{T_k} DFC_t, \ \forall k \in [1;9] \tag{4.3}$$

Table 4.1: Comparison between the three different fuel consumption results obtained for each arc, as well as the result of a correlation test between the fuel consumption results and road grade of the arc set.

Arc k: (x)	**Telemetry Fuel Consumption [ℓ]**	**Derived Fuel Consumption [ℓ]**	**Simplified Fuel Consumption [ℓ]**
Source:	Telemetry output	Equation (4.3)	Equation (4.4)
arc 1 (-14.0%)	101.94	1.70	0.97
arc 2 (-10.5%)	101.57	1.71	1.08
arc 3 (-7.0%)	101.22	3.83	7.77
arc 4 (-3.5%)	101.20	23.13	23.14
arc 5 (0.0%)	101.20	51.75	51.77
arc 6 (3.5%)	101.20	98.51	98.55
arc 7 (7.0%)	101.24	128.51	128.55
arc 8 (10.5%)	101.58	190.15	190.22
arc 9 (14.0%)	102.01	220.69	220.72
Correlation coef.	0.046	0.9573	0.9577
P-value	0.9058	5.065E-05	4.909E-05

Also included in Table 4.1, is the *Simplified Fuel Consumption* (SFC_k) value for each arc. This value is calculated by multiplying the final *odometer* and *fuel average consumption* outputs together at the last timestamp , timestamp T_k, as shown in (4.4). Using only the last timestamp results in a simplified calculation when compared to (4.3). Although (4.4) is simplified, it still incorporates the entire simulated journey due the the *fuel average consumption* and *odometer* output at timestamp T_k, being dependent on previous timestamps leading up to T_k.

$$SFC_k = Odometer_{Tk} \times FAC_{Tk}, \text{ where } k \in [1; 9] \tag{4.4}$$

Table 4.1 summarizes the results for the three fuel consumption outputs identified. Stated earlier, the *telemetry fuel consumption* output is not dependent on road grade. This was confirmed after conducting a correlation test between the *telemetry fuel consumption* output and the road grade of the arc set, which resulted in a weak correlation coefficient value of 0.046. The remaining fuel consumption outputs have a significant and strong linear relationship with road grade due to the correlation coefficients being close to 1 and the p-values for both outputs approximating zero. Due to this significant relationship, it can be concluded that these fuel consumption outputs of SATS is indeed sensitive to road grade. The *simplified fuel consumption* output resulted in a correlation coefficient of 0.9577, which is slightly higher than the 0.9573 correlation coefficient obtained from the *derived fuel consumption* output. This means that the *simplified fuel consumption* has a slightly stronger linear relationship with road grade. Accordingly, the output of (4.4) is the most sensitive to road grade and should be used to calculate the fuel consumption for a simulated journey in SATS when road grade is present.

The following subsection, subsection 4.2.3, will compare the *simplified fuel consumption* output obtained from SATS, with the *theoretical fuel consumption* estimates. The goal is to determine the accuracy of the simulation game's fuel consumption output.

4.2.3 Accuracy of SATS's Fuel Consumption Output

It was concluded in subsection 4.2.2, that the fuel consumption output of SATS is indeed sensitive to road grade when using either (4.3) or (4.4), with the latter being the preferred method. Sensitivity is unfortunately not enough to use SATS as a tool to educate about the effect of road grade, a moderate degree of accuracy is also required. This section aims to take it a step further by investigating the accuracy of these outputs.

For the SATS fuel consumption output to be deemed accurate, it should have the same trend as the *theoretical fuel consumption* estimates calculated using (3.9). The *theoretical fuel consumption* estimates for slope percentages, x, between -15.0% and 15.0%, is represented with the thick blue line in Figure 4.15. The remainder of the coloured lines visible in Figure 4.15 are based on the telemetry output of SATS. The list below describes each coloured line the order of increasing importance:

1. *Red line*: In the previous section, it was found that the *telemetry fuel consumption* output was only dependent on the distance travelled. Consequently, this output does not vary significantly according to different road grades, as indicated with the red line. The *telemetry fuel consumption* output is therefore not sensitive, nor accurate when compared to the blue line.

2. *Purple line*: The purple line represents the *derived fuel consumption* output, as well as the *simplified fuel consumption* output obtained using (4.3) and (4.4) respectively. The purple line conveys the desired upwards trend, but unfortunately the growth between slope percentages is not as drastic as expected when compared with the *theoretical fuel consumption* estimates (blue line). This could be due to a variety of

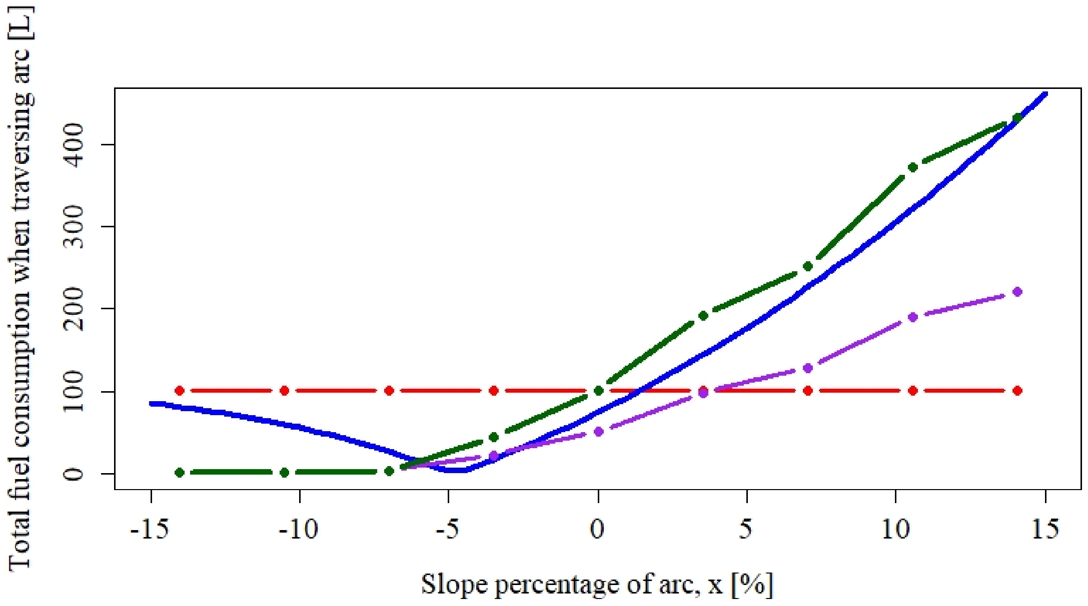


Figure 4.15: Comparison of the *theoretical fuel consumption* estimate (blue line) with different fuel consumption outputs obtained from SATS, when traversing an arc of length 285 km and specified slope percentage, x.

reasons, such as the actual weight of the truck used in the simulator might be less than 16 tonnes, since the precise weight is unknown. The purple line is promising, but not accurate enough.

3. *Green line*: This line is an approach to maintain the promising trend of the purple line, while improving the inadequate growth between successive slope percentages.

   The green line assumes that the *telemetry fuel consumption* output (red line) and the *fuel average consumption* output used to calculate the *simplified fuel consumption* output (purple line) is related to each other. This assumption is based on the fact that both outputs are obtained using telemetry. Since the red line is concluded to be independent of road grade, the reference point is chosen as the arc with 0% inclination. Accordingly, the *simplified fuel consumption* output should be equal to the *telemetry fuel consumption* output at this reference point. This is achieved by multiplying the *simplified fuel consumption* output with a factor of 1.956 to obtain the green line. The equation for the green line is given with (4.5), where T_k refers to the last timestamp in arc k's telemetry dataset.

$$FC_k = 1.955 \times \textit{simplified fuel consumption} \text{ output for arc k}, \ k \in [1;9] \qquad (4.5)$$

   For slope percentages between -5% and 14%, the trends of the green and blue lines are very similar. Compared to the blue line, the green line appears to slightly overestimate the fuel consumption. It should also be noted that the green line does not account for increased fuel consumption due to steep downwards slopes. This might however off-sett the overestimated fuel consumption for slopes between -5% and 14%. The trends between these two lines are however very similar, hence the green line is considered to be moderately accurate.

This section therefore concludes that SATS can fulfil the need to educate about the effect of road grade on fuel consumption. This is due to an output of SATS, the *fuel average consumption* (FAC), being sensitive to road grade. This section determined that (4.5) can be used to obtain a moderately accurate fuel consumption result when traversing a 285 km road segment, with a predefined inclination (x), at a constant speed of 60 km/h in SATS. Since (4.5) was only applicable to the arc set defined earlier, (4.6) was constructed to apply to any simulated journey in SATS. Again, T refers to the last timestamp recorded in the telemetry dataset.

$$FC_{SATS} = 1.955 \times (Odometer_T \times FAC_T) \tag{4.6}$$

Knowing that the fuel consumption can be calculated using (4.6), it was decided to put this equation to the test in Chapter 5.

Chapter 5

Simulating a drive on the N3

The elevation difference between Johannesburg and Durban is at least 1500 m. And as stated in the literature, the direction of travel between two points can results in different fuel consumptions when road grade is considered. This means that a *downhill* trip from Johannesburg to Durban should require less litres of fuel compared to an *uphill* trip in the opposite direction, from Durban to Johannesburg. This chapter aims to test the ability of (4.6) to reflect a difference in fuel consumption resulting from the direction of travel, in a more realistic scenario. The scenario that will be considered is the N3 - the most preferred route between Johannesburg and Durban. The N3 stretches between the N1 and N3 intersection (Johannesburg) and the N2 and N3 intersection (Durban), totalling a distance of approximately 570 km. Unfortunately, the N3 is only 520 km long in the simulation game due to a known error beyond the scope of this project.

For this experiment, two simulation runs will be completed in the South African Truck Simulator (SATS) at a speed of 60 km/h. The first simulation run will start at the N3's lowest elevation point, Durban, and end in Johannesburg. The second simulation run will be in the reverse direction, therefore driving mostly downhill from Johannesburg to Durban. The route for both simulations are exactly the same, therefore the distance travelled will also be the same. Consequently, the only difference is the direction of travel being either mostly uphill or downhill. The following elevation points have been added to the mapped N3 in SATS for the purpose of this experiment:

1. Durban (N2 and N3 intersection) - 7 m
2. Pietermaritsburg - 635 m
3. Howick - 1051 m
4. Mooirivier 1380 m
5. Estcourt - 1269 m
6. Ladysmith - 1102 m
7. Van Reenen - 1656 m
8. Harrismith - 1680 m
9. Warden - 1649 m
10. Additional point not related to a city - 1580 m

11. R34 intersection - 1633 m
12. Villiers - 1516 m
13. Heidelberg - 1555 m
14. Johannesburg (N1 and N3 intersection) - 1520 m

For each simulation run, various telemetry data was recorded during every timestamp until the simulation run was completed. One of these telemetry outputs, the truck's *elevation*, is shown in Figure 5.1 for each timestamp observed. The two elevation profile's shown in the figure are mirror images of each other. This is due to the route driven being the same but the direction of travel being opposites. Clearly the amount of ascending and descending distances differ between these two simulation runs, thereby creating the expectation that the fuel consumption should vary. But, as found in a previous section, the *telemetry fuel consumption* output is only dependent on the distance travelled and therefore not influenced by road grade. Consequently, the *telemetry fuel consumption* output for both simulation runs is equal to 184 litres.

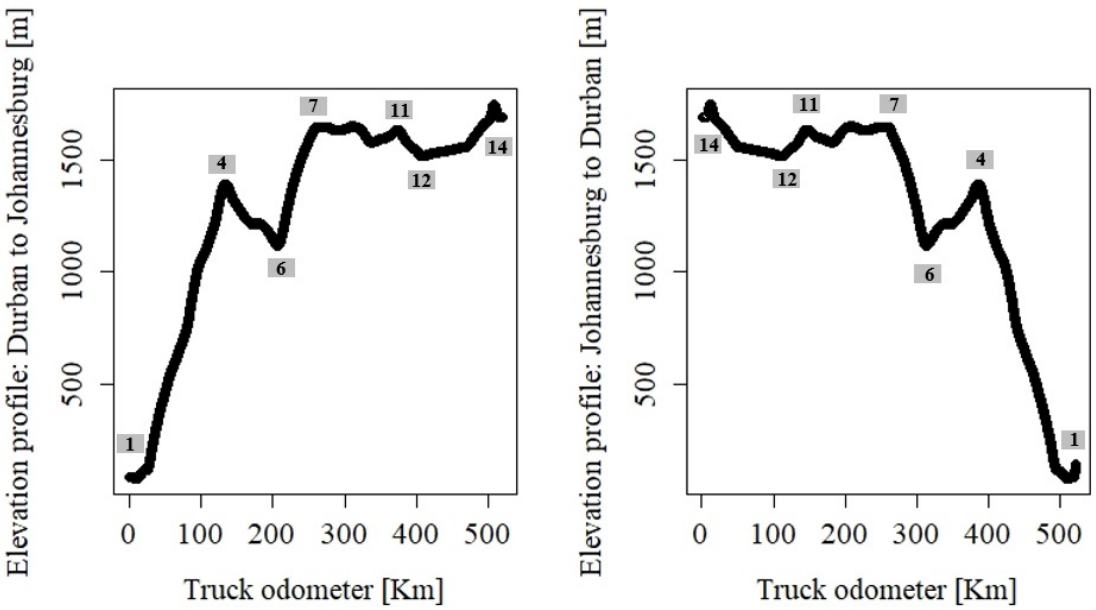


Figure 5.1: Elevation profile when travelling from *left*: Durban to Johannesburg, *right*: Johannesburg to Durban.

When travelling from Durban, a truck would have to climb at least 1500 meters over a distance of 520 km, resulting in an average overall slope percentage of 0.288%. It was determined in subsection 4.2.2 that slope percentages between 0% and 3.5%, will result in *fuel average consumption* outputs in the range of [0.1815; 0.3454], as shown in 4.14. Consequently, it is expected that the simulation run from Durban to Johannesburg must have a *fuel average consumption* output slightly higher than 0.1815 at the end of the simulation run. This expectation was met with a final *fuel average consumption* value of 0.1883, when travelling from Durban to Johannesburg.

When travelling from Johannesburg to Durban, a truck would have to descend a distance of at 1500 meters over a distance of 520 km. This results in an average overall slope percentage of -0.288%. The expected *fuel average consumption* output for slope percentages between -3.5% and 0% was found to be in the range of [0.0811; 0.1815]. Since the current slope is closest to 0%, it is expected that the *fuel average consumption* output should be close to 0.1815. Once again, the expectation was met with a final *fuel average consumption* value of 0.1721, when travelling from Johannesburg to Durban.

To visualize the impact of the travel direction on fuel consumption, the fuel consumption for each individual timestamp was derived using (4.2). The results for both simulation runs are shown in Figure 5.2. For convenience, the related elevation profile is included as a grey line in the graph's background. As expected, a steep uphill resulted in increased fuel consumption for each individual timestamp. Some of these occurrences are indicated with a green circle on the figure. Since the journey from Durban to Johannesburg is mostly uphill, this simulation run has more timestamps with increased fuel consumption. Also, as mentioned earlier, downhills are more favourable as they can result in fuel savings. This can be seen in the figure where the red circles indicate reduced fuel consumption for individual timestamps due to the presence of a downhill road segment. Since the simulation run from Johannesburg to Durban has more downhill sections, it is expected that this simulation run should be the most economical in terms of fuel consumption.

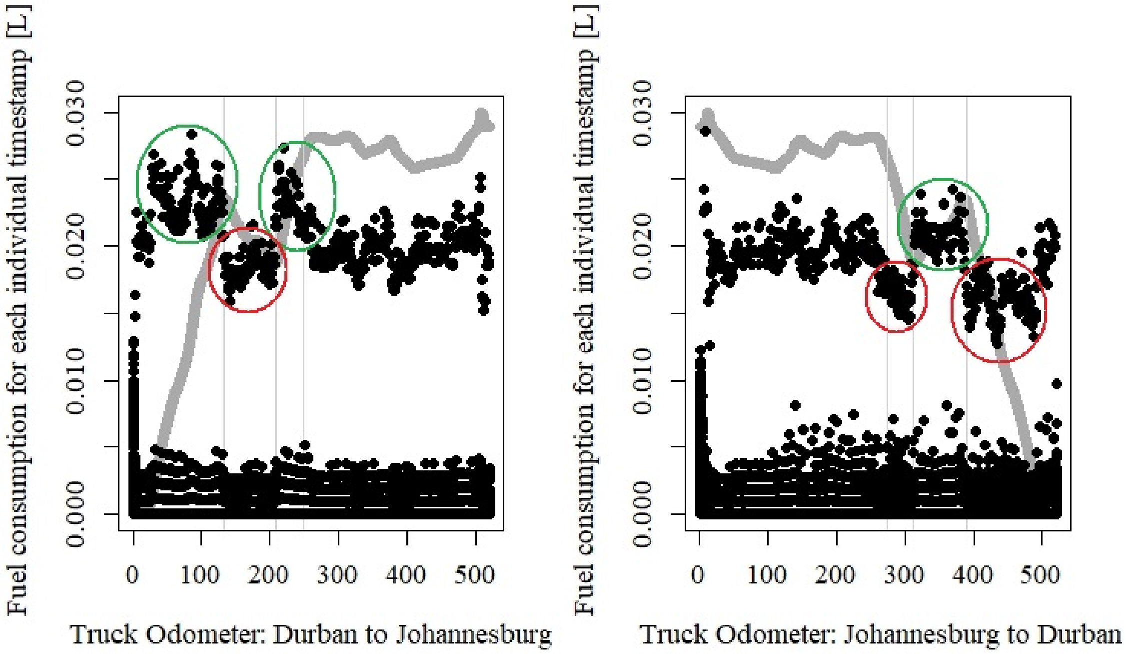


Figure 5.2: Fuel consumption [ℓ] for every individual timestamp recorded when simulating a drive from *left*: Durban to Johannesburg, *right*: Johannesburg to Durban, in SATS.

Upon further inspection of this figure, one would realize that the majority of timestamp observations are below 0.010ℓ. The exact cause for this occurrence is unknown, but it is believed to be related to the cruise control and steering of the truck during the simulation run. When driving downhill, the cruise control results in more frequent braking to maintain a constant speed of 60 km/h. Consequently, the bottom observations are more compacted during a downhill road segment section.

To determine the most economical travel direction, (4.6) was used to calculate the number of litres required to complete each simulation run. The results are tabulated in

Table 5.1: N3 simulation run results

Simulation run:	**Durban to Johannesburg**	**Johannesburg to Durban**
Fuel Consumption [ℓ]	191.46	174.93
SATS fuel efficiency [**km/ℓ**]	2.72	2.97
Industry fuel efficiency [**km/ℓ**]	1.87	1.97

Table 5.1. The results obtained indicate that the simulation run from Johannesburg to Durban is indeed the most economical, with a fuel *savings* of 16.52 ℓ (191.46ℓ - 174.93ℓ). According to Casper Dercken, the Operations Executive at Imperial Logistics, the fuel efficiency for a 34 tonne truck is approximately 1.97 km/ℓ when driving from Johannesburg to Durban, and 1.87 km/ℓ when driving from Durban to Johannesburg, resulting in a fuel efficiency difference of 0.1 km/ℓ. As shown in Table 5.1, the fuel efficiencies obtained from the simulation runs are slightly higher than the given industry fuel efficiencies, with a difference of 0.26 km/ℓ. The most probabilistic factor for the observed difference between SATS and industry's fuel efficiencies, is most likely due to the weight of the truck. The weight of the truck used in the simulation runs could be any value between 16 to 32 tonne, whereas the values obtained from industry, is based on a truck weighing 34 tonnes. Another probable reasons is due the the simulation environment. The simulation runs were completed at a constant speed of 60 km/h, without any stops or deceleration. This is however not possible in reality, since a truck must stop or reduce it speed due to traffic, red lights, weather conditions and low speed limitations. Consequently, it is expected that the fuel efficiencies of the simulation runs will be better than the industry values, therefore validating the results obtained when using (4.6).

It can be concluded that (4.6) does take road grade into account when calculating the fuel consumption for routes driven in SATS. Ultimately, thanks to (4.6), SATS can be used as an educational tool to educate about the effect of road grade.

Chapter 6

Conclusion

This project confirmed that some of the South African Truck Simulator (SATS)'s outputs is sensitive to road grade and can therefore be used to determine a truck's fuel consumption to a moderate degree of accuracy. Accordingly, the simulation game can be used to create awareness about the effect of road grade and how incorporating road grade in route choice selections can lead to fuel cost savings. During the execution of this project, (4.6) was developed to calculate the fuel requirements of a simulated journey. This equation, along with SATS, could therefore be used to determine the fuel requirements for various route in order to assist in a company's route choice planning.

Is should be noted that SATS is not a short-term project, as the development of a South African version of Euro Truck Simulator 2 (ETS2) can take a few years to develop. It is worth mentioning that the development of SATS is part of a much larger project. The Centre for Transport Development, from the Department of Industrial and Systems Engineering at the University of Pretoria, is establishing an *Advanced Trucking Simulator*, in partnership with 5th Dimension Technologies. This simulator will consist of hardware replicating the cabin and its motion and will be used to provide valuable truck driving training, as well as a means to determine the competence of the driver. This will require a software component that is able to measure various telemetry data, such as the vehicle's fuel consumption. Accordingly, a major part of this project was aimed at determining whether or not SATS can measure fuel consumption accurately when incorporating road grade.The progress made in this project in terms of the development of the South African map could therefore be used as a demonstration for what is expected from the soft-components of the simulator.

SATS is therefore not only a standalone simulation game, but can also be used to create realistic truck simulators. Accordingly, SATS can provide basic training for individuals in the comfort of their home, as well as advanced training at companies willing to invest in the required hardware. Since the simulation game is a from of gamiciation applied to an educational context, it is expected that the training provided by SATS will be effective and enjoyable. In return, this will attract more young people to the truck driving profession and increase the competence and knowledge of truck drivers. In other words, it will reduce the shortage of truck drivers that results in high driver wages in South Africa. Additionally, it can help to create awareness of the impact of road grade on a heavy vehicle's fuel consumption.

New technology, such Volvo's I-Shift technology, is however combating the effect of road grade. This I-Shift technology, designed specifically for road grade variations, uses build-in intelligence to choose the right gear at the right time, leading to fuel savings of up to 5% (*Volvotrucks.com*). When combined with their I-Roll momentum technology, an additional fuel savings of 2% can be achieved. I-Roll technology maximises a truck's momentum when going downhill by disengaging the engine. Volvo truck's also use I-Cruise and I-See to implement the above technologies. I-Cruise adjusts the truck speed according to the route being driven, which is memorised and continuously updated by the I-see technology. I-see consists of a database containing the elevation profiles of all the routes travelled by Volvo trucks with I-see technology. Thus, the I-Shift and I-Roll technology uses I-See to predict upcoming changes in road grade and take action accordingly to reduce fuel consumption. This Volvo technology has great potential, but unfortunately it will take at least a few years before every truck uses this type of technology. Fortunately, during this period, SATS can educate drivers about the effect of road grade on a heavy vehicle's fuel consumption in order to decrease fuel consumption and ultimately, to reduce logistics cost.

A major concern about SATS worth mentioning, is the use of *Promods* when creating the South African map. *Promods* is a collection of prefabricated components, such different types of roads, intersections and objects, that can be added manually to ETS2's build-in map editor in order to enlarge the component library. Unfortunately, SATS updates are not always compatibility with the existing *Promods*. Consequently, new versions of *Promods* will also be required, but the availability of new versions is not guaranteed. SATS is currently extremely dependent on the use of *Promods*, since *Promods* provides components specific for left-hand traffic drive. The concern is thus that the unavailability of newer versions of *Promds* can influence the life-span of SATS. A short-term solution is to use older-versions of ETS2 with compatible *Promods*, until new *Promods* versions become available. This solution is however not ideal. It therefore suggested that future efforts must be committed to develop left-hand traffic component designs specifically for SATS that can be updated manually, if required.

An additional recommendation when further developing SATS is to complete a detailed study on how the *fuel average consumption* output is calculated. According to the SCS Support, the *fuel average consumption* is based on the skills of the driver's character in the game. But in this project, it was determined that this output is also dependent on the road grade of the route travelled. Thus, gaining more insight on this variable can result in more accurate fuel consumption calculations for routes driven in SATS.

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Appendix A

Appendix A: Remaining intersections mapped in SATS

The remainder of the intersection's mapped in South African Truck Simulator (SATS) is given shown in this section, from Figure A.1 to Figure A.11.

Figure A.1: Top view comparison of N1 and N6 intersection.
Source: Google Maps, $29^{\circ}05'30.4"S26^{\circ}10'15.9"E$, accessed 25 Augustus 2018.

Figure A.2: Top view comparison of N1 and N14 intersection.
Source: Google Maps, $25^{\circ}52'43.3"S28^{\circ}10'11.1"E$, accessed 25 Augustus 2018.

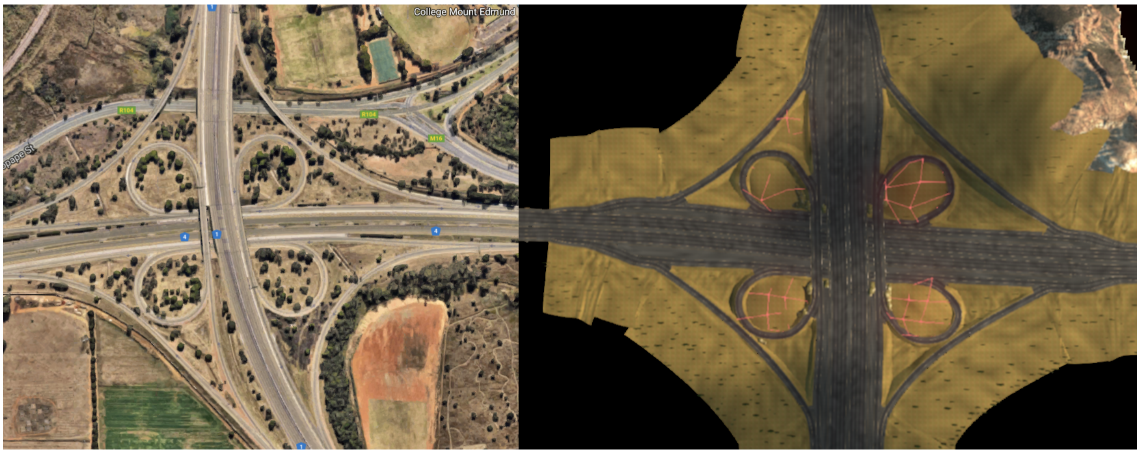


Figure A.3: Top view comparison of N1 and N4 intersection.
Source: Google Maps, 25°44′25.9”S28°15′53.4”E, accessed 25 Augustus 2018.

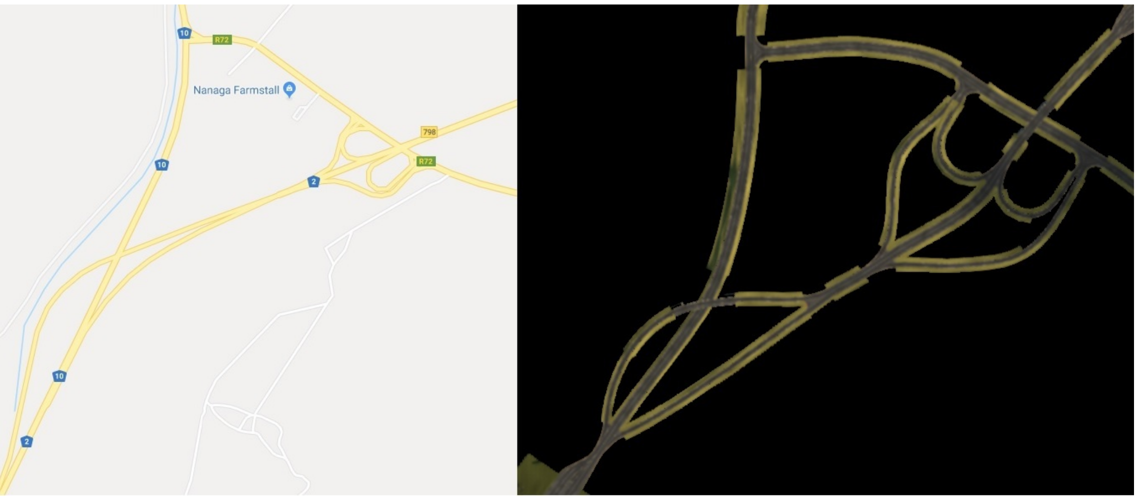


Figure A.4: Top view comparison of N2 and N10 intersection.
Source: Google Maps, 33°36′39.2”S25°55′07.3”E, accessed 25 Augustus 2018.

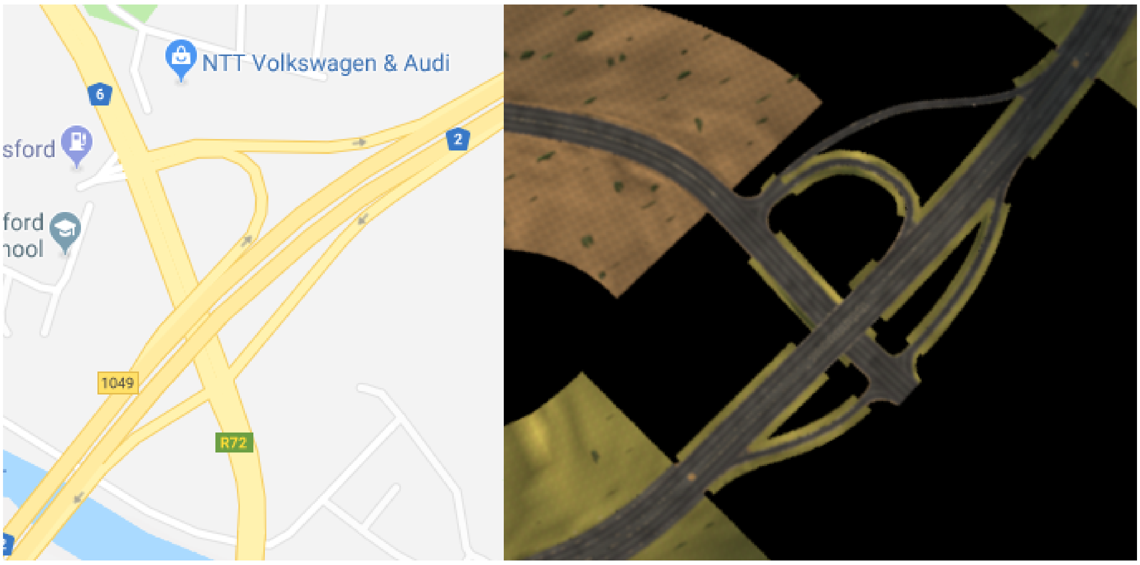


Figure A.5: Top view comparison of N2 and N8 intersection.
Source: Google Maps, $32^{\circ}57'49.7"S27^{\circ}55'08.9"E$, accessed 25 Augustus 2018.

Figure A.6: Top view comparison of N1 and N4 intersection.
Source: Google Maps, $25^{\circ}38'45.9"S28^{\circ}16'23.7"E$, accessed 25 Augustus 2018.

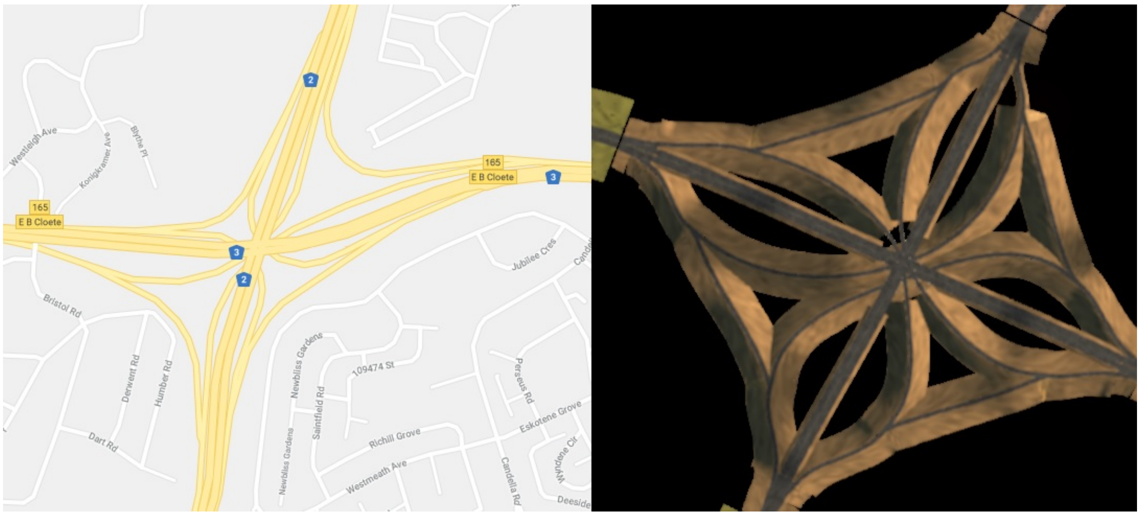


Figure A.7: Top view comparison of N1 and N7 intersection.
Source: Google Maps, 29°50′27.8”S30°57′27.2”E, accessed 25 Augustus 2018.

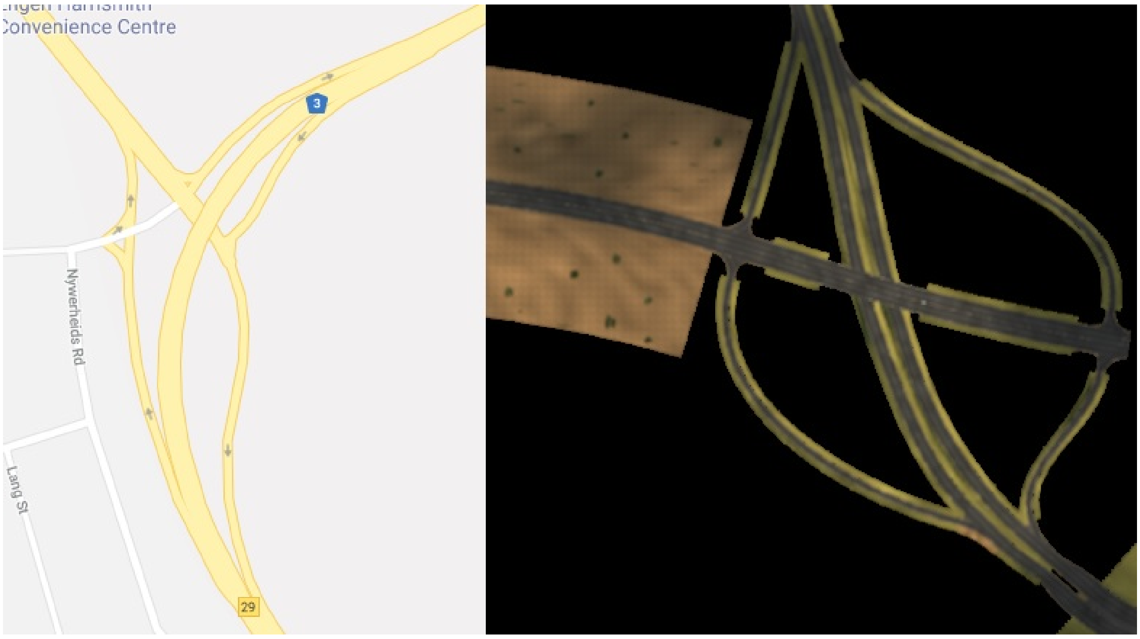


Figure A.8: Top view comparison of N3 and N5 intersection.
Source: Google Maps, 28°17′21.7”S29°08′04.7”E, accessed 25 Augustus 2018.

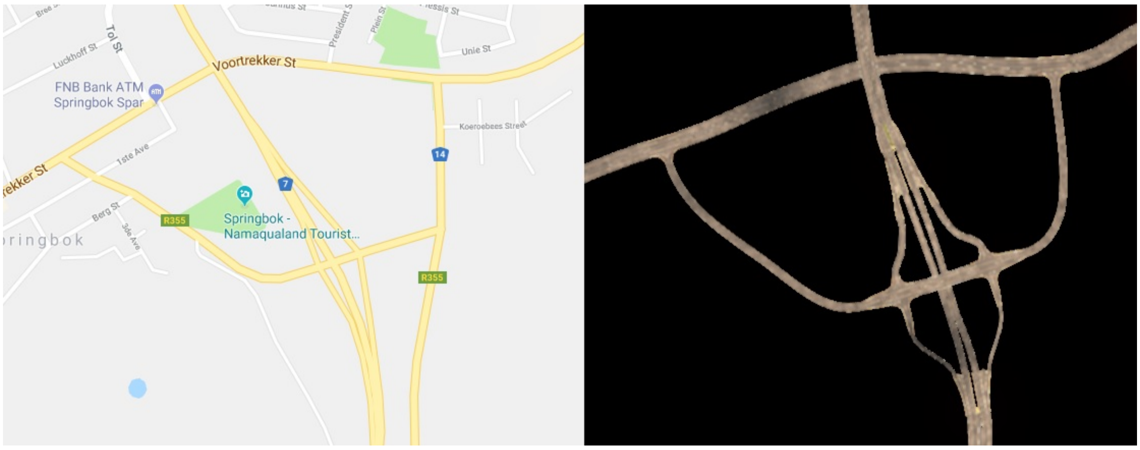


Figure A.9: Top view comparison of N1 and N7 intersection.
Source: Google Maps, 29°39′50.0”S17°53′45.0”E, accessed 25 Augustus 2018.

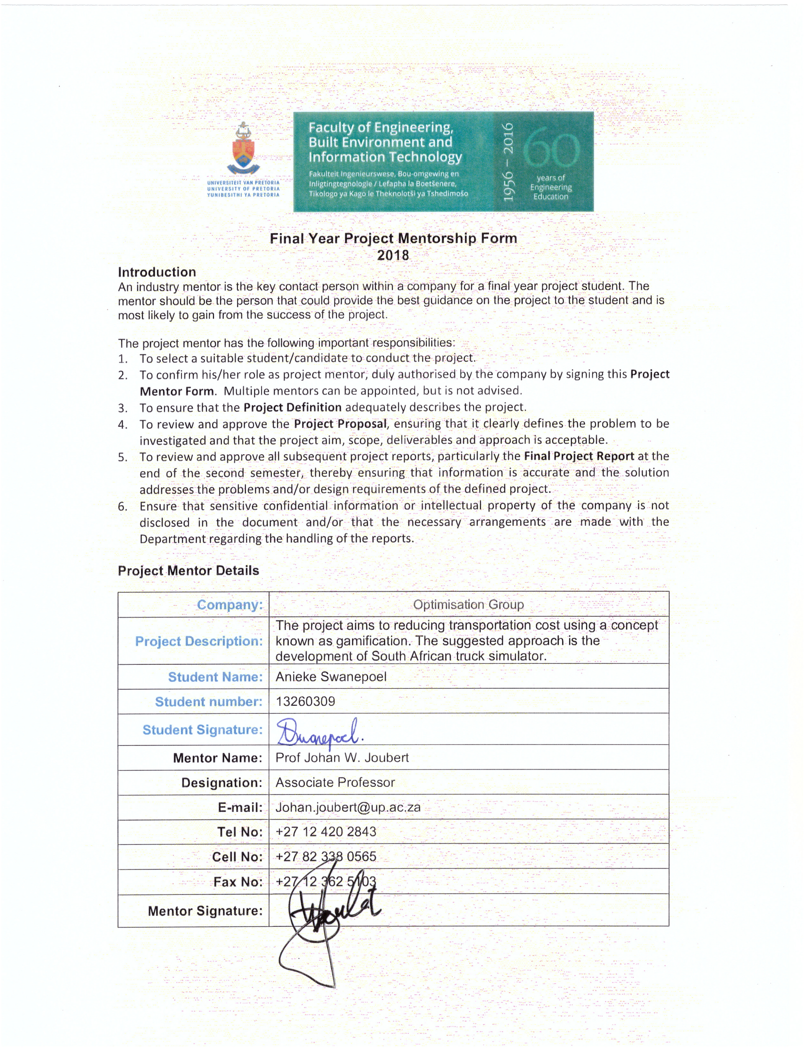
Figure A.10: Decor at the N1 and N7 intersection.

Figure A.11: View of the N1 and N4 intersection.

Appendix B

Appendix B: Industry sponsorship form

This project's industry sponsorship form is given in Figure B.1.



UNIVERSITEIT VAN PRETORIA
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Faculty of Engineering, Built Environment and Information Technology
Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

1956 – 2016
60 years of Engineering Education

Final Year Project Mentorship Form
2018

Introduction

An industry mentor is the key contact person within a company for a final year project student. The mentor should be the person that could provide the best guidance on the project to the student and is most likely to gain from the success of the project.

The project mentor has the following important responsibilities:

1. To select a suitable student/candidate to conduct the project.
2. To confirm his/her role as project mentor, duly authorised by the company by signing this **Project Mentor Form**. Multiple mentors can be appointed, but is not advised.
3. To ensure that the **Project Definition** adequately describes the project.
4. To review and approve the **Project Proposal**, ensuring that it clearly defines the problem to be investigated and that the project aim, scope, deliverables and approach is acceptable.
5. To review and approve all subsequent project reports, particularly the **Final Project Report** at the end of the second semester, thereby ensuring that information is accurate and the solution addresses the problems and/or design requirements of the defined project.
6. Ensure that sensitive confidential information or intellectual property of the company is not disclosed in the document and/or that the necessary arrangements are made with the Department regarding the handling of the reports.

Project Mentor Details

Company:	Optimisation Group
Project Description:	The project aims to reducing transportation cost using a concept known as gamification. The suggested approach is the development of South African truck simulator.
Student Name:	Anieke Swanepoel
Student number:	13260309
Student Signature:	Swanepoel.
Mentor Name:	Prof Johan W. Joubert
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Fax No:	+27 12 362 5103
Mentor Signature:	

Figure B.1: Industry sponsorship form for this project