AN EVALUATION OF THE BENEFITS OF INTELLIGENT SPEED ADAPTATION FOR SOUTH AFRICA

Prepared by

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Executive Summary

Intelligent Speed Adaptation (ISA) describes the suite of technologies employed to influence the speed of a vehicle by either notifying the driver via visual or auditory stimulus, or by actively regulating the fuel intake into the engine. ISA systems are informed of the prevailing speed limit either via removable media, such as compact discs or flash memory, or via radio signals transmitted via pole mounted transponders along the road. Typically, GPS navigation satellites are used to locate the system within the road network.

ISA systems result either in a translation of the speed distribution curve downwards, or a transformation of the speed distribution curve by truncation at the speed limit. ISA has been found to have differing levels of effectiveness, depending on the level of intrusiveness of the system installed in the vehicle and on the rate of penetration of ISA into the vehicle fleet. The most effective systems, excluding those that limit vehicle speeds to speed limits by default, can achieve speed reductions of up to 13km/h. As ISA is primarily a speed reducing measure, the benefits it can deliver can be calculated by estimating what the effects of speed are, by how much ISA would be able to mitigate these effects, and what the monetary value of that function might be.

A survey of the literature reveals that there is a strong correlation between speed and the frequency and severity of road accidents. Speed limits are set to minimise the risk of an accident occurring, and consequently the higher the levels of adherence to these limits, the lower the incidence of road accidents. It has been estimated that excessive speed is directly responsible for up to 30% of all road accidents (Broughton, 2005; TRB, 1998).

The cost of road accidents is made up of a number of factors. Amongst these are damage to property, medical costs, administrative costs of insurances and the loss of output of the injured and the deceased involved in the crash. It has been estimated that road accidents cost South Africa in excess of R11.4 billion annually[1]. Further estimates place this cost at as much as R25 billion annually[2].

[1] Derived elsewhere in the report from values given at http://www.arrivealive.co.za

[2] Derived elsewhere in the report from values given in Barnett, Clough and McWha (1999)

Road accidents on busy roads cause congestion. This is an indirect cost of road accidents. This congestion results in an increased amount of fuel consumed, an increase in emissions and a cost associated with the time delay. It was calculated that incident induced congestion delay, where speed was the major cause of the accident causes as much as 33300 vehicle years in delay annually. An estimate of the cost of this delay was calculated at R75 891 000 annually. The additional fuel consumed because of this delay was estimated at 607 589 litres annually. This translates into a cost of R3 584 774.

The additional fuel consumed and the maintenance costs combine to form the extra operating costs incurred because of incident-induced congestion. Maintenance costs were calculated as being between 50 and 70% of the fuel costs, depending on the type of vehicle. If maintenance costs are added to fuel costs, the operating costs because of incident induced congestion increases to R5 902 689.

In addition to these costs, an estimate was made as to the increased emissions resulting from this congestion, and what these extra emissions might represent in Rand terms. It was found that these costs were approximately R2 529 724 per year.

It was found that ISA could potentially save up to 160 967 000 litres of fuel per year. This is based on a saving of 0.1 l/100km per vehicle. This translates to a monetary saving of R1 094 575 600. A second study (Lui and Tate; 2000) was found to have recorded savings of up to 8% in total fuel consumed. This translates to R7 180 415 936 saved per year. If maintenance costs are added to this, the savings increases to between R11 861 329 084 and R14 225 122 010 per annum.

Emissions savings resulting from lowered average speeds and the eradication of speeding was estimated as being between R 5 083 426 750 and R 6 096 480 861. Data sourced from a second study (Delucchi et al, 1998) and adapted to the South African context showed that these costs range from as little as R48 million annually to as much as R10.4 billion annually.

In addition to the costs mentioned above, an investigation was done into the infrastructural and administrative costs associated with the enforcement of the speed limits in South Africa. These costs includes the cost of resources in the form of moneys, time, and manpower devoted to enforcing the speed restrictions, the administrative costs in dealing with fines and the jurisdictional and legal costs associated with prosecuting offenders.

Infrastructural costs also include the installation of devices such as speed camera's and traffic calming schemes, and the maintenance of these.

It was estimated that the administrative costs associated with enforcing the speed limits is on the order of R1.125 billion annually. It was not possible to determine the extent traffic calming or speed camera maintenance and installation costs annually, but it was estimated that a single camera site can cost up to R180 000 per year to operate. The total cost savings that can be realised from implementing ISA as was calculated in this report was found to range from R18.74 billion annually to R51.2 billion annually.

A summary of the potential savings calculated in the report that can be made should ISA be implemented in South Africa is given in the table below:

Category	Cost Item	Value Range
Road Accidents	Cost of road accidents caused by excessive speed	R11 400 000 000 R5 622 144 000 R25 367 600 000
Time Delay	Costs of time delay as a result of accidents caused by excessive speed	R75 891 000
Operating costs	The additional vehicle operating costs because of incident-induced delay caused by incidents resulting from excessive speed	R5 902 000
	The additional vehicle operating costs as a result of speeding	R11 861 329 000 R14 225 122 000
Environmental Costs	The cost of damages to the environment because of incident-induced delay caused by incidents resulting from excessive speed	R2 529 000
	The cost of damages to the environment because of the additional pollutants resulting from excessive speed	R5 083 426 000 R6 096 480 000 R48 000 000 R10 400 000 000
Infrastructural Costs	The cost of the enforcement of speed limits	R1 125 000 000
	The cost of infrastructure installed to enforce the speed limit	unknown
Total Potential Savings	**Maximum**	**R51 202 046 000**
	Minimum	**R18 740 797 000**

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Terms of Reference

This dissertation was completed in partial fulfilment of the requirements of the degree of Master of Science in Engineering in the field of Civil Engineering (MSc.Eng (Civil Engineering)).

The person appointed to supervise the author's research and to receive the completed dissertation is Dr Marianne Vanderschuren.

The date for submission of the completed dissertation is the 31st of August 2006.

1. INTRODUCTION

1.1. Background

1.1.1. ITS In South Africa

Intelligent Speed Adaptation (ISA) is an Intelligent Transport Systems (ITS) technology developed to influence or control vehicle speeds. Intelligent Transport Systems are rapidly beginning to form an integral part in modern road and traffic authorities suite of tools, as they often offer more efficient and/or more cost-effective solutions to everyday traffic problems.

ITS systems can be categorised into three groups[3]:

- Intelligent Traffic Management Systems measure and analyse traffic flow information and take ITS measures to reduce problems. They consist of computerised traffic signal controls, highway and traffic flow management systems, electronic licensing, incident management systems, electronic toll and pricing, traffic enforcement systems and intelligent speed adaptation.

- Intelligent Passenger Information Systems improve the knowledge base of Customer and consist of passenger information systems, in-vehicle route guidance systems, parking availability guidance systems, digital map database and variable messaging systems.

- Intelligent Public Transport Systems include ITS measures that aim to improve public transport performance. They are consisting of intelligent vehicles, Intelligent Speed Adaptation, transit fleet management systems, transit passenger information systems, electronic payment systems, electronic licensing, transportation demand management systems and public transport priority.

ITS systems have in recent years garnered much attention from transportation researchers in South Africa, and a number of pilot studies and research papers have been published that attempt to quantify the effects and possible benefits of different ITS measures for

[3] www.ertico.com

South Africa. Vanderschuren (2006) completed a thorough review of the available literature on ITS in South Africa. Her findings are given below.

> *In eThekwini the effects of ITS on highways was investigated (e-Mobility). An integrated system, including incident management providing incident information and ramp metering, was introduced (Mkhizi and Thomas, 2005). The estimates show a decrease in speed (44%-45%) as well as a decrease in travel time (27%-32%).*
>
> *Roux and Bester (2002) investigated an HOV lane in the Cape Town region. The implementation of an HOV lane does not look as promising. Although a substantial decrease in travel time (76%) and an incredible increase in average speeds (+319) were measured, the throughput (40%) of the highway decreased substantially. Many vehicles apparently were not able to enter the highway. It needs to be mentioned that this site is further investigated in this thesis.*
>
> *De Jongh-Schreuder (De Jongh-Schreuder and Venter, 2005) investigated an Interchange Control system (kind of ramp metering) at the junction where the two national roads meet. The aim was to optimise traffic flows on the junction. Generally, a decrease in travel time (1%-19%) and an increase in throughput (2%-37%) were estimated. After manual changes to the settings, the decrease in travel time was between 17% and 46%, while the increase in throughput rose to between three percent and 54%.*
>
> *A Public Transport Priority system was investigated for the Soweto-Parktown corridor (Beer, de et all, 2005). A wide range in results was found. An upgrade of signalised intersections generally did not make the service level good enough to cope with future demand. Travel times for private cars increased by eight percent, while the LOS for public transport increased by up to 20%. Priority for public transport showed to be helpful. A decrease in travel time for private cars (20%), as well as public transport (29%), was estimated. If public transport services were extended to the Soweto-Parktown area, the LOS for private cars, as well as public transport, would be similar as in the current situation. Obviously, the number of vehicles would have increased. As mentioned before, in South Africa the majority of people are dependent on public transport. An additional benefit of improving public transport services is poverty alleviation, as the (urban) poor will have extended access to economic opportunities.*

The first published estimate of the benefits of Ramp Metering in South Africa (Clote, 2002) also indicate an increase in speed (+13%) and a decrease in travel time (-28%). In this study, the transferability of developed world models was not investigated. As driver behaviour in the developing world is not necessarily the same as in developed countries, the estimated effects might, therefore, not be completely accurate.

As mentioned before, in the developing world the introduction of Toll Roads is seen as a means to generate additional revenue. South Africa has already implemented toll plazas. The interest in electronic toll collection is, therefore, obvious. Two authors have reported on toll studies conducted. Oberholzer (Oberholzer et al, 2001) finds that the introduction of toll collection on highways will change driver behaviour. Some drivers will use an alternative route, which will decrease the intensities on highways (decreases up to 16%). Due to this change in behaviour, travel time will decrease by between 23% and 31% (Oberholzer et al, 2001). Venter (Venter et al, 2001), the other author, also finds a demand decrease in the toll road (up to 85%).

Based on the seven studies published with regards to South African ITS systems, the following conclusions can be drawn. A general reduction in travel time was found. The only exception was the public transport priority systems. Obviously, a thorough analysis needs to be undertaken to make sure that public transport priority systems work optimally. Furthermore, interchange control and ramp metering predicts an increase in throughput. HOV lanes show a decrease in throughput due to the reduction in capacity offered. In the case of toll roads, a decrease in throughput is measured due to a reduction in the demand. Some travellers decide to take the non-tolled, but longer road.

Road managers should be concerned about the findings with regards to toll roads and HOV lanes. The diversion of traffic due to toll roads often happens through small towns that cannot cope with the additional traffic. Moreover, diversion of heavy traffic causes additional damage to roads that were not designed to accommodate these vehicles.

HOV lanes aim to generate a shift in the demand from Single Occupancy Vehicles to HOV and public transport. If this shift does not occur, the reduction of capacity in congested areas causes unwanted effects. Vehicles will be 'trapped' in the suburbs, not being able to enter the highway, causing an unliveable environment for residents.

Source: Vanderschuren (2006)

1.1.2. Intelligent Speed Adaptation

ISA encompasses the use of in-vehicle mechanical and/or electronic devices to physically control or limit a vehicle's speed, or to notify the driver when he has crossed a certain speed threshold. ISA can have varying levels of influence on a vehicles speed, and a number of systems have been developed to implement each of these different levels.

At the lowest level of influence, an in-vehicle system warns or notifies the driver either via auditory or visual stimulus in the form of a flashing light emitting diode or a liquid crystal display panel that he has crossed a certain speed threshold. Additionally, tactile pedal technology, otherwise known as active accelerator technology, consisting of a small motor that causes the accelerator pedal to vibrate lightly when activated, may be employed to warn the driver when the posted speed limit has been crossed. This system can be coupled with controls on the dashboard or the steering wheel so that the driver can acknowledge the warning and deactivate the system. These types of systems are often termed advisory or informative ISA systems.

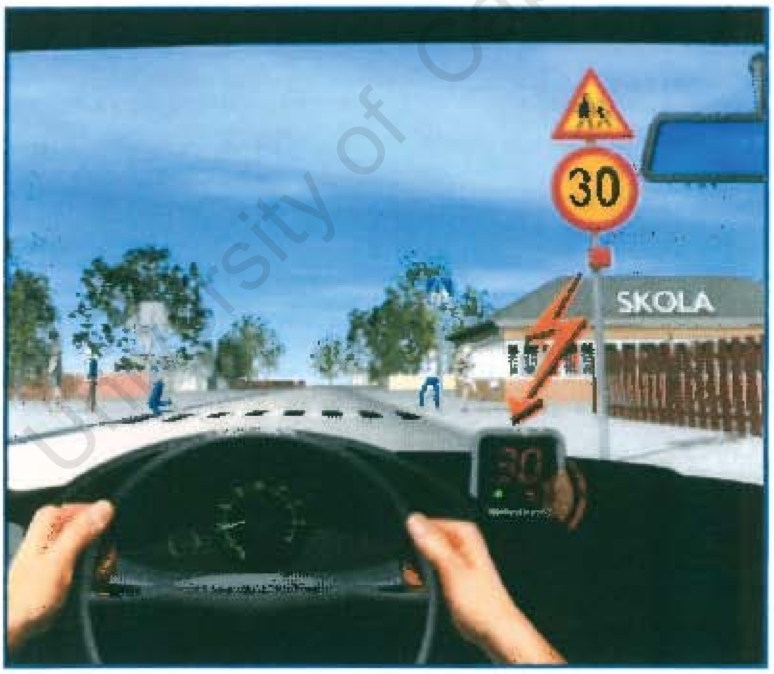

Figure 1: Advisory ISA system[4]

[4]http://www.isa.vv.se/novo/filelib/ppt/isaresultateng.pdf#search=%22filetype%3Apdf%20swedish%20isa%20presentation%22

At an intermediate level of influence, when the driver crosses the speed limit, a hydraulic device attached to the accelerator pedal can be employed to apply a light counterforce to the driver's foot once the speed limit has been reached. The driver then has to apply more force to the accelerator pedal to push through this pressure barrier and deactivate the system. This technology can be coupled with the tactile pedal technology and a combination of auditory or visual warnings.

Figure 2: Force feedback pedal as used in Continental Automotive Systems' ACDIS system[5]

At the highest level of influence, the vehicles fuel supply is regulated so that the vehicle is physically not able to accelerate any faster than the speed limit. This technology, known as dead pedal technology can be coupled with the Adaptive Cruise Control (ACC) systems currently available on higher end luxury motorcars. These systems use low-level radar and intelligent software to determine the proximity of other vehicles or objects and to regulate the speed of the vehicle accordingly.

[5]http://www.contionline.com/generator/www/de/en/cas/cas/themes/press_services/press_archive/press_archive_2004/pr_2004_09_14_acdis/pr_2004_09_14_acdis_en.html

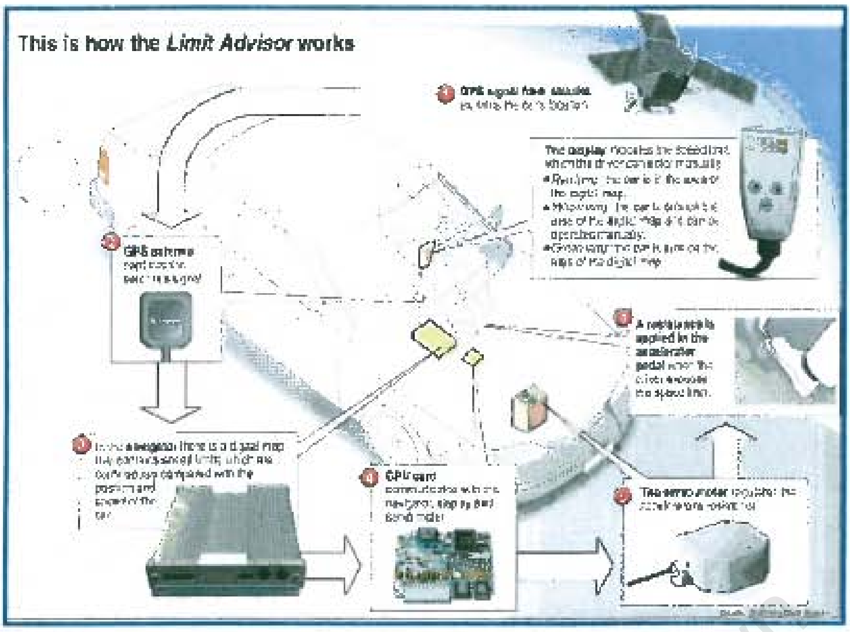

Figure 3: Functionality of the Limit Advisor system developed by Imita.se Active Car Safety products manufacturer[6]

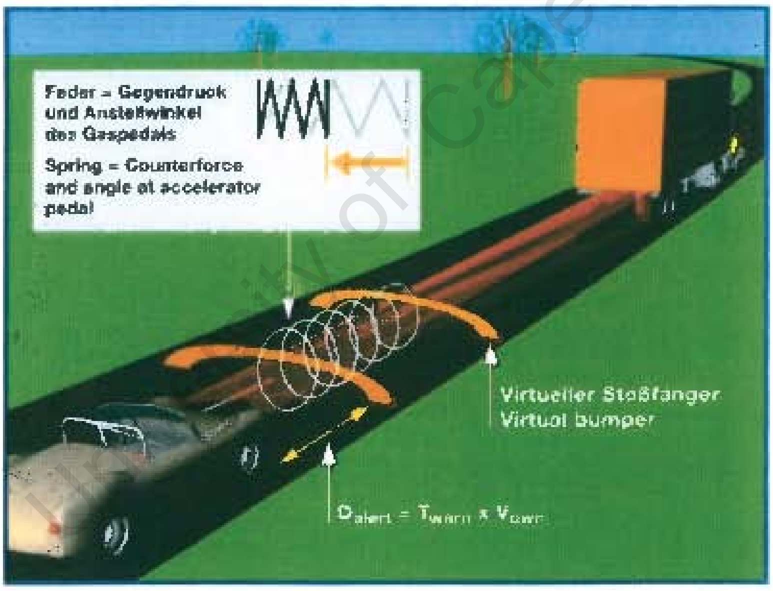

Figure 4: Functionality of an Adaptive Cruise Control System[7]

The technology used to inform the ISA system of the prevailing speed limit has improved remarkably over the years. Currently, there are three distinct categories of the technology.

[6] http://www.imita.se/limit_advisor.htm

[7] http://www.contionline.com/generator/www/de/en/cas/cas/themes/products/powertrain_and_chassis/chassis_control_systems/acdis_en.html

The simplest method is where the vehicle is simply programmed to adhere to a maximum speed limit no matter where it is in the road network (sometimes referred to as static speed control). The next more advanced method relies on Global Positioning Systems (G.P.S.) to locate the vehicle within a pre-programmed grid of links, each with its own relevant speed limit (sometimes referred to as variable speed control). These systems often rely on mapping data provided by a service provider on compact disk, similar to current day GPS navigation systems. The most advanced systems available rely on external radio transponders located on or within road signage or street furniture, each of which is controlled from a central station that monitors traffic conditions, weather conditions and other factors to determine the appropriate speed limits on that link. These radio transponders then signal the passing vehicle equipped with ISA as to what the maximum speed limit may be on that particular stretch of road at that particular time. These systems are often referred to as dynamic speed control.

As can be seen, there are many possible configurations for an ISA system, each with its own set of advantages and disadvantages. The most advanced systems using networks of pole mounted transponders signalling in-vehicle receivers coupled to ACC type ISA systems can adjust speeds on a road network based upon congestion levels, inclement weather and the presence of accidents or road works. These systems can be used to do a lot more than simply lower speed. They can be used to inform the driver of conditions ahead, they can suggest alternative routes and, by combining information distribution with speed attenuation, they can optimise flows along a link and influence the usage patterns of a road network.

However, the more complex or advanced a system is, the more expensive it tends to be. The more advanced systems are also often perceived as highly invasive, and are subject to great resistance from motorists. A lot of research has been done into user attitudes towards ISA systems, and the results generally indicate that although acceptance does increase with exposure, there are still high levels of antagonism towards concepts such as ISA. On the other hand, research indicates that ISA effectiveness increases with market penetration. This shows that for an ISA system to be effective, a lot of work needs to be done to educate and familiarise the broader public about its functioning, aims and benefits, so that an adequate level of market penetration can be achieved.

In its 2003 report on Transport Safety Performance in the E.U. the European Transport Safety Council states "Involvement in road accidents is one of the three leading causes of death and hospital admission for E.U. inhabitants (together with cancer and coronary heart diseases), and it is the leading cause of death for E.U. citizens under 50 years old. Road accidents cause a larger loss of expected life years than any kind of disease in the E.U., due to the low mean age (about 32) of road accident victims."[8] In addition, the O.E.C.D. report on the impact of new technologies on road safety (2003) states that "Most O.E.C.D. countries suffer from similar safety problems. In particular, run-off-the road, intersection and head-on crashes are the main crash types of concern in O.E.C.D. countries, which also share a common set of factors that contribute heavily to all crash types. Specifically, alcohol, speed, fatigue and seatbelt usage patterns all play a role in crash scenarios. As a result, there is a generally common expectation among the countries that four types of technology (collision avoidance, driver status and performance, speed control, and automated enforcement) offer the greatest potential for lessening the number or severity of road crashes."[9] In South Africa, the Arrive Alive campaign states, "Speed on its own plays a contributory role in 75 % of all the crashes on our roads"[10].

There, therefore, seems to be consensus across the globe that any measure that succeeds in reducing the incidence of speeding will have a direct impact on the frequency of road accidents.

ISA was developed in Europe and is currently undergoing trials to clarify the following issues:

- How efficient are the use of road speed management methods based on information technology (ISA) in comparison with traditional physical means?
- How will road users across Europe react to such developments?
- What are suitable strategies for implementation and what obstacles have to be overcome[11]?

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[8] ETSC (European Transport Safety Council) 2003. Transport Safety Performance in the E.U. A Statistical Overview.

[9] Road Safety: Impact of New Technologies – ISBN-92-64-10322-8 ©O.E.C.D. 2003

[10] http://www.transport.gov.za/projects/arrive/closer.html

[11] Network Effects of Intelligent Speed Adaptation; MJWA Vanderschuren, JP Ojungu-Omara, NL Wilson-Harris; 2005

There are a number of empirical studies being conducted across Europe to find answers to the above questions. These trials are also seeking to determine whether one implementation strategy can be applied universally, or whether differing approaches are needed from region to region.

In tandem to the European trials, a South African initiative has been launched in partnership with the University of Cape Town, in part to determine whether European findings correlate in any way to South African conditions, but also to determine how the particular circumstances here affects the possibility of implementing ISA in South Africa.

The Project for Research On Speed adaptation Policies on European Roads (PROSPER) and the earlier Managing Speeds of Traffic on European Roads (MASTER) Project forms the basis of investigation into the applicability of ISA in Europe. South Africa played a minor role in the PROSPER project. Research here was focussed on estimating the possible safety and environmental benefits of ISA in the local situation. Research was, however, constrained by a lack of existing data and funding. It was not possible to conduct field trials with vehicles equipped with ISA systems, as was done in the European sections of the project. Instead, the research approach was to use what existing data there was, supplement it with information obtained from interviews, and then to infer conclusions from this.

1.2. Problem Description

Excessive speed is widely recognised as a major concern on all classes of roads in both rural and urban environments. Higher speeds require a greater distance for the driver to perceive a danger, decide on a course of action and then react accordingly.

In urban areas, the increased complexity of the environment places a greater strain on motorists, often requiring heightened driver awareness and performance. The presence of vulnerable road users also increases the likelihood of fatalities should accidents involving these road users occur.

On rural roads, higher speeds requires greater driver concentration, and accidents often occur when drivers make incorrect judgements with sight distances or sharp curves, often coupled with unexpected events or roadway hazards. Driver perceptions around what is an acceptable speed on a particular stretch of road are influenced by sight distances, road alignment, traffic volumes and the width of the paved way. However, this may not be an appropriate speed for that stretch of road. This raises the question of enforcement, which in South Africa is often inadequate in both urban and rural areas.

In South Africa, we have the additional hazard of having relatively large volumes of pedestrians walking alongside or crossing our arterials and freeways. Livestock in the road reserve is also problematic in certain areas, and poorly maintained roads present dangerous hazards in the form of potholes and other pavement failures.

Various physical or infrastructural tools have been developed to enforce appropriate speeds or the speed limits in both rural and urban roadway scenarios. Locally, traffic-calming elements such as speed humps, speed tables and traffic circles have become relatively widely used in urban environments as speed reducing measures. Speed cameras and traffic police surveillance are used on both urban and rural roads.

The effectiveness of these measures varies depending upon how they are implemented, but their effects have been shown to be localised unless an area wide approach is adopted (Comte S L, Várhelyi A, and Santos J (1997)). This, however, could often be prohibitively expensive, especially here in South Africa.

ISA offers an alternative to these methods in that it deals with excessive speed at the source. It is also not localised in its application in that it allows speed enforcement irrespective of where in the network the vehicle is. These properties make ISA a promising new technology that could significantly lower the cost of excessive speed.

Quantifying the benefits that ISA may have for South Africa would allow decision makers to evaluate its potential and would provide the groundwork and motivation for any further research into this area.

1.3. Aim

The aim of this report was to find, list and quantify all of the benefits that Intelligent Speed Adaptation (ISA) might hold for South Africa. An attempt was made to provide an initial estimate of the cost savings that ISA could offer the country if it is implemented in full.

1.4. Scope and Limitations

The scope of research for this report is focussed on the potential benefits from implementing ISA in South Africa. The implementation methodology for introducing ISA to South Africa has not been investigated, unless where this may impact the potential benefits or where it could potentially cause problems.

ISA has only in recent years begun to be investigated to any serious extent abroad, and almost no empirical research has been undertaken locally. Much of this report, therefore, draws upon the findings of international studies and projects. It was not possible to undertake any sort of empirical research into the effectiveness of ISA in this study due to cost and time constraints.

All quantities or savings calculated and used in this report are to be understood as being preliminary estimates, because they are often derived from international results. They are therefore in certain instances presented as a range of possible values. A much more thorough investigation is required to establish more accurate values for the benefits of ISA.

It must also be noted that some of the larger projects from which this report draws its findings, have not been completed yet, and any findings from these projects are, therefore, still under review.

1.5. Research Method

The research method adopted for this report consists mainly of a review of the existing literature and documentation on ISA and its implementation internationally. A thorough review of work done on ISA for South Africa was done in order to avoid the duplication of findings. The local context was informed by a collation of research done into the transport situation in South Africa. The potential benefits of the implementation of ISA in South Africa were identified, quantified and an attempt was made to monetise these benefits. The findings of the analysis informed any conclusions that formed the basis of the recommendations that were made.

1.6. Content of the Report

The literature review conducted for this report sought to find the prevailing views and opinions, as well as any supporting data regarding the following questions:

- What are the potential benefits of implementing ISA?
- What are the various forms of ISA and what are the relative benefits and disadvantages of each system?
- What obstacles need to be overcome in order to implement an ISA system successfully?
- What are the quantitative benefits associated with ISA?

The questions posed above have been designed to inform a preliminary costing of the benefits of ISA that will form the body of the following chapter. The review thus forms the basis of the research and the analysis will examine what data or information was uncovered during the literature review.

The literature review was conducted using predominantly internet sourced journal papers and information from websites, primarily because there are practically no other forms of literature readily available, or that could be sourced within the time period set aside for the completion of this report.

2. Intelligent Speed Adaptation

2.1. The Effectiveness of ISA Systems

A survey of the potential speed reductions offered by ISA as reported in the available literature was done to determine what the quantitative prospects of implementing ISA would be.

In a paper produced produced for the External Vehicle Speed Control project (EVSC) initiated by the UK Department of Transport, Carsten and Fowkes (1998) identified two possible effects of the large-scale implementation of an ISA system. These were defined as translation and transformation.

Translation is where the shape of the speed distribution curve remains essentially constant, but is translated downwards with respect to speed. The figure below illustrates:

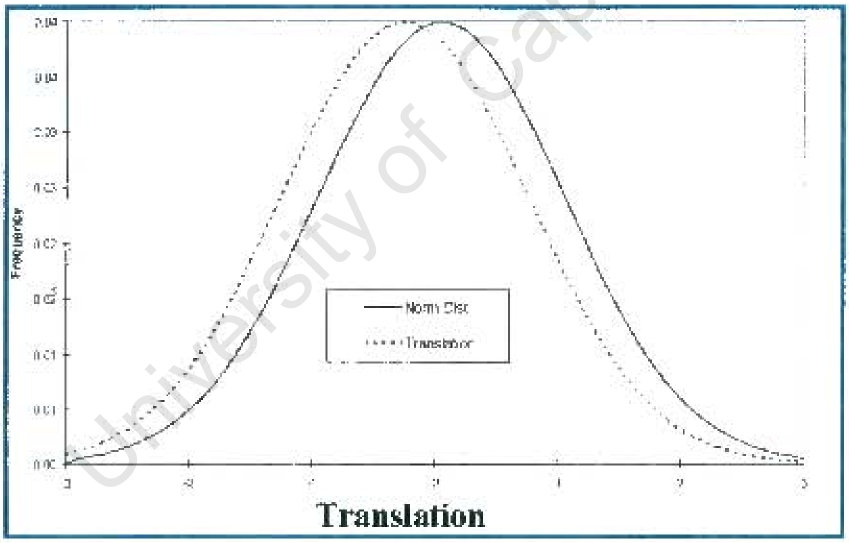

Figure 5: Translation of speed distribution

Transformation was defined as the situation, expected to come about with the implementation of mandatory ISA systems, where the speed distribution is truncated at the posted speed limit, as is illustrated in Figure 6:

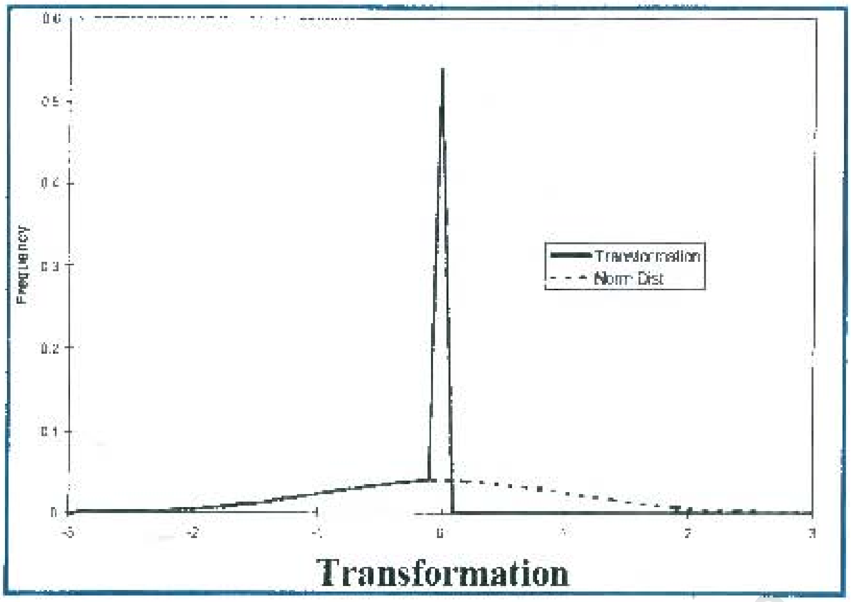

Figure 6: Transformation of speed distribution

A paper by Rook, Hogema and van der Horst (2005) detailed the findings of two experiments designed to measure the effective drop in mean speeds over a given course in both urban and rural driving environments. The ISA measures included in the vehicles were as follows:

Experiment (a) was defined as:

- low-force ISA: The active gas pedal produced a clearly distinguishable, and easy to overrule counter force, when exceeding the speed limit, which was mainly informative in nature.
- high-force ISA: ISA equipped with an active gas pedal with a more strongly dimensioned counter force and therefore much more compulsory in nature.
- Control: No ISA (as a reference for comparison of driving behaviour and workload)

Experiment (b) was defined as:

- tactile gas pedal: The tactile gas pedal produced a clearly distinguishable vibration modulated by a block-signal, when exceeding the speed limit for approximately 1 percent, which was mainly informative in nature.

- dead throttle: ISA equipped with dead throttle, which restrained the driver from exceeding the speed limit. Additionally, a similar vibration as used in the tactile gas pedal is produced at the pedal position on the speed limit plus approximately 10 percent of the pedal stroke.
- Control: No ISA.

Within both experiments, the three conditions were all varied within subjects. The order of presentation of these conditions were balanced over subjects (Figure 7).

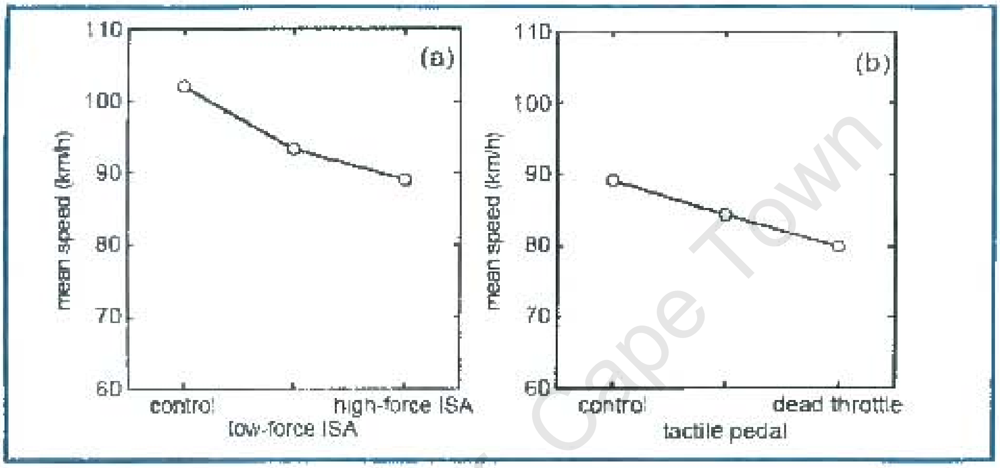

Figure 7: Mean free-driving speed as a function of road environment and ISA condition.

The results show that in urban environments, a drop in travelling speed was measured.

The results are examined further in the Table 1.

	Mean speeds (km/h)			Absolute Reduction (km/h)		Percentage Reduction (%)	
	Control	ISA 1	ISA 2	ISA 1	ISA 2	ISA 1	ISA 2
Exp. (a)	102	93.3	89.1	8.7	12.9	8.5	12.6
Exp. (b)	89.3	84.3	80	5	9.3	5.6	10.4

Table 1: Reduction of the mean free-driving speed: absolute (km/h) and percentage reduction (ISA1: low-force ISA – tactile pedal; ISA2: high-force ISA – dead throttle).

It is important to note that the posted speed limit for both experiments was 80km/h. The implication is that ISA (excluding the dead throttle alternative described above, which by default enforces the posted speed limit) does not necessarily ensure that motorists would comply with speed limits at all times. ISA does, however, have the potential to lower mean driving speeds by between five and 13%.

Another study, undertaken by Hogema and van der Horst (2000), also concluded that a mandatory ISA system yielded the most positive results. The study was undertaken using the TNO Human Factors Research Institute Driving Simulator, a detailed description is given by Hoekstra, van der Horst and Kaptein (1997). The simulations were run to evaluate the effects of combining Adaptive Cruise Control (ACC) with an ISA system. The ISA system was run on two levels, being informative (the driver is notified of the prevailing speed limits but can act as he sees fit) and intervening (the driver is notified of the prevailing speed limits and the ACC system reduces the speed to the appropriate level).

The intervening system is for all intents and purposes very similar to a mandatory as described elsewhere in this report, but the in these simulations the driver was allowed to disable the ACC system.

The study considered three scenarios, these being:

- a 100 km/h speed limit for no reason,
- an 80 km/h speed limit due to a relatively sharp curve,
- a 50 km/h speed limit due to a sudden traffic queue.

A simulation was also run for a standard free flowing motorway-style operating environment with a speed limit of 120km/h. The simulation yielded the results provided in Figure 8:

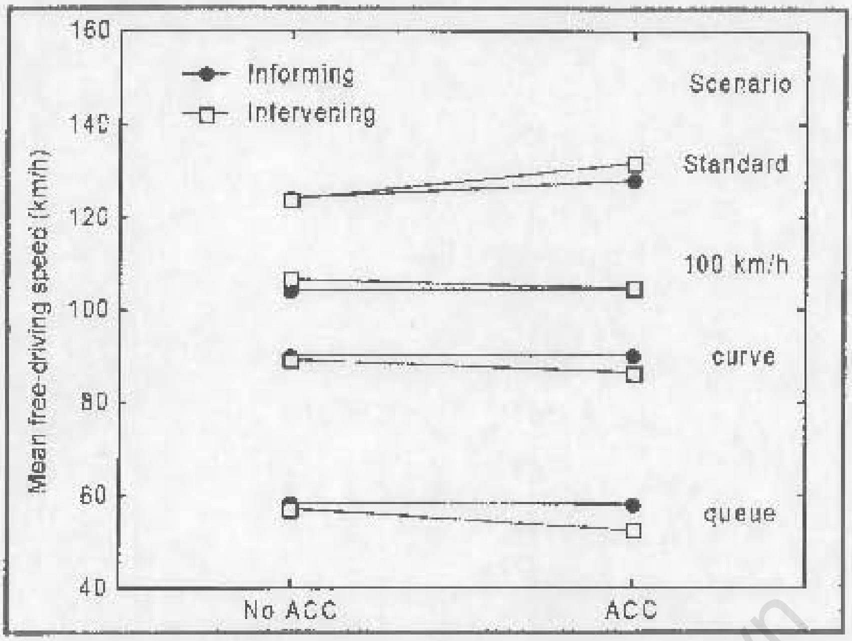

Figure 8: Mean free-driving speed as a function of presence of ACC and scenario

The results show that, in general, intervening ISA systems yield better results than informative systems. There was very little to no change in vehicle speed when the informative system was used, whereas there was a marked decrease in mean speed when the intervening system was used. Although the source from which this data was obtained provided no more detailed data as to the exact speed differences, it can be inferred from the chart that the decrease was between 5 and 10km/h.

This result is very similar to what was obtained from the study done by Rook, Hogema and van der Horst (2005). It could, therefore, be assumed that ISA systems can provide a range of positive results in improving adherence to speed restrictions.

At the least intrusive level, such as that investigated by Hogema and van der Horst (2000) in the form of their purely informative ISA/ACC system, the speed reductions are negligible. A higher level or more intrusive form of ISA, such as the combination of the low force tactile accelerator pedal ISA warning system, as discussed by Rook, Hogema and van der Horst (2005), the results are improved. The average speed reduction measured here was between 5 and 9km/h. At the highest level, represented by the intervening ISA/ACC systems of Hogema and van der Horst (2000), and the high force-dead throttle combination of Rook, Hogema and van der Horst (2005), the results were found to be between 10 and 13km/h in both studies.

2.2. The Acceptance of ISA Systems

One of the primary concerns around the viability of ISA systems is that of user or public perceptions and acceptance of the systems. Negative connotations to ISA such as the "big brother" analogy are commonly raised in the media[12].

A number of studies have been conducted into user acceptance in Europe. Rook, Hoegema and Van der Horst (2005) ran a series of tests with volunteer drivers in a driving simulator. Volunteers were requested to fill in questionnaires about their driving styles and attitudes towards speeding, as well as their experience of the ISA systems tested before and after the test runs.

The study concluded that low-force ISA is more acceptable than high-force ISA, and it was suggested that the tactile gas pedal is more acceptable than the dead throttle. These findings are in line with the hypothesis that the more intrusive the level of ISA, the greater the resistance to its implementation will be.

The PROSPER project also looked at user acceptance, and the working report[13] (The project is still underway) found that the acceptance of ISA was fairly high among most test drivers. The test users in all trials also stated that they drove more comfortably with ISA and that they paid more attention in the traffic because of the presence of the system.

The study found that when asked how they vote in a referendum on the introduction of mandatory ISA for all road users, the general public was in favour of the concept. 66.1% would vote in favour, 22% said they would vote against ISA and 11.9% had no opinion.

Katteler (2005) conducted a study into the acceptance of mandatory ISA systems. He defined a mandatory ISA system as one that does not allow the vehicle to breach the speed limit at any time or anywhere on the road network. His study was conducted using questionnaires given to volunteer users before, during and after they were given ISA equipped vehicles to use for a period of approximately two months. In this manner, he was able to track changes in user perceptions throughout their exposure to the ISA system.

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12 The back-seat Big Brother: Lara Bradley; Irish Independent; 26 July 2004; COPYRIGHT 2004 Financial Times Information Ltd.

13 Olsson, Transek Deliverable 2.5; Project for Research On Speed adaptation Policies on European Roads; November 2004

He found that more than 60% of the some 120 test drivers had a positive attitude to the ISA system once they had had an initial practice run with the vehicles equipped with it. The acceptance was still at that level a few months after the tests were conducted.

This result is surprising in that it goes against the belief that acceptance of ISA decreases as the level of intrusion of the ISA system into driver control increases. It could, however, be argued that since the drivers were not exposed to other types of ISA systems, they had nothing to compare the test system to. The study also found that acceptance of mandatory ISA systems increased the lower the order of the road, with test drivers showing more support for ISA on residential roads than on secondary and tertiary roads.

Attitudinal studies have been a major component of research on ISA. A study by Persson et al (1993) in Lund, Sweden, found that drivers were more positive about the benefits of mandatory speed limiters after having driven in the ISA car. Subsequent studies have tended to confirm this increase in positive attitudes.

Almqvist and Nygård (1997) conducted trials in Eslöv, Sweden They found that 73% of participants rated themselves as more positive about ISA after using it. Their results indicated a strong preference for the feedback from the active accelerator pedal over auditory and visual warnings.

Trials conducted by Comte (1999), found indications of more positive attitudes after using ISA. Test subjects rated the mandatory system as more "useful" after they had used than when they were questioned beforehand. They also rated it less negatively in terms of "satisfaction", although they were still quite negative about it in this respect. It was also found that the drivers who drove with the voluntary system were much more positive about their experiences than the ones who drove with the mandatory system.

Studies regarding ISA acceptance appears, therefore, to be in agreement regarding the fact that user acceptance increases with exposure to ISA, and acceptance decreases with the level of intrusiveness into driver control. However, it does appear that the European public is at least marginally in favour of the concept. Further education and awareness programmes may influence this situation positively. No comment can, however, be given on the levels of acceptance in South Africa and further research in this area would certainly be required to further the develop ISA locally.

3. Estimated Effects of ISA in South Africa

3.1. Safety

3.1.1. Speed, Speed Limits and Road Accidents

Intelligent speed adaptation has developed from the realisation that speed plays a critical role in the severity and frequency of road accidents. The Arrive Alive website notes that speed is regarded as a factor in nearly one third of all fatal road accidents in South Africa[14]. It also states that speed contributes to both the frequency and the severity of accidents, because:

- speed reduces the amount of available time needed to avoid a crash/to stop the vehicle;
- speed extends the distance a vehicle travels while the driver reacts to a dangerous situation; and
- speed reduces the ability of the driver to steer safely around curves or objects on the road.

Central to the complexities surrounding speeding on public roads is the setting of speed limits. Speed limits on public roads directly influence the mean speed on a link and dictate the operating speeds of the link. The following figure illustrates the linear relationship between an increasing speed limit (which influences the operating speed on the link) and an increase in the number of fatalities experienced on the link.

[14] http://www.arrivealive.co.za/pages.asp?mc=speeding&nc=accidentsspeed

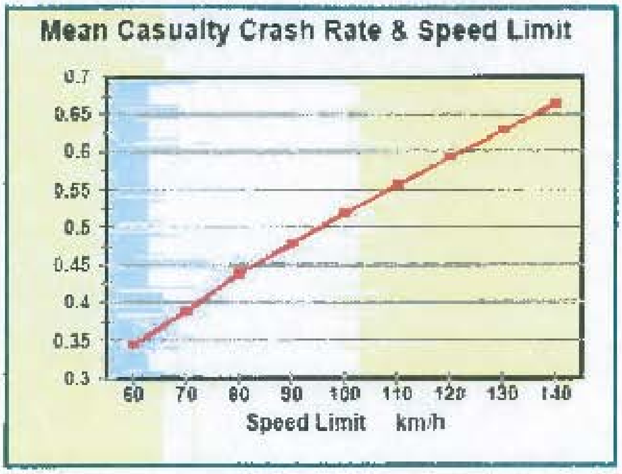

Figure 9: Mean Casualty Crash Rate and Speed Limit[15]

Figure 9 clearly illustrates that as the speed limit or operating speeds increase on a link, the percentage of casualties occurring in accidents on that link increases as well.

Speed limits are primarily determined by the geometric alignment of the road, but a number of other factors play an important role when the posted limits are set. These include, but are not limited to:

- the number of lanes;
- whether it is a divided or undivided road;
- the presence or absence of shoulders;
- the quality and type of surfacing on the roadway and shoulders;
- the road construction method (e.g., high or low crown, thickness of underbed);
- how often the road is rebuilt or undergoes major repairs;
- the driver visibility (e.g., line of sight for cars entering the road at much lower speeds);
- the superelevation in curves;
- the number of and radius of curves;
- the number of access points;
- the presence of driver distractions (e.g., scenic route);
- the normal range of weather conditions (e.g., snow, ice, fog);
- the expected volume of traffic;

[15] http://www.arrivealive.co.za/pages.asp?mc=speeding&nc=SpeedFactor

- the accident patterns of drivers on comparable roads;
- the location of the road (e.g., urban in neighbourhood with children, limited access without pedestrians or slow vehicles).

The setting of speed limits in urban environments can become a contentious issue. In certain instances, the decision may be influenced by political concerns. Inappropriate speed limits run the risk of low driver compliance and of losing overall driver support. Additionally they can create dangerous situations arising from driver frustration.

The enforcement of what is perceived of as an unjustifiably low speed limit by speed cameras has already created much controversy in the UK. A Financial Times report from 2004 notes that "speed cameras have become hugely unpopular in Britain where more than 700 of the 5,000 fixed cameras have been shot at, blown up or pulled down by irate drivers. The cameras are widely thought to be little more than money-making schemes for the private companies that own them."[16]

A study done for the Federal Highway Administration of the US department of Transport (Stuster et al, 1998) included the data presented in Table 2 to illustrate the effects of raising the speed limit from 55mph to 65mph.

	mi/h	km/h
Brown et al. (1990)	2.1	3.9
Freedman and Esterlitz (1980)	2.8	4.5
Mace and Heckard (1991)	3.5	5.6
Pfefer, Stenzel and Lee (1991)	4 - 5	6 - 8
Parker (1997)	0.2 - 2.3	0.3 - 3.7

Table 2: Effects of raising the speed limit from 55mph to 65mph

Source: Stuster et al, 1998

The document cites Finch (Finch et al. 1994) as having analysed the changes in speeds from raising and lowering speed limits reported in a number of international studies and found that the change in mean traffic speed is roughly one-fourth of the change in the

[16]COPYRIGHT 2004 Financial Times Information Ltd; The back-seat Big Brother, July 26, 2004

posted limit. It also cites Knowles et al. (1997) as having reported similar findings from observational before and after studies in Canada.

It, therefore, seem that a change in the speed limit leads to a similar change in operating speeds on that link. It is also interesting to note then that the majority of studies undertaken seem to indicate that where there is a change in speed, there is a corresponding change in the frequency of road accidents.

Intensive research undertaken by the C.S.I.R. in South Africa from the mid 1970's to the mid 1980's, it was found that the lowering of speed limits (resulting in lower operating speeds on the rural road network) had an overwhelming effect on the occurrence of road accidents. A reduction in the speed limit from 120 km/h to 80 km/h resulted in a decrease in the casualty crash rate (number of casualty crashes per million vehicle kilometres travel) from about 0,59 to about 0,44[17]. The tables (Stuster et al, 1998) given in appendix 1 cite international case studies that indicate similar findings.

It can, therefore, be concluded based on international literature that speed is recognised as a major contributing factor to road accidents. A 2003 report issued by the O.E.C.D. (Organisation for Economic Development and Cooperation) on the impacts of new technologies on road safety notes that:

"Inappropriate and excessive speed are primary causal factors of traffic crashes in O.E.C.D. countries (O.E.C.D. 2001, 1999). In addition, there is overwhelming evidence that the risk of injuries and fatalities increases as a function of pre-crash speed, (Baruya, 1998; Finch et al., 1994; Transportation Research Board, 1998)"[18].

ISA in its various forms directly addresses the issue of inappropriate speeds or the transgression of the local posted speed limits (based upon the assumption that these are appropriate). Therefore, in order to determine what the advantages of ISA are, we would first have to consider what the disadvantages of excessive speed are.

As was mentioned previously, the primary disadvantage of excessive speed most cited in literature is that of road safety. However, a number of other advantages to the

[17] http://www.arrivealive.co.za/pages.asp?mc=speeding&nc=SpeedFactor

[18] O.E.C.D. 2003; Road Safety: Impact of New Technologies, pg 22

implementation of ISA are also commonly mentioned in the literature. These are examined further in the next section of this report.

3.1.2. The Cost of Road Accidents

The high incidence of road accidents globally places a great strain on hospitals and emergency services. On average, 30-35 people die on South African roads each day, another 20 are permanently disabled and 100 are seriously injured. In 2005 there were 11 616 fatal accidents, a 10.9 percent increase on the 2004 total. The C.S.I.R. has estimated that road accidents have an overall annual cost equivalent to R38 billion[19].

If one considers that excessive speed is said to account for nearly one third of all road accidents in South Africa[20], applying the C.S.I.R.'s figure of R38 billion gives an estimated cost of R11.4 billion annually, purely as a result of speeding motorists.

Reynolds (1956) composed a listing of the costs of road accidents that could be evaluated quantitatively by an economist. He cited the following costs:

- Damage to property;
- Medical costs associated with the treatment of casualties;
- Administrative insurance costs which can be ascribed to the occurrence of accidents;
- The net reduction in output of goods and service due to the loss of output from people who have been killed.

Damage to property was calculated considering only the cost of the vehicles involved in the accidents. The administrative costs of insurance only considered the costs associated with motor insurance, and did not include medical aid or life insurances.

[19] http://www.finance.gov.za/documents/budget/2006/review/chapter%206.pdf; The 2006 budget review issued by the National Department of Finance of South Africa; ch 6; 2006

[20] http://www.arrivealive.co.za/pages.asp?mc=speeding&nc=accidentsspeed

Item	Cost (£)	Percentage
Damage to property	18 ±4	25
Cost of medical treatment	6 ±2	8.3
Administrative cost of motor insurance	12 ±6	16.7
Net loss of output due to deaths	10 ±2	13.9
Loss of output due to injury	26 ±13	36.1
Total	**18 ±4**	**100**

Table 3: Proportional relationships of costs due to road accidents

Source: Reynolds (1952)

The exact figures are no longer relevant since they date back to the 1950's. It is also doubtful whether their proportional relationships to each other are still relevant and since the data is from the United Kingdom, whether these proportional relationships are applicable to the South African situation.

It is of interest to note that according to Reynolds, approximately 50% of the total cost of road accidents (Table 3) is due to the loss of potential output of goods and services of those killed or injured in road accidents. These costs can be considered longer-term costs, since they accumulate over the period that the deceased individual would have been actively working, or that the injured person is not able to work. By implication, the immediate costs of an accident are, therefore, approximately 50% of the total cost of road accidents.

These costs are borne in part by society as a whole, and in part by the individual or the deceased individuals surviving relations. As mentioned earlier, excessive speed not only increases the likelihood of an accident, but also the severity of the accident when it does occur. It, therefore, follows that the higher the incidence of speeding, the higher the overall costs to society.

In addition to the costs noted by Reynolds (1952), road accidents very often lead to medical insurance claims and in the case of fatalities, life insurance claims. In South Africa, there are also claims made from the Road Accident Fund (RAF). In 2004/05 the Road

Accident Fund spent R5,5 billion in settling the claims of road accident victims, and the accumulated claims backlog rose to an estimated R24 billion[21].

Reynolds (1952) also noted the following further costs that he said could not be accurately quantified either due to a lack of data or due to the nature of the costs:

- Administrative costs due to the occurrence of accidents, incurred by the police, the government and lawyers. These cannot be separated from the cost incurred during the performance of their other duties.
- The economic effects of a smaller population; with the existence of road accidents the population of Great Britain will be slightly smaller and of a slightly different age/sex occupational structure.
- The effect of transfers of income within the community. With the occurrence of accidents, income is transferred from the rest of the community in compensation to those who suffer loss from the accidents, without any necessary change in the resources at the disposal of the community. It is impossible to estimate this change.

Reynolds (1952) notes the significance of the costs incurred by the authorities and the legal fraternity in dealing or processing road accidents, but fails to mention anything regarding the opportunity costs that the time lost in dealing with road accidents represents. Police, traffic officials, government officials, hospital staff, emergency assistance personnel and road maintenance personnel, all play a role when an accident occurs. As an illustration of this point, in all of the South African National Roads Agency Limited's (SANRAL) routine road maintenance contracts there are budgeted amounts of approximately 5% of the contracts value set aside for the provision of emergency personnel for accident scene management.

The costs represented by the time all these parties spend in dealing with road accidents, and more specifically, road accidents where excessive speed was the contributing factor, could equal or even surpass the costs directly related to the accident itself. In a 2003 article listed on the Arrive Alive campaign's website[22] a spokesperson for the Automobile

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[21] http://www.finance.gov.za/documents/budget/2006/review/chapter%206.pdf; The 2006 budget review issued by the National Department of Finance of South Africa; ch 6; 2006

[22] http://www.arrivealive.co.za/oldletter.asp?p=letter&t=media&id=15

Association of South Africa, Mr Gary Ronald said that fatal accidents cost the government approximately R400 000 each (in 2003). This amount included the dead person's loss of earnings, the emergency services' time at the accident scene, medical costs and insurance. This figure, when combined with the total road accident fatalities in South Africa for 2005 of 11 616 cited by the C.S.I.R.[23] and assuming a 10% annual inflation in the cost (giving R484 000 for 2005), yields a total cost of R5 622 144 000.

Barnett, Clough and McWha (1999) presented a paper at the Road Saftey, Policing and Education Conference in Canberra, Australia in 1999 that outlines the methods used to quantify the social cost of road accidents. They noted that the costs of accidents could be divided or categorised in the following way:

- Real resource costs, such as the damage and consequent repair to vehicles and roadside structures; the opportunity cost of ambulance and traffic patrol staff and equipment attending to the scene of accidents; judicial costs incurred in prosecuting and imprisoning offenders; the costs of medical treatment and funeral services brought forward in time;
- Output costs, such as the productive work lost from individuals through accident-induced injury and impairment; accident-induced traffic delays; and transitional costs, such as costs incurred in recruiting and training replacement staff; and
- Psychological and social costs, reflecting most individuals' aversion to risks to their own, or others', safety.

They noted that it is generally recognised that road accidents often cause significant disruptions to traffic flow. However, the probability of an accident and hence of accident induced delays on any particular stretch of road might be very low. On a national or regional scale, the cumulative impact of accident-induced delays might be significant enough to warrant its inclusion in the calculation of accident costs to society as a whole.

According to Barnett et al (1999), there were 22 785 reported injury accidents in New Zealand during 1995 and 1996. The total social costs of these accidents were estimated in

[23] http://www.finance.gov.za/documents/budget/2006/review/chapter%206.pdf; The 2006 budget review issued by the National Department of Finance of South Africa; ch 6; 2006

1998 to be in the region of NZ$5 581 million. These accidents were categorised into fatal, serious and minor according to the severity of the accident. The findings are given below:

	Fatal	Serious	Minor	Total
Total cost by accident type NZ$	2573	2079	929	5581
Total cost by injury type NZ$	2479	2106	996	5581

Table 4: Total social cost of road accidents in 1998 prices (1000 NZ$)

Average cost per accident NZ$	Fatal	Serious	Minor
Hospital/medical	6100	7800	100
Emergency/pre-hospital	3100	1200	600
Follow-on	1500	3800	100
Sub-total Medical	10700	12800	800
Lost output from incapacitation	300	600	200
Loss of life/permanent impairment	2659400	218400	12000
Property damage	6700	4300	3500
Legal and court costs	6300	1000	300
Total	2683500	237200	16900

Table 5: Average social cost of road accidents per accident in 1998 prices (NZ$)

Average cost per injury NZ$	Fatal	Serious	Minor
Hospital/medical	2600	6500	100
Emergency/pre-hospital	2100	800	500
Follow-on		3200	100
Sub-total Medical	4700	10500	700
Lost output from incapacitation		400	200
Loss of life/permanent impairment	2248000	179900	9000
Property damage	3500	2400	2600
Legal and court costs	5100	800	200
Total	2262300	194100	12600

Table 6: Average social cost of road accidents per injury in 1998 prices (NZ$)[24]

The data was used to calculate the average cost per fatal accident, per serious accident and per minor accident. The average social costs of road accidents were estimated to be

[24] Note: estimates have been rounded to the nearest $100 and may not sum precisely

NZ$2.684 million per fatal accident, NZ$237,200 per serious accident and NZ$16,900 per minor accident (June 1998 NZ$ terms). The corresponding figures per injury are NZ$2.262 million per fatal injury, NZ$194,100 per serious injury and NZ$12,600 per minor injury.

It is important to note that the cost per accident will always be greater than the cost per injury, since a fatal accident will involve at least one fatality and may include a number of non-fatal injuries.

In June 1998, NZ$1 cost R2.66[25]. So a quick conversion yields the estimates provided in Table 7:

	Fatal	Serious	Minor
Accident	R7 139 440	R630 952	R44 954
Injury	R6 016 920	R516 306	R33 516

Table 7: Average cost of accidents converted into June 1998 ZAR

The figures in Table 7 are quite startling, assuming a consumer price inflation index of on average 4% since 1998, the figures for 2006 would have increased as follows:

	Fatal	Serious	Minor
Accident	R9 770 816.62	R863 501.37	R61 522.65
Injury	R8 234 570.49	R706 600.41	R45 868.96

Table 8: Average cost of accidents adjusted to 2006 terms

It must be noted that these costs do not account for the cost of road accident induced traffic delays.

25 http://www.discount-currency-exchange.com/historical-rates/discount-currency-ZAR-Y1998-M6-D15.cfm?CFID=9299907&CFTOKEN=85804132

3.2. Operating Costs

3.2.1. Incident-Induced Congestion Delay

3.2.1.1. Introduction

In the event of an accident on any particular link, significant disruption is caused to the flow of traffic along that link. This leads directly to costs associated with an increase in the travel time of motorists and an increase in the running costs of the vehicles using that link.

The extent of the delay may vary significantly depending on the class of the road and the traffic volume it carries, the day and the time of day the accident occurred and the severity of the accident.

Incident induced delay has been calculated using a variety of methods. Morales (1986) described the delay by combining two cumulative volume curves, one for arrival at the incident site and one for departure from the incident site. The area between the curves represented the delay because of the incident.

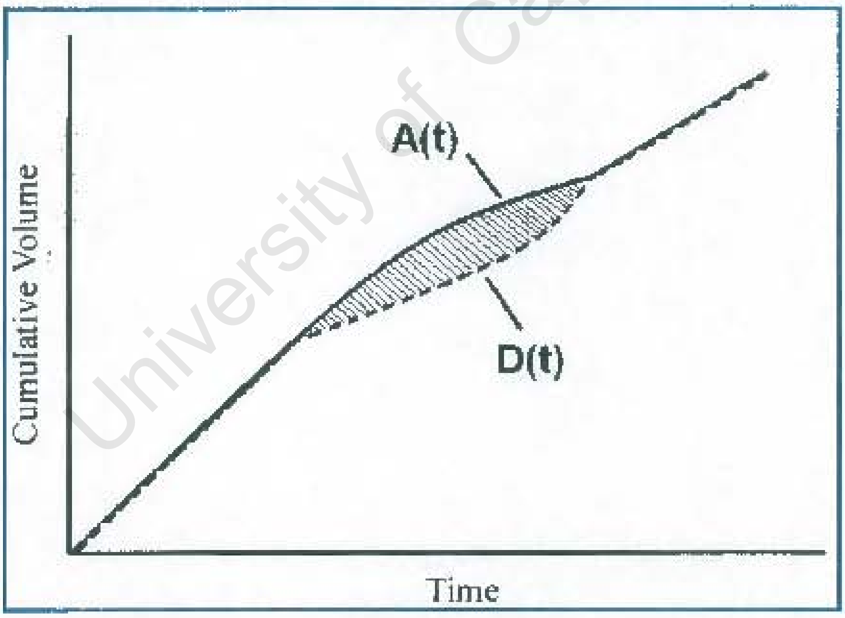

Figure 10: Representation of Incident Induced Delay

Source: Morales (1986)

In Figure 10, A (t) represents the cumulative volume for vehicles arrival and D (t) represents the cumulative volume for vehicles departing. The shaded area represents the delay experienced due to the incident.

3.2.1.2. Quantifying Incident Induced Delay

Skabardonis, Varaiya and Petty (2002) studied recurrent and non-recurrent congestion in California. They found that non-recurrent congestion delay, or incident induced congestion delay, accounts for between 13 and 30% of the total congestion delay. They noted that the portion of non-recurrent congestion delay depends on the study section characteristics, frequency and type of incidents, and the presence of recurrent congestion. Most importantly, the percentage of non-recurrent delay depends on the extent of recurrent delay. Clearly, if there is no recurrent delay, non-recurrent delay will account for 100 % of total delay.

Kwon, Mauch and Varaiya (2005) investigated the components of congestion in a study conducted along the western seaboard of the USA. They found that on the links they studied, incident induced delay accounted for 18% of the total congestion delay. Furthermore, a regression analysis of total daily delay vs. number of accidents for all of Los Angeles yields a slope of 560 vehicle-hours per accident.

According to statistics released by the South African National Department of Transport[26], in 1998 in South Africa there were 511 605 recorded accidents of varying severity across the country. Applying Kwon, Mauch and Varaiya's (2005) value of 560 vehicle hours per accident yields the startling figure of 286 498 800 vehicle hours attributed to accident induced delay per year. That equates to approximately 32682.95 vehicle years per year.

Naturally, these values cannot simply be applied indiscriminately, because conditions vary from place to place. However, this can give one an indication of the magnitude of the problem, and the potential savings if it can be resolved.

Interestingly, none of the studies mentioned consider the effects of incident-induced delay on the opposing lane's traffic. Theoretically, there should be no delay, as the incident occurred in the other lane, but practical knowledge indicates that an incident can and often does affect traffic on both carriageways, irrespective of whether the incident occurred across both lanes. This phenomenon is colloquially referred to as "rubbernecking". A study by Masinick and Teng (2004) found that rubbernecking occurred at approximately 10% of all accidents scenes causing an average of 12.7% reduction in capacity of the lane in

[26] http://www.transport.gov.za/library/docs/stats/2001/statistics.html#2.4

question. The average delay due to rubbernecking was found to be around 107veh hours per incident.

The study (Masinick and Teng, 2004) found that the likelihood of rubbernecking occurring is related to a number of factors. These included the timing of peak periods, the weather, the presence of barriers and the volume of weekday travel. The extent of the delay is influenced by the duration of the incident, the presence of barriers and the volume-capacity ratios of traffic before the occurrence of the incident. The capacity reduction ratio is influenced by the peak periods, the duration of the incident, and the time of day or night that the incident occurred.

As it is, the study shows that the incidence of rubbernecking can be significant in its contribution to overall incident induced traffic congestion, and should, therefore, be included when calculating the costs of incident induced traffic congestion. This is especially relevant when trying to estimate the potential impact an ISA system might have on travel patterns on the road network.

If an ISA system is capable of reducing the incidence of speeding on the road network, and consequently reducing the incidence of speed related accidents, it will have an impact on the incidence of incident induced traffic congestion. This influence can be quantified, because all of the inputs are quantifiable.

Using Masinick and Tengs (2004) values of 10% occurrence of rubbernecking, and 107veh hours per incident of rubbernecking, one can then begin to form a more accurate estimate of what the total annual delay figures might be for South Africa. The assumption is naturally that these values are relevant in South Africa.

Using Kwon, Mauch and Varaiya's (2005) value of 560 vehicle hours per accident we calculated earlier that the total accident induced delay was approximately 286 498 800 vehicle hours annually. This was if one used the 1998 accident rate of 511 605 accidents. Now, 10% of 511 605 is approximately 51 160 accidents. Masinick and Teng (2004) contend that each incident adds an additional 107 vehicle hours. This would correspond to a value of 5 474 120 vehicle hours annually. Amending the value derived earlier with the value for rubbernecking gives 291 972 920 vehicle hours annually. This equates to approximately 33307.43 vehicle years annually. This would indicate that rubbernecking might account for approximately 2% of all incident-induced delay.

In order to determine the monetary value of incident induced delay, a number of factors, such as fuel consumption, vehicle maintenance costs, the cost of time delays and the additional environmental costs have to be taken into account. The quantity of time delay caused by incident induced congestion delay has now been established, and the value of that time will be derived per factor during the sections that follow.

3.2.2. Fuel consumption

Fuel consumption is directly related to vehicle speed and to engine loading. Instinct leads one to assume that as vehicle speed increases, fuel consumption increases as well. The reality, however, is a little more complex.

Figure 11 shows the relationship between instantaneous speed and fuel consumption for a typical internal combustion engine using the Otto cycle.

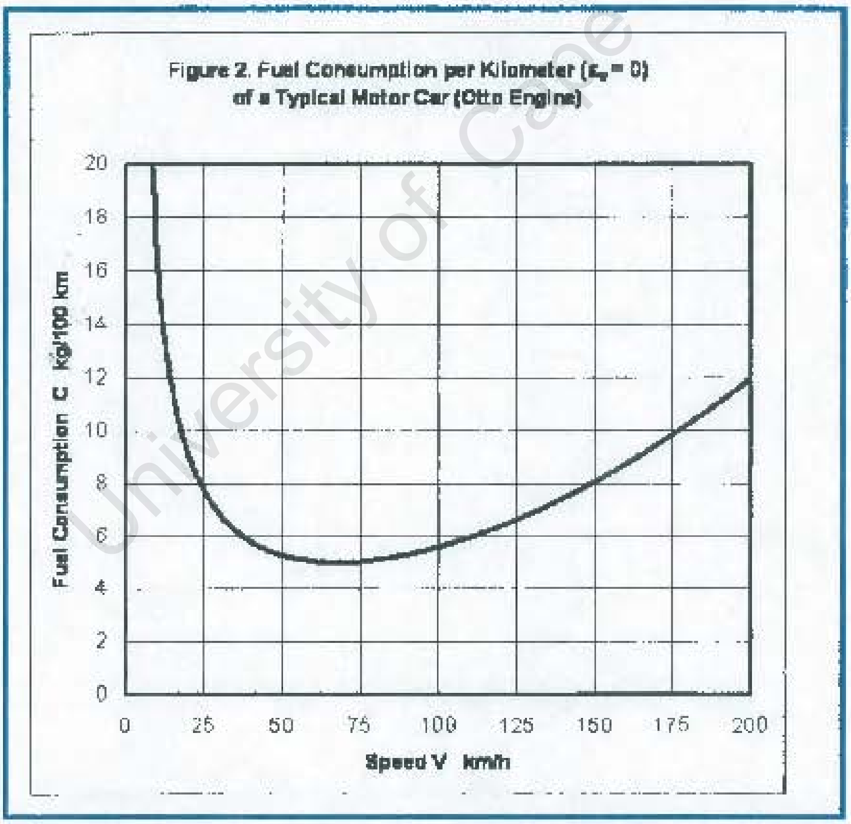

Figure 11: The relationship between speed and fuel consumption[27]

[27] http://www.verkehrswissenschaftler.de/berichte/bericht_4.htm

The figure indicates that the optimum cruising speed for lowest fuel consumption is approximately 70km/h. The obvious implication is that over a fixed distance, a vehicle travelling at speeds of between 50km/h and 70km/h will use the least amount of fuel. This is important as it implies that the benefits that ISA offers must be viewed in the context of what the desired outcome from its implementation is. If ISA is implemented at a mandatory level in a residential area, with the aim of improving the road safety in the area, and the imposed speed limit is lower than approximately 50km/h, then it cannot easily be argued that ISA has any fuel consumption benefits for that particular application. In fact, the additional fuel costs incurred due to the introduction of ISA should be weighed against the benefits associated with an increase in safety.

However, should ISA be implemented on a freeway with the aim being to increase capacity and avoid congestion by lowering speeds from 120km/h to 60km/h, then, depending on the speed reduction in question and the associated increase in travel time, it could be argued that there would be fuel savings.

ISA works by limiting a vehicle to the posted speed limit. Assuming that all vehicles are fitted with a speed regulating ISA device, all vehicles would be restricted to the posted speed limit. There would, therefore, be a potential fuel saving in proportion to the frequency of speeding. Quantifying the potential savings in fuel consumption due to ISA would require ascertaining what proportion of the total kilometres travelled is travelled at above the speed limit. Although information regarding speed transgressions is commonly available, this data is not necessarily representative of the actual proportions of speeding. This is, because it is reliant on data from either fines (enforcement may not be pervasive enough to form a realistic picture of the situation on the roads), or traffic monitoring stations, (often simply counting stations, which are only able to estimate speeds, and not widely distributed enough to draw any reliable conclusions for the whole network).

Furthermore, on an average trip, a vehicle might transgress a series of differing speed limits. It is not possible to determine how frequently different speed limits are transgressed. Additionally, a speed limit is not necessarily overshot for the length of the link. A vehicle might only periodically overshoot the speed limit (whilst overtaking for instance).

These complications make it exceedingly difficult to quantify what effect ISA would have on fuel consumption. However, a UK National Statistics publication produced by Transport Statistics for the UK Department for Transport (2005) included the data presented in **Figure 12** and **Figure 13** on the incidence of speeding in the UK:

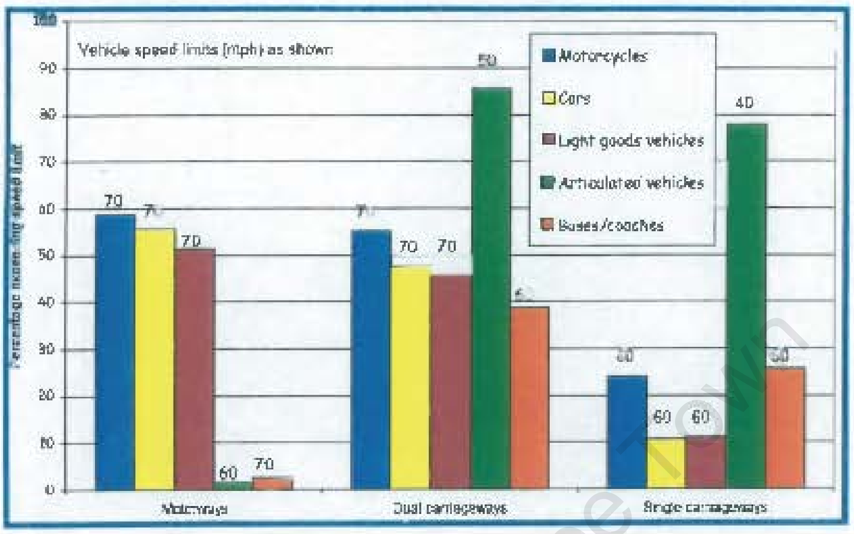

Figure 12: Percentage vehicles exceeding the speed limit on rural roads

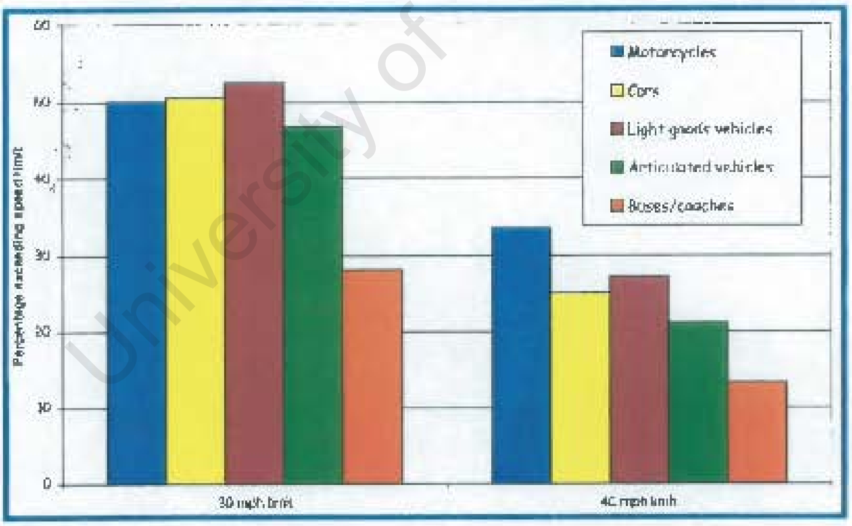

Figure 13: Percentage vehicles exceeding the speed limit on urban roads

In the UK at least, it would seem that a large percentage of motorists exceed the speed limits. The figures are especially high on motorways, dual carriageways and roads with a 30mph (48km/h) limit.

Further analysis of the data (see Appendix 4 for the full data set) for the different road and traffic classes was carried out (see Figure 14 and Figure 15):

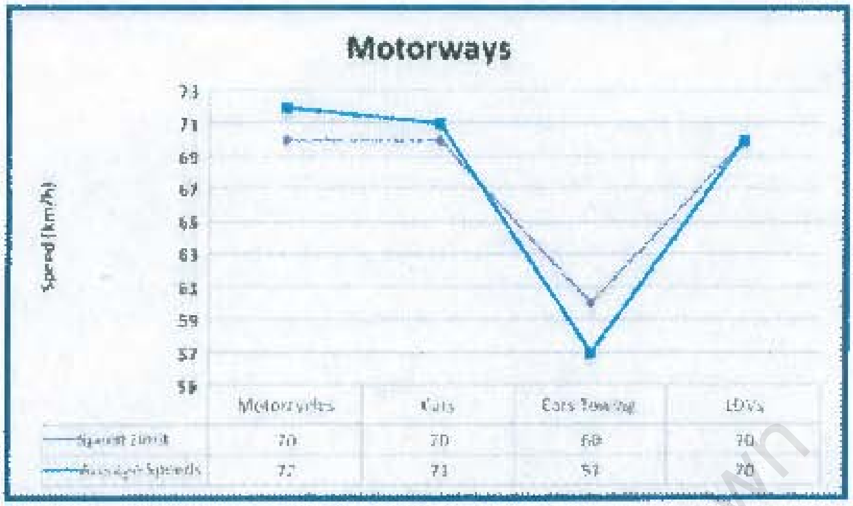

Figure 14: Relationship between average speed and the speed limit on UK motorways

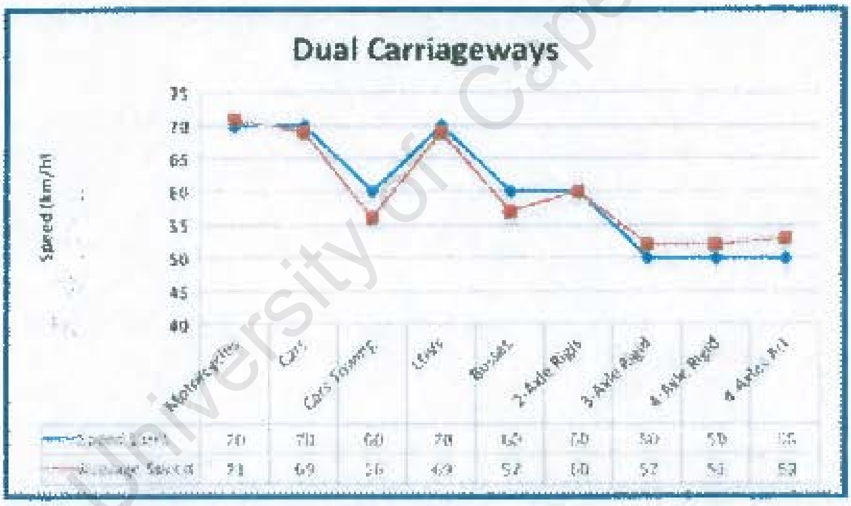

Figure 15: Relationship between average speed and the speed limit on UK dual carriageways

The figures for motorways and dual carriageways show that in general, the average speeds travelled by all classes of vehicle on these roads closely follows the speed limit. This indicates that, although large numbers of motorists are speeding, most of the transgressions occur at speeds very near to the speed limit. On single carriageways, the picture is somewhat different.

Figure 16: Relationship between average speed and the speed limit on UK single carriageways

Average speeds on these roads are substantially lower than the speed limit (Figure 16) for all classes of vehicles except heavy vehicles. Without an understanding of the traffic patterns or the geometry and environment of these roads, it is difficult to form a conclusive opinion as to the reason, other than to speculate that perhaps the 40mph speed limit imposed on heavy vehicles is too low.

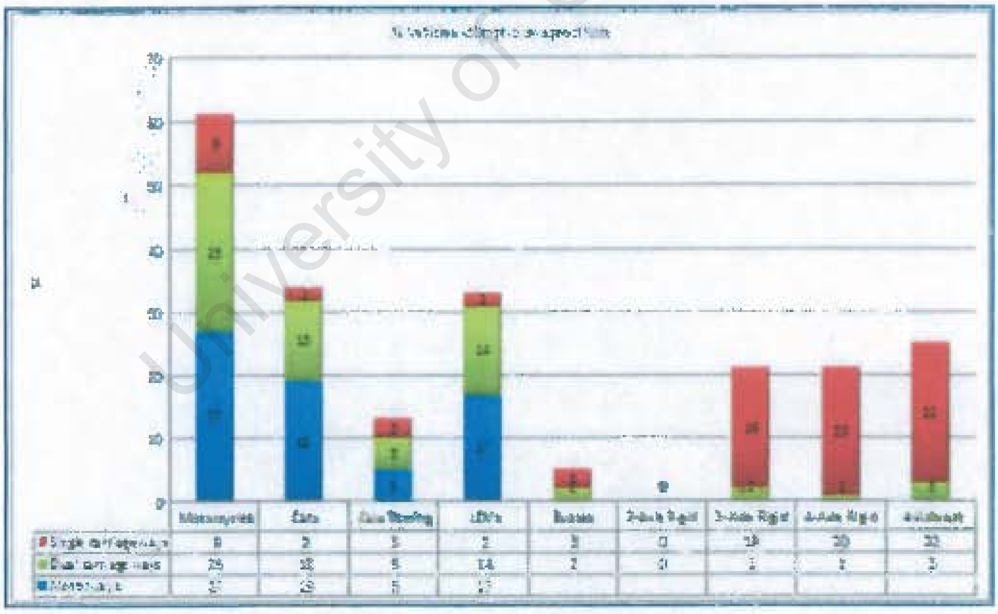

Figure 17: Incidence of speeding > 10mph above the speed limit on different classes of UK roads

Figure 17 gives an indication of the incidence of vehicles exceeding 10mph above the speed limit by vehicle type and road classification. It can be seen that in general, motorcycles have the highest proportions of serious transgressors, and cars and LDV's are frequent serious transgressors on motorways and dual carriageways. Notably, a large percentage of heavy vehicles (on average 20%) are speeding in excess of 10mph above the speed limit.

A second study, conducted in Perth, Australia, was done to determine the baseline driver behaviour on roads with a 60km/h speed limit prior to the implementation of a blanket 50km/h speed limit (Radalj T, 2000). The study uncovered some interesting results regarding the incidence and severity of speeding on metropolitan roads in Perth.

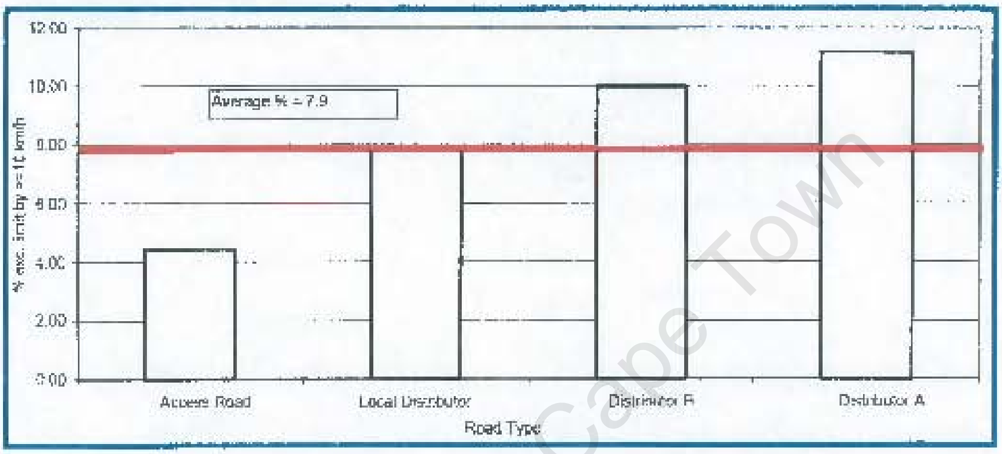

Figure 18: Vehicles exceeding limit by 10 km/h or more by road type on 60 km/h local roads

Source: Radalj, 2000

Figure 18 shows that the higher the road category, the higher the incidence of excessive speeding.

Figure 19 shows the distribution of speeds by road type. It can be seen that on the higher order district distributors, similar percentages of vehicles were found to be speeding as were found in the study done by the UK Department of Transport. On lower order roads, between 20 and 40% of vehicles were speeding, and of these, only between 5 and 8% were speeding in excess of 10km/h above the speed limit of 60km/h. Similar to the findings in the UK study, the vast majority of vehicles speeding, were travelling at less than 10km/h above the speed limit.

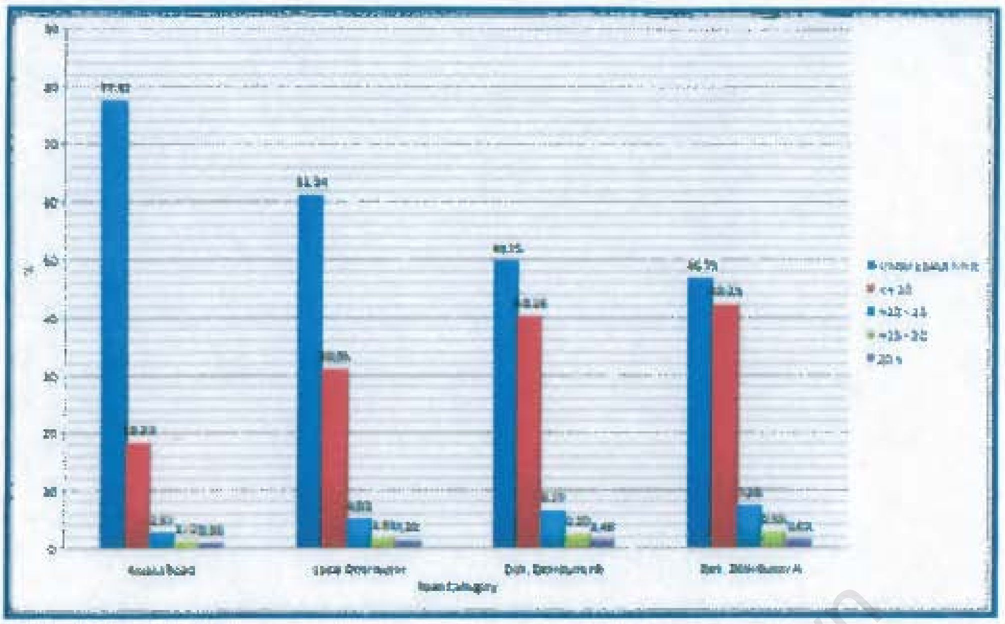

Figure 19: Distribution of speeds by road type

The conclusions that can be drawn from these studies are as follows:

- The incidence of speeding increases the higher the category of the road.
- On average, between 20 and 50% of vehicles travel at less than 10km/h above the speed limit, and less than 10% of vehicles travel at speeds greater than 10km/h above the speed limit.

It is understood that the incidence of speeding fluctuates with the time of day as well as the day of the week. It is also understood that weather and traffic conditions affects the incidence of speeding. However, using the conclusions drawn from these two studies above, it is possible to derive an estimate of what impact ISA could have on fuel consumption, assuming that speed-regulating ISA was made mandatory.

Returning to the diagram in Figure 11, it can be seen that the potential savings or increases in fuel consumed 10km/h on either side of the 60km/h mark, are very marginal. So much so, that it is not possible to estimate the change from the graph alone.

Nairn and Partners et al (1994) investigated the potential effects of strategies to reduce speeds to reduce fuel consumption and emissions in Melbourne, Australia. They found that should the strategies successfully manage to lower all vehicle speeds to below the 60km/h limit, the average fuel consumption rate would lower from 8,2 L/100km to 8,1 L/100km.

The potential saving of 0,1 L/100km is trivial for a single automobile, but potentially substantial if it is expanded across the entire countries fleet.

A paper done by Ahn, Rakha, Trani, and Van Aerde (2000) to develop mathematical models that predict vehicle fuel consumption and emissions using instantaneous speed and acceleration as explanatory variables produced Figure 20 to explain the relationship between fuel consumption, acceleration and instantaneous speed.

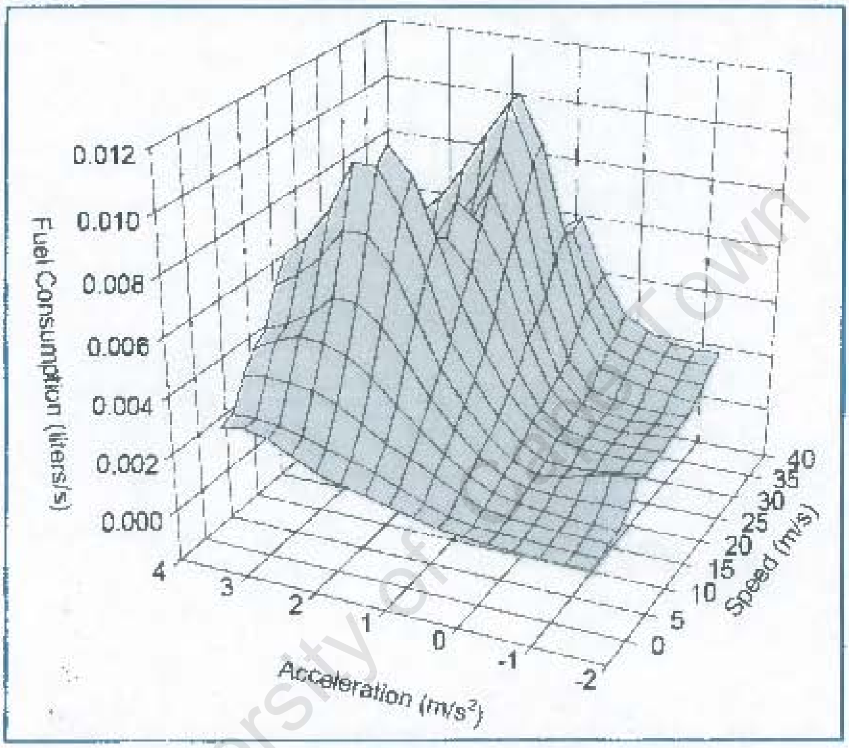

Figure 20: Fuel Consumption as a function of acceleration and instantaneous speed

Source: Ahn, Rakha, Trani, and Van Aerde (2000)

The chart is useful as it highlights that fuel consumption at cruising speeds as shown in Figure 11 is different to fuel consumption when accelerating. In the local or residential road network, vehicles are often forced to accelerate and decelerate at regular intervals. This increases the amount of fuel consumed. On freeways, vehicles are mostly operating at cruising speeds, unless traffic is congested.

Lui and Tate (2000) explain that the microsimulation of an urban road network yielded decreasing total fuel consumption with increasing ISA penetration rates. The study found that at 100% ISA penetration, a saving of 8% in fuel consumed could be achieved.

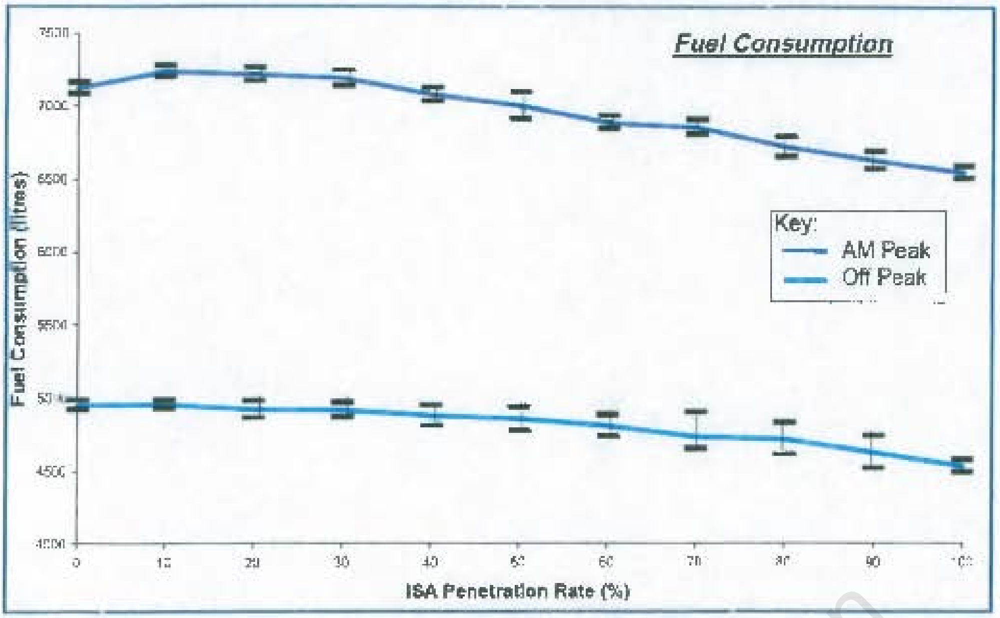

Figure 21: Fuel consumption as a function of ISA penetration rate

Source: Lui and Tate (2000)

Lui and Tate (2000) explain that the saving achieved is due to the speed control system limiting maximum speeds to the speed limit and also reducing the acceleration and deceleration cycles, thereby keeping the vehicles cruising at slower and more constant speeds.

To determine what the potential savings for South Africa may be, one has to know what the total mileage travelled is. Two sets of statistics were used, total travel and travel on national roads. The analysis would be able to show what impact ISA might have on fuel consumption were it only to be implemented on national roads, and if it was implemented on all South African roads.

The South African National Roads Agency released statistics for travel on South African national roads. The statistics were divided into toll and non-toll roads.

NON-TOLL ROADS					
Total Length	Vehicle km/day	Heavy Vehicles	Percentage	Light Vehicles	Percentage
5,464.54	44,097,018.46	4,931,799.27	9.10%	39,165,219.19	72.30%
TOLL ROADS					
Total Length	Vehicle km/day	Heavy Vehicles	Percentage	Light Vehicles	Percentage
1,267.82	10,088,570.46	1,547,151.78	2.90%	8,541,418.68	15.80%
COMBINED					
Total Length	Vehicle km/day	Heavy Vehicles	Percentage	Light Vehicles	Percentage
6,732.36	54,185,588.92	6,478,951.05	12.00%	47,706,637.87	88.00%

Table 9: Vehicle travel on national roads

The data indicates that approximately 54 185 000 kilometres is travelled on South African national roads each day. This converts to 19 777 million kilometres per year.

Statistics South Africa released data for travel on all South African roads as presented in Table 10:

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	2005
km travelled	96,067	96,513	97,798	102,280	111,476	119,189	126,042	126,897	130,137	160,967

Table 10: Total Travel on South African roads (millions of kilometres)

Due to the lack of updated information, an estimate was made of the growth from 1998 to 2005 by simply adding the growth from 1990 to 1997 to the total for 1998.

Assuming the value of 0,1 litres per 100km saving found by Nairn and Partner et al's holds for South Africa, the potential saving in fuel is 160 967 000 litres per year for 2005. Using a price per litre of R5,90 for fuel, this equates to R949 705 300 per year for 2005. Assuming the values are similar for 2006, and using the most recent petrol price of R6,80, this sum increases to R1 094 575 600.

An eight percent reduction as was found by Lui and Tate (2000) equates to approximately 656ml of fuel per 100km using an average consumption of 8,2 litres per 100km. This would yield a value 6,56 times greater than what was derived from the figures given by Nairn and Partner et al. The value would be on the order of R7 180 415 000 for 2006.

3.2.3. Additional Fuel Consumption due to Incident-Induced Congestion

Fuel consumption is not only determined by running time, but is governed by instantaneous speed and acceleration as well as general engine loadings.

In a study published in the Journal of the Air & Waste Management Association, Tong, Hung, and Cheung (2000) measured fuel consumption and the level of emissions at varying instantaneous vehicle speeds. A range of vehicle types was used.

The figures presented in Appendix 2 outline the findings from two perspectives, that of fuel consumption factors relative to instantaneous vehicle speeds and that of fuel consumption rates relative to instantaneous vehicle speeds. The results obtained display different trends and reveals different aspects of the data.

Fuel consumption factors are quoted in g/km whereas fuel consumption rates are quoted in g/sec. The results for fuel consumption factors show that in general the consumption factors decrease with an increase in vehicle speed, whereas fuel consumption rates increase with speed.

This is to be expected because at low speeds, the distance travelled during any time would be short, so the running time for the vehicle would be longer. Put simply, less fuel would be used travelling 1km at 100km/hr than would be travelling at 5km/hr. Conversely, travelling at higher speeds means that the engine consumes more fuel and as a result, it can be seen that fuel consumption rates increases with speed.

These results allow for some conclusions regarding fuel consumption during congested conditions as opposed to free flow conditions to be drawn. In Table 11 the average speeds and distances travelled for the vehicles used in the field trials conducted by Tong, Hung, and Cheung (2000) are listed.

	Duration (sec)	Average Speed (km/hr)	Total distance (km)
Passenger Car	2613	19.47	14.13
Petrol Van	6500	23.85	43.06
Diesel Van	3133	24.91	21.68
Diesel Bus	1690	15.32	7.19

Table 11: Characteristics of test runs from Tong, Hung, and Cheung

The average speed for all the vehicles was approximately 20.89km/hr. The vehicles in this particular study all travelled different routes and, in addition, due to the different vehicle types, their acceleration and deceleration characteristics would be different. There were also different drivers used for the different vehicles. The result is that none of the individual test runs has similarities other than that the areas in which the routes were taken were both areas well known for their congested conditions. This is beneficial in that it allows for a generalised picture of travel in congested areas.

	Petrol Car	Petrol Van	Diesel Van	Bus
Consumption Factor	65	105	100	15
Consumption Rate	0.4	0.55	0.6	0.12

Table 12: Summary of results at 20 - 25 km/hr

The results show a relatively large spread of values at 20 – 25 km/hr. Other than for petrol and diesel vans, there does not appear to be much consistency across the different vehicle types. This is, however, to be expected, since the vehicles have substantially different characteristics.

This raises another consideration that must be taken into account when attempting to quantify and monetise fuel consumption. The vehicular split on any particular link could significantly influence the overall cost of delay. If hypothetically only heavier vehicles, such as trucks or busses, were affected by congestion, the outcomes would differ significantly, if only passenger cars were affected by congestion.

The solution to this problem cannot immediately be resolved without more detailed information regarding the congestion levels on roads, and the corresponding vehicular split. However, if it is assumed that the vehicular split on links that experience significant levels of congestion is relatively uniform, national statistics can be used for the vehicle population to determine the average vehicular split on those links. The figures in Table 12 can then be applied in order to determine a reasonable estimate of the contribution of fuel consumption to the cost of incident-induced delays.

The National Department of Transport[28] lists on its website the statistics for the national vehicle population during 1998, 1999 and 2000 as given in Table 13:

Vehicle Class	31-Dec-98		31-Dec-99		31-Dec-00	
	Total RSA	% of total self propelled	Total RSA	% of total self-propelled	Total RSA	% of total self propelled
Motorcars & stationwagons	3 784 289	64.68	3 847 952	64.62	3 913 470	64.69
Minibuses	248 698	4.25	252 977	4.25	248 837	4.11
Buses, bus-trains & midibuses	25 133	0.43	25 741	0.43	25 943	0.43
Motor- / Tri- / Quadrocycles	158 895	2.72	156 848	2.63	158 606	2.62
Ldv's & panelvans (<3,5t)	1 219 471	20.84	1 261 815	21.19	1 297 383	21.44
Trucks (heavy load draw >3,5t)	227 123	3.88	227 468	3.82	226 937	3.75
Other self-propelled vehicles	186 957	3.2	182 148	3.06	178 788	2.96
Total self-propelled vehicles	5 850 566	100	5 954 949	100	6 049 964	100
Caravans	120 508	17.24	117 595	16.63	113 965	15.91
Light load trailers (<3,5t)	479 283	68.58	491 262	69.46	502 322	70.15
Heavy load trailers (>3,5t)	99 107	14.18	98 410	13.91	99 806	13.94
Total caravans & trailers	698 898	100	707 267		716 093	100
All other and unknown vehicles	54 114		52 968		48 474	
Total number of live" vehicles "	6 603 578		6 715 184		6 814 531	
Number of heavy trailers per truck	0.44		0.43		0.44	

Table 13: "Live" Vehicle Population for 1998, 1999, 2000

[28] http://www.transport.gov.za/library/docs/stats/2001/statistics.html#2.4

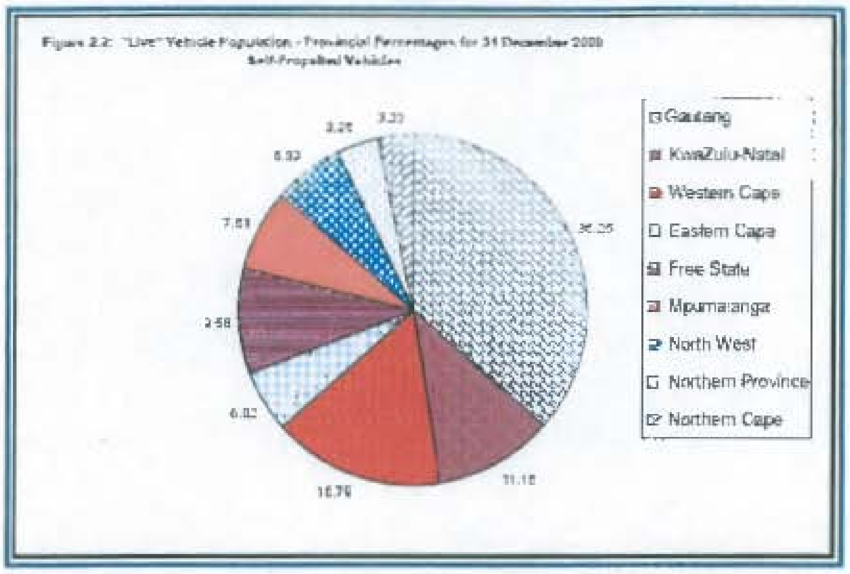

Figure 22:Live Vehicle Population: Provincial Percentages for 31 December 2000[29]

As can be seen from Table 13, on 31 December 2000, there were 6 049 964 self-propelled vehicles on South Africa's roads. In order to update this value to 2005 terms, an investigation into new vehicle sales was done, the results of which are presented in Table 14[30].

Year	Vehicle population	Vehicle population adjusted for scrappage	Annual vehicle sales
31/12/2000	6 049 964		
31/12/2001	6 049 964	5 868 465	382 529
31/12/2002	6 231 649	6 044 700	363 184
31/12/2003	6 413 170	6 220 775	368 470
31/12/2004	6 670 378	6 470 266	449 603
31/12/2005	7 088 294	6 875 645	618 028

Table 14: South African vehicle population adusted for scrappage[26]

The total vehicle population for South Africa is in the order of 7 088 000 vehicles. The vehicle split for South Africa is shown in Table 15.

[29] http://www.transport.gov.za/library/docs/stats/2001/statistics.html#2.4

[30] See Appendix 3 for further detail on how these results were arrived at.

Vehicle Type	1998 (%)	1999 (%)	2000 (%)	Average (%)
Motorcars & stationwagons	64.68	64.62	64.69	64.66
Minibuses	4.25	4.25	4.11	4.20
Buses, bus-trains & midibuses	0.43	0.43	0.43	0.43
Motor- / Tri- / Quadrocycles	2.72	2.63	2.62	2.66
Ldv's & panelvans (<3,5t)	20.84	21.19	21.44	21.16
Trucks (heavy load draw >3,5t)	3.88	3.82	3.75	3.82
Other self-propelled vehicles	3.2	3.06	2.96	3.07

Table 15: Vehicular split in South African fleet

The value derived earlier on for total delay due to congestion was 291 972 920 vehicle hours annually. It would be impossible to determine accurately how this time is split amongst the different categories of vehicle. As a result, the assumption was made that the time is split along the percentage split for the vehicular fleet as given in Table 15. Additionally, the fuel consumption rates are not available for all of the categories of vehicle listed in Table 15. As a result, the various categories were grouped into representative categories similar to what was used by Tong, Hung, and Cheung (2000). Table 16 illustrates how the total congestion induced delay was split amongst the categories and how the varying vehicle categories were amalgamated into the four categories used by Tong, Hung, and Cheung (2000).

Vehicle Type	Average (%)	Consumption Rate	Vehicle hours	Fuel Consumption (kg/year)	Fuel Consumption (Diesel) (l/year)	Fuel Consumption (Petroleum) (l/year)
Motorcars & stationwagons	64.66	0.4	188799423	271871168.40	307199.06	368778.88
Minibuses	4.20	0.55	12272595.1	24299738.24	27457.33	32961.31
Buses, bus-trains & midibuses	0.43	0.12	1255483.56	542368.90	612.85	735.69
Motor- / Tri- / Quadrocycles	2.66	0.4	7756747.24	11169716.03	12621.15	15151.13
Ldv's & panelvans (<3,5t)	21.16	0.55	61771737.4	122308040.13	138201.18	165904.40
Trucks (heavy load draw >3,5t)	3.82	0.12	11143633.1	4814049.50	5439.60	6530.00
Other self-propelled vehicles	3.07	0.4	8973301.07	12921553.55	14600.63	17527.41

Table 16: Estimated additional fuel consumption as a result of incident induced delay

Table 16 contains estimates for the amount of additional fuel consumed by vehicles due to incident induced congestion. Table 17 gives some clarification of the figures presented in Table 16.

Vehicle Type	Fuel Consumption (Petroleum) (l/year)	Fuel Consumption (Petroleum) at 20 – 25 km/hr (l/100km)	Fuel Consumption (Petroleum) at 0 – 5 km/hr (l/100km)
Motorcars & stationwagons	368778.88	8.82	54.26
Minibuses	32961.31	14.24	12.89
Buses, bus-trains & midibuses	735.69	2.03	13.56
Motor- / Tri- / Quadrocycles	15151.13	8.82	54.26
Ldv's & panelvans (<3,5t)	165904.40	14.24	12.89
Trucks (heavy load draw >3,5t)	6530.00	2.03	13.56
Other self-propelled vehicles	17527.41	8.82	54.26

Table 17: Fuel consumption rates for different types of vehicles at different speed regimes

The values for fuel consumption presented in Table 17 have been calculated using Tong, Hung, and Cheung's (2000) fuel consumption factors as given in Appendix 2. Converting the fuel consumption factors from grams per kilometre to litres per 100 kilometres provides a useful comparison to average driving conditions.

Under average free driving conditions, the average vehicle uses approximately 9 litres per 100 km. This is demonstrated by the fuel consumption values given in Table 17 for speeds between 20 and 25 kilometres per hour. However, when accelerating from standstill, as is repeatedly done during periods of heavy congestion, fuel consumption increases dramatically. This can be seen in Table 17. Motorcars are shown to consume up to 50 litres per 100 kilometres when accelerating from standstill.

Using the values for fuel consumption per year as calculated in Table 16, we are able to derive the actual monetary costs that can be attributed to the additional fuel consumed because of incidents on roads in South Africa.

Vehicle Type	Fuel Consumption (Petroleum) (l/year)	Cost of Yearly Fuel Consumption (Petroleum) (R) (Fuel Price = R5,90/l)
Motorcars & stationwagons	368778.88	R2 175 795.40
Minibuses	32961.31	R194 471.74
Buses, bus-trains & midibuses	735.69	R4 340.59
Motor- / Tri- / Quadrocycles	15151.13	R89 391.67
Ldv's & panelvans (<3,5t)	165904.40	R978 835.95
Trucks (heavy load draw >3,5t)	6530.00	R38 527.02
Other self-propelled vehicles	17527.41	R103 411.69

Table 18: Monetary costs of yearly fuel consumption.

The values in Table 18 sum to a total of R3 584 000. This can be said to be an initial approximation for the cost of the additional fuel consumed due to incident-induced delay, where speed was the primary causal factor in the accident.

3.2.4. Maintenance Costs

The operating cost for vehicles not only includes fuel consumption, but also the additional wear on the vehicles consumable components. These include tyres, brake linings and shock absorbers, as well as the periodic servicing of the vehicle.

The South African National Department of Transport presents the data in Table 19 on their website[31], as an estimate of the operating costs of vehicles in South Africa in 2001.

Engine Capacity	Service & Repair Cost	% of fuel cost	Tyre Cost	% of fuel cost	Fuel Cost	Total Cost
	c/km	%	c/km	%	c/km	c/km
DIESEL						
< 1849	20.9	81.32	8	31.13	25.7	54.6
1850 - 2049	23.1	80.49	11.8	41.11	28.7	63.6
2050 - 2549	25.4	53.47	10.8	22.74	47.5	83.7
2550 - 3049	30.9	63.32	12	24.59	48.8	91.7
3050 - 4049	34.5	65.71	13.3	25.33	52.5	100.3

[31] http://www.transport.gov.za/library/docs/stats/2001/statistics.html#2.4 (average values were calculated from the original data)

>4049	39.4	69.86	13.4	23.76	56.4	109.2
Average	**29.03**	**69.03**	**11.55**	**28.11**	**43.27**	**83.85**
PETROL						
<1350	13.9	36.48	5.4	14.17	38.1	57.4
1350 - 1549	15.2	38.78	5.8	14.80	39.2	60.2
1550 - 1849	18.2	43.86	8	19.28	41.5	67.7
1850 - 2049	20.1	43.70	9.9	21.52	46	76
2050 - 2549	22.1	43.76	11.9	23.56	50.5	84.5
2550 - 3049	26.9	49.18	12.6	23.03	54.7	94.2
3050 - 4049	30	48.23	13	20.90	62.2	105.2
>4049	34.2	51.82	16	24.24	66	116.2
Average	**22.58**	**44.47**	**10.33**	**20.19**	**49.78**	**82.68**

Table 19: April 2001 Vehicle Operating Costs in RSA

Table 19 shows that, on average, the service costs (which include the consumable spares mentioned previously) can be estimated at 69.03% of the fuel costs for diesel vehicles and at 44.47% of the fuel costs for petrol driven vehicles. The tyre costs can be averaged as 28.11% of the fuel cost for diesel vehicles and at 20.19% of the fuel cost for petrol vehicles.

These amounts signify that, in order to provide a more holistic estimate of the actual increase in operating costs for vehicles in South Africa due to excessive speed, an increase of the estimates for fuel consumption as calculated in section 3.2.2 and 3.2.3 by at least a factor of 1.5 is needed.

The additional fuel costs calculated for excessive speed in section 3.2.2 was R7 180 415 000 for 2006. Applying the estimate that the maintenance costs for vehicles is between 45 and 70% of the fuel cost depending on the vehicle as derived previously yields that the additional maintenance cost is between R3 231 187 000 and R5 026 291 000. The additional tyre costs are calculated as being between R1 449 725 000 and R2 018 414 000.

This increases the value for the additional operating costs due to speeding, and consequently the potential savings ISA holds for South Africa to be between R11 861 329 000 and R14 225 122 000.

Similar increases can be expected when considering the increased costs due to incident induced congestion delay. The additional fuel costs were calculated in Table 18 and summed to a total of R3 584 000. The values in Table 18 have been amended with the factors for maintenance costs as per Table 19. The amended totals are given in Table 20:

Vehicle Type	Cost of Yearly Fuel Consumption (Petroleum)	Additional Service Costs	Additional Tyre costs	Total Costs
Motorcars & stationwagons	R2 175 795.40	R967 576.21	R439 293.09	R3 582 664.71
Minibuses	R194 471.74	R86 481.58	R39 263.84	R320 217.17
Buses, bus-trains & midibuses	R4 340.59	R1 930.26	R876.37	R7 147.22
Motor- / Tri- / Quadrocycles	R89 391.67	R39 752.48	R18 048.18	R147 192.32
Ldv's & panelvans (<3,5t)	R978 835.95	R435 288.35	R197 626.98	R1 611 751.28
Trucks (heavy load draw >3,5t)	R38 527.02	R17 132.97	R7 778.61	R63 438.59
Other self-propelled vehicles	R103 411.69	R45 987.18	R20 878.82	R170 277.69
Total	**R3 584 774.06**	**R1 594 149.03**	**R 723 765.89**	**R5 902 688.98**

Table 20: Amended Total Costs

Summing the total costs in Table 20 gives a grand total of R5 902 000. This amended value is 64.7% greater than the original fuel cost of R3 584 000, which would definitely indicate that these additional costs are significant and should be included in any calculation of operating costs. The new amended value provides a more accurate figure of the increased vehicle operating costs for vehicles in South Africa because of incident-induced delay caused by incidents whose primary causal factor is speed.

3.3. The Cost of Time Delays

In addition to the more direct costs associated with congestion, there are also costs associated with the time delay caused to the travellers caught in the congestion.

A study undertaken in Canada by Transport Canada, a department of the Canadian department for Environmental Affairs in 2006, to determine the cost of congestion for Canadian urban centres found that the cost due to delay accounted for by far the majority of the total costs of congestion.

Table 21 lists the total costs of congestion found by the Canadian study. The study calculated costs at three different "threshold" levels. These thresholds form the watersheds between what is taken as an acceptable and an unacceptable level of congestion. This methodology was chosen in response to attacks on the assumption that the free-flow condition is the standard or ideal benchmark from which to judge congestion levels. The percentage value in this case refers to the percentage of the posted speed limit maintained during congested periods.

Urban Area	Year	at 50% Threshold	at 60% Threshold	at 70% Threshold
Vancouver	2003	$402.8	$516.8	$628.7
Edmonton	2000	$49.4	$62.1	$74.1
Calgary	2001	$94.6	$112.4	$121.4
Winnipeg	1992	$48.4	$77.2	$104.0
Hamilton (all)	2001	$6.6	$11.3	$16.9
Toronto	2001	$889.6	$1,267.3	$1,631.7
Ottawa-Gatineau (all)	1995	$39.6	$61.5	$88.6
Montréal	1998	$701.9	$854.0	$986.9
Québec City	2001	$37.5	$52.3	$68.4
Total, all urban areas		$2,270.2	$3,015.0	$3,720.6

Table 21: Total cost of congestion as found by Transport Canada[32]

Table 21 shows that the costs associated with congestion in Canada range between $2,27 billion and $3,72 billion for the years shown. Table 22 shows the percentage of each years cost that can be directly attributed to delay.

Urban Area	Year	at 50% Threshold	at 60% Threshold	at 70% Threshold
Vancouver	2003	92.40%	91.90%	92.70%
Edmonton & Calgary	2000/2001	--	--	--
Winnipeg	1992	88.10%	88.00%	90.20%
Hamilton (all)	2001	79.40%	85.40%	90.10%
Toronto	2001	87.40%	90.40%	92.40%
Ottawa-Gatineau (all)	1995	84.40%	87.00%	90.40%
Montréal	1998	92.30%	93.10%	93.90%
Québec City	2001	87.40%	87.00%	88.50%
Total, all urban areas		90.60%	91.80%	93.00%

Table 22: Percentage of costs attributable to delay

32 Cost in millions of Canadian dollars

The totals in this case are actually averages. It can be said, however, that, on average, the delay component of the costs of congestion accounts for on average of at least 90% of the total cost of congestion. These costs are, however, for recurrent congestion, and do not include costs of non-recurrent congestion, such as those of incident-induced congestion. However, it is important to note the overall proportions of the various cost factors cited in the study. The study considered time delay, fuel wasted and additional emissions as being primary cost factors. The study noted that the costs are approximately spread as follows:

- Time delay 90%;
- Fuel wastage 7%; and
- Emissions 3%

An approximation for the additional operating and maintenance costs due to incident-induced congestion caused by incidents, where speed was the main contributory factor, can be extrapolated for the time delay using the percentages before. Table 23 illustrates:

Operating costs	Congestion delay costs (=90/7*Operating costs)
R5 902 689	R75 891 715

Table 23: Calculation of Congestion delay costs

In Table 23, using the proportions obtained in the Canadian study, we derived a value for the annual time delay as a result of incident-induced congestion caused by road accidents where speed was the primary causal factor. It must be noted that the assumptions made here are, that the values used to derive the operating costs are accurate and that similar proportions of costs are applicable here in South Africa.

In comparison, the 2005 Mobility Report undertaken by Shrank and Lomax of the Texas Transport Institute of the Texas A&M University provides costs of congestion as (Table 24):

Population Group	Average Cost ($)	Average Delay (hours)	Average Fuel (gallons)
Very Large areas	1,038	61	36
Large areas	620	37	23
Medium areas	418	25	15
Small areas	222	13	8
85 area average	794	47	28
85 area total	63.1 billion	3.7 billion	2.3 billion

Table 24: Congestion Effects on the Average Traveler in the USA - 2003

The data was categorised by urban area size. This was done as it was found that in larger urban areas, such as large cities, overall congestion tends to be more severe. In this way, the full effect of congestion is not diluted by the presence of smaller, less congested urban areas in the data sample.

It must be noted that the US data presented in Table 24 has very little bearing on the South African situation. As the US population is significantly larger, the vehicle population is orders of magnitude greater and the mobility patterns in the US are different to the South Africa ones.

What can be done, is to compare the cost ratio's they've applied to what was applied in the Canadian example. In 2003, gasoline prices varied dramatically in the USA, but the average was $1.895 per gallon[33]. Applying this value to Table 24 will give the cost of excess gasoline used as a result of congestion as per the values in Table 24. The costs applied to the time delay can then be derived and the relevant proportions in the case of the US study can then be calculated (Table 25).

[33] http://www.energy.ca.gov/gasoline/statistics/gasoline_cpi_adjusted.html

Population Group	Average Fuel: gallons	Average Cost of Fuel ($)	Average Cost ($)	Average Time delay Cost ($)	Average Time delay (hours)	Cost per hour ($)	Fuel as a % of cost	Time delay as a % of cost
Very Large areas	36	68.22	1,038	970	61	15.90	6.57	93.43
Large areas	23	43.585	620	576	37	15.58	7.03	92.97
Medium areas	15	28.425	418	390	25	15.58	6.80	93.20
Small areas	8	15.16	222	207	13	15.91	6.83	93.17
85 area average	28	53.06	794	741	47	15.76	6.68	93.32
85 area total	2.3	4.3585	63.1	59	3.7	15.88	6.91	93.09
Averages						15.77	6.80	93.20

Table 25: Further Analysis of US results

The US study did not consider the cost of emissions, and focussed mainly on the effects of congestion on the individual traveller. As can be seen from the analysis of the data presented in Table 25, the percentages found in the Canadian study very closely resemble the percentages of the US study. Also, if one considers that the Canadian study made explicit mention of emissions as a cost contributor, and that this cost amounted to approximately three percent of the total cost of congestion, then subtracting three percent from the cost due to time delay in the US study would bring the two data sets even closer together.

It cannot be said with certainty whether the proportions uncovered in the data are representative globally or whether it is a geographic phenomenon, considering that the US and Canada are so closely related geographically, but the trend does seem very strong and the values can be accepted with relative confidence. This being the case, it can concluded that a reasonably robust estimate of the cost of the time delay due to incident induced congestion where speed is the primary causal factor, is R75.89 million per year.

3.4. Environmental Costs

Much has been written about the environmental costs of congestion, and many forms of pollution from automobiles have been mentioned in the literature. In this section all major pollutants cited in the various papers read will be identified, and the extents to which these contribute to the cost of excessive speeding and the cost of congestion as a result of accidents caused by excessive speed will be explored.

A study (Wicking-Baird, De Villiers and Dutkiewicz; 1997) into the so-called "brown haze" phenomenon encountered in Cape Town during temperature inversion conditions made some interesting findings as to the sources of air pollution in Cape Town. It found that the primary sources of air pollution in Cape Town are motorised vehicles. Figure 23 illustrates:

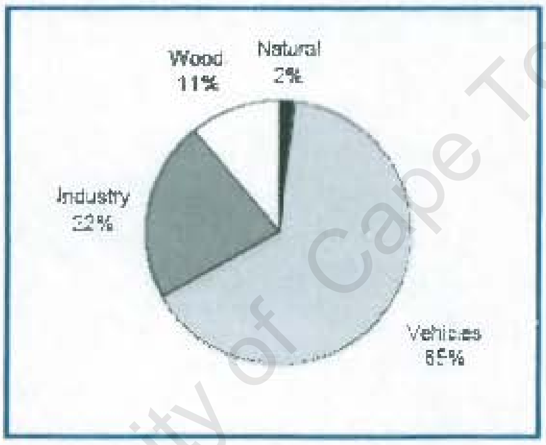

Figure 23: Apportionment of Visibility Impairing Particle Sources

Figure 23 is an aggregation of a more detailed diagram. The various sectors show that motor vehicles account for nearly two thirds of all visibility impairing particle emissions. Of the 65% attributed to motor vehicles, the study found that nearly half of all visibility-impairing particles in the air above Cape Town come from diesel burning vehicles. Petrol burning vehicles only account for 17%, which is less than the 22% attributed to industry. The industry sector is an amalgamation of boilers, refineries and power station emissions. It must be noted that the figure relates only to visibility impairing pollutants. These were defined in the study as particles of diameter smaller than 2.5 microns. In addition, the study made a listing of the various sources of emissions contributing to air pollution in general (Table 26).

	EMISSION RATES (tons/year)				
	SO2	NOx	VOCs	PM10	PM2.5
Residential					
Coal	185	15	49	40	16
Paraffin	344	61	4	8	8
LPG	0	31	11	2	2
Wood	1	542	2387	1877	1314
Transport					
Petrol vehicles	1591	16848	33696	562	472
Diesel vehicles	2716	1781	460	1927	1773
Brake and tyre wear				86	0
Paved roads				2129	213
Unpaved roads				1391	139
Aviation fuel	46	576	470	33	30
Ship diesel	69	739	31	52	47
Ship bunker oil	1145	582	109	67	60
Industry and commerce					
Coal	4750	1875	6	975	390
HFO	7686	695	4	451	406
FFS fuels	146	154	1	100	90
Diesel	84	900	38	64	59
Power paraffin	39	7	0	1	1
Caltex	10880	1643	1700	432	302
Kynoch		888		135	122
Athlone power station	2261	893	3	464	186
Other					
Tyre burning	241	13	107	335	168
Medical Incineration	1	2	0	3	3
Wildfires	40	107	647	460	322
Other VOCs			15618		
Total	**32225**	**28352**	**55341**	**11594**	**6123**

Table 26: Summary of primary atmospheric emissions in Cape Town (tons/year)

Of interest to this report is the contributions made by the transport sector and in particular, by diesel and petrol driven motor vehicles. A graph illustrating the data for the transport sector is given in Figure 24.

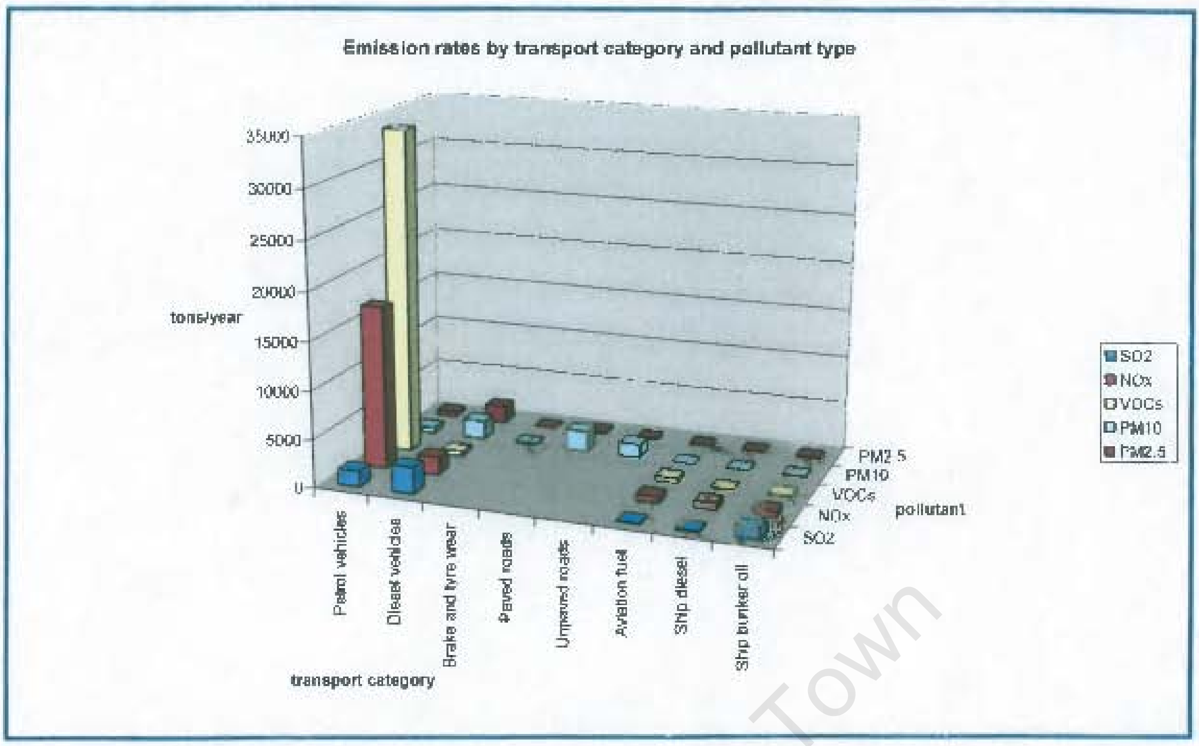

Figure 24: Emission rates by transport category and pollutant type

Figure 24 clearly indicates the petrol vehicles account for by far the majority of Nitrogen oxides (NOx) and Volatile Organic Compounds (VOC's). The study had the following to say regarding these pollutants:

> *"Of the oxides of nitrogen (NOx), nitrogen dioxide (NO2) is linked with health effects. NO is emitted from high temperature combustion, and later partially converted to NO2 by photochemical reactions. Sources of NO include motor vehicles and fossil fuel burning power plants. Nitrogen oxides are less soluble in water than sulphur dioxide and are therefore associated with deep lung penetration as scrubbing of the gas in the nasal passages is not efficient. Animal experiments have shown that NO2 causes alteration in lung metabolism, structure and function, and an increase in the susceptibility to pulmonary infections. Studies on humans have shown that, with asthmatics in particular, NO2 has a bronco-constricting effect."*

Source: Wicking-Baird et al, 1997

Regarding Volatile Organic Compounds (VOC's) the study held that:

"Volatile organic compounds (VOC's) are described by the United Nations Economic Commission for Europe as "all organic compounds of anthropogenic nature other than methane that are capable of producing photochemical oxidants by reactions with oxides of nitrogen in the presence of sunlight". Most VOC's do not occur in appreciable enough concentrations in the atmosphere to constitute a health risk, but the ones that do are: benzene, aldehydes, 1,3-butadiene, n-hexane, and some chlorinated hydrocarbons. The sources of these VOC's are vehicle exhausts, petroleum fuel evaporation from refineries and vehicles, and industries that use solvents such as the paint or plasticizer industry. Health effects of VOC's differ from compound to compound, but in general, they have one of the following effects: carcinogenicity, neurobehavioural or nephrotoxic. Benzene is a well known carcinogen and has been linked to incidences of leukemia as has 1,3-butadiene. Aldehydes such as formaldehyde have been linked with irritation of the eyes, nose, throat and upper respiratory tract. n-Hexane effects respiratory and cardiovascular function."

Source: Wicking-Baird et al, 1997

The graph in Figure 24 indicates that of all the sources of pollution, particulate pollutants constitute a very small fraction overall. However, these may form the most hazardous type of pollutant for human health as the following quotation taken from the study shows:

"Particulate air pollution and its health effects are associated with complaints of the respiratory system. More specifically researchers have shown that particulates are linked to increased mortality and an increase in the hospital admissions for respiratory and cardio-vascular illnesses.

Furthermore particulates are associated with mutagenic activity which in turn indicates their cancer causing potential. In many countries the primary health standard for particulates is PM10, which refers to particles of aerodynamic diameter less than 10μm.

This standard was chosen as representing the particulate size that has the potential to penetrate the upper airways of the respiratory system.

PM10 can be subdivided into three categories, based on the methods of formation of particles:

- *Nucleation Mode Particles (10 - 200 nanometres) which are formed by the condensation of hot gases. The ratio of the number of particles to the total mass of particles in this mode is high, and have a short lifetime in the atmosphere.*

- *(b) Accumulation Mode Particles (0.2 - 2 microns) which are formed by the coagulation and growth of Nucleation Mode Particles. These have a long atmospheric lifetime and make up the bulk of the atmospheric airborne particles. These are also primarily associated with emissions from combustion sources.*

- *(c) Coarse Mode Particles (2-10 microns) which are mechanically generated and have a short atmospheric lifetime due to their high deposition rate. Relative to the Nucleation Mode, the ratio of the number of particles to the total mass of the coarse mode is low.*

These three categories are, however, generally simplified to a coarse fraction (2.5 to 10 microns) and a fine fraction (less than 2.5 microns). Coarse particles are associated with particulate deposition in the bronchial region while fine mode particles are deposited further into the respiratory system resulting in their slower clearance from the lung.

This had lead to separate research into the health effects of the fine mode and coarse mode of particulates. Researchers have shown that PM2.5 has a much stronger correlation to health effects than PM10. It is postulated that this is due to the greater penetration into the lung; the fact that fine particles readily infiltrate buildings cause indoor and outdoor levels to be similar and thus exposure times longer; and the larger number of particles in the fine mode may effect the ability of the respiratory system to clear out the particles efficiently."

Source: Wicking-Baird et al, 1997

Figure 23 showed that the study found that motor vehicles account for at least 65% of all particulate pollutants. In Figure 24 it appeared that petrol vehicles contribute by far the greatest volumes of Nitrous pollutants and Volatile Organic Compounds. Overall then, it can be said with some confidence that motor vehicles in general are the largest polluters in the transport sector in Cape Town.

During congested conditions, vehicles tend to burn more fuel and emissions tend to increase. This, is due to the constant acceleration and deceleration of stop-go traffic. When the vehicle is accelerating, it uses more fuel due to the additional strain placed on the engine.

De Vlieger, De Keukeleere and Kretzschmar (2000) conducted an investigation into the environmental effects of driver behaviour and congestion related to passenger cars. Figure 25 highlights some of their findings.

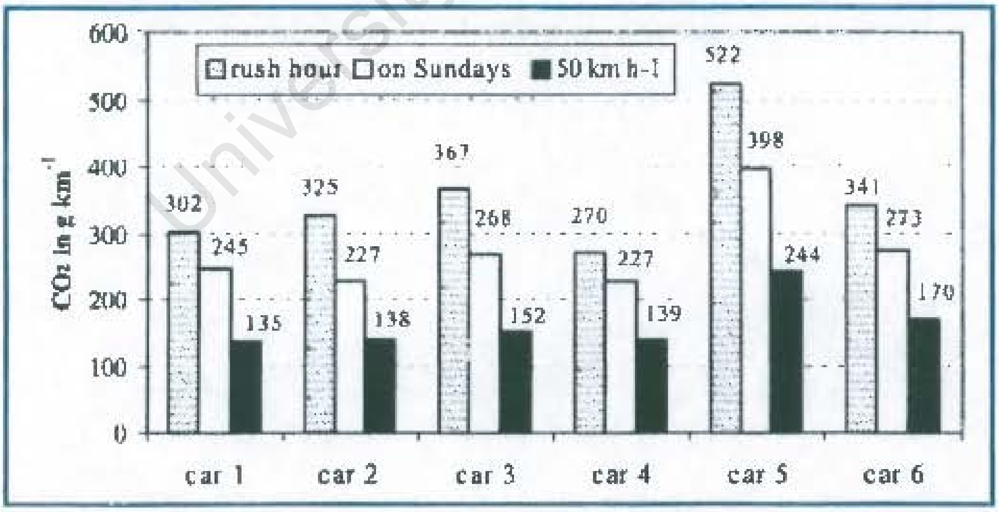

Figure 25: Average measured CO2 values for calm to normal driving behaviour under various traffic conditions in Brussels and at 50km/h.

Figure 25 clearly demonstrates that during rush hour, when the greatest levels of congestion prevail, the levels of CO2 given off by each test vehicle are highest. Furthermore, during congested conditions, the levels of all typed of pollutants given off during the journey increases. Figure 26 illustrates the findings of two test runs, one done during congested and the other uncongested conditions, by the same vehicle, in this case a Renault Mégane, for two different route options.

Figure 26 shows that during congested conditions, emissions tended to be more severe. Figure 26 was compiled using De Vlieger, De Keukeleere and Kretzschmar's (2000) values, and illustrates this finding.

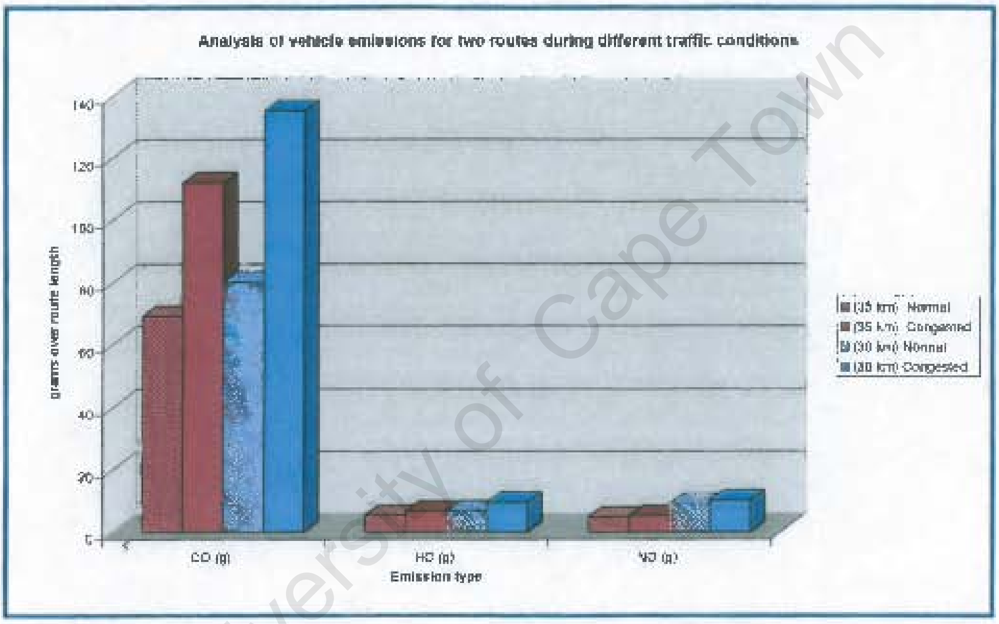

Figure 26: Analysis of vehicle emissions for two routes during different traffic conditions

The route characteristics clearly influences the emissions produced by the vehicle. In the example, the shorter route (30 km - blue) resulted in higher emissions in both congested and uncongested conditions. This once again illustrates that different levels of engine loadings result in different emissions profiles.

Figure 27 and Figure 28 were taken from a study conducted by Kean, Harley, and Kendall (2003). The study shows CO and NOx emissions as a function of the specific power being put out by the engine.

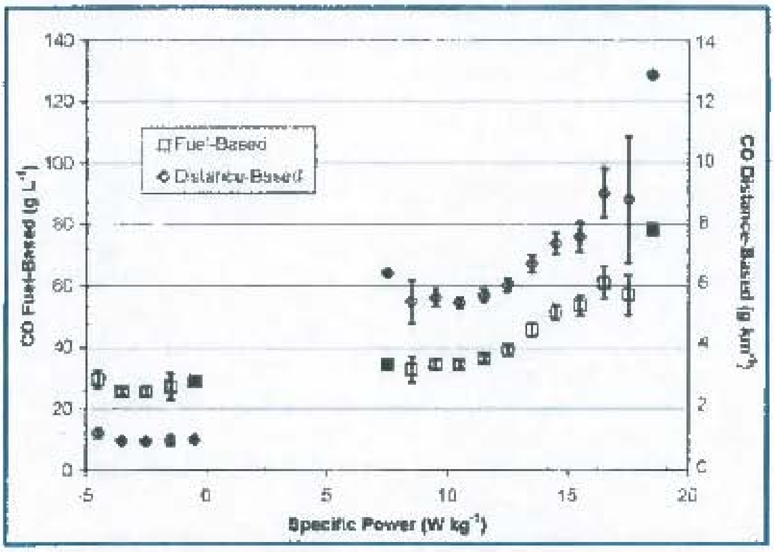

Figure 27: CO emission factors plotted versus specific power.

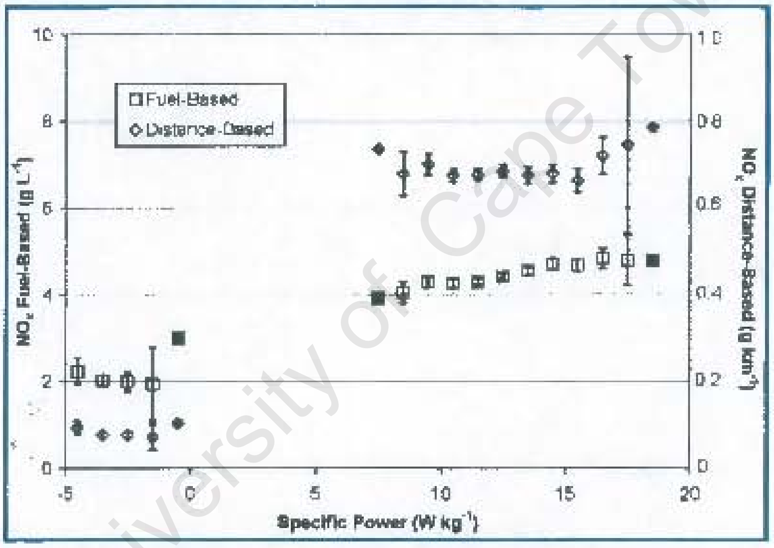

Figure 28: NOx emission factors plotted vs specific power.

The figures show that as the engine output increases, so the rate of emission increases. This indicates that during congested periods, when vehicles are repeatedly accelerating and decelerating, the overall level of vehicular emissions increases.

The primary question that needs to be answered is of course, by how much. If these increases can be ascertained, an attempt to quantify and monetise the values we derive can be made.

Previously, it was shown by manipulating the data from the study done by Transport Canada (2006) that emissions accounted for approximately three percent of the total cost of incident-induced congestion caused by road accidents where speed was the primary causal factor (see page 54). This was corroborated to a certain extent by an analysis of data produced in an American study done by Shrank and Lomax of Texas A&M University (2005). The American study did not explicitly consider emissions, but the correlation between the data sets was very strong and it was inferred that the three percent value for emissions was included in the value for time delay.

According to this estimation, and using the same basis for calculation as was used to estimate the cost of the additional time delay due to accident induced congestion, where the accident was as a result of excessive speed, the emissions cost are between R5 083 426 000 and R6 096 480 000 for speeding and approximately R2 529 000 for incident induced congestion due to incidents where the main contributing factor was excessive speed.

	Operating costs	Emissions costs (=3/7*Operating costs)
Low estimate for costs due to speeding	R11 861 329 000	R 5 083 426 000
High estimate for costs due to speeding	R14 225 122 000	R 6 096 480 000
Costs due to incident-induced congestion	R5 902 000	R2 529 000

Table 27: Cost of vehicular emissions

Estimating the cost of emissions is a very complex task primarily because the emissions themselves have a very wide range of influence on nature, health and human activities. It would seem that, exhaustive though the literature on this subject may be, some of the negative impacts of emissions in general becomes trivial even on the largest scale, and thus including them unless in the most thorough of reviews would not be very meaningful. At the paired down level under consideration here, that of additional vehicular only emissions because of incident induced congestion where the incidents (road accidents) were as a direct result of excessive speed, many of the effects vehicular of emissions becomes very insignificant.

Considering that the previously examined studies in this report have yielded the result that pollution due to congestion accounts for only 3% of the total costs of congestion, an extensive review of this aspect of congestion was considered unnecessary within the scope of this report.

However, prudence dictates that adequate consideration is given in order to verify these previous results. To this end, a very comprehensive study undertaken by Delucchi (1998), from the Institute of Transportation Studies at the University of California in Davis, California, was reviewed and analysed.

Delucchi (1998) evaluated the effects of vehicular emissions in their entirety, considering both the direct and the indirect emissions caused by motor vehicles. The indirect or "upstream" emissions include emissions, such as those from petroleum refineries, road dust, emissions from the servicing of motor vehicles, emissions from road construction and the like. Since the study was evaluating the effects of motor vehicle use in general, it included costs such as those generated by oil spills from tankers on route to deliver crude oil to be used in the manufacture of fuel for motor vehicles.

As indicated previously, the scope of this investigation does not necessarily warrant the inclusion of such an exhaustive analysis, simply because ISA may not be able to mitigate these effects to any significant degree. It is, therefore, necessary to discern which of these negative effects of vehicular emissions ISA might have any significant effect on. These will then be quantified and monetised and the results compared to what was derived previously. Delucchi's (1998) findings are outlined in Appendix 5, is summarised in Table 28. The most burning question is how do these values apply to the South African situation. The conversion of these values is not necessarily as simplistic as doing a quick conversion from 1991 US dollars to 2005 South African Rands. However, Table 28 provides an indication of what that calculation would yield.

Section	Cost item	Low	High	Low (ZAR 2005)	High (ZAR 2005)
1a	Air pollution: human mortality and morbidity due to particulate emissions from vehicles	16.7	266.4	83.66	1334.59
1b	Air pollution: human mortality and morbidity due to all other pollutants from vehicles	2.3	17.1	11.52	85.67
1c	Air pollution: human mortality and morbidity, due to all pollutants from upstream processes	2.3	13	11.52	65.13
1d	Air pollution: human mortality and morbidity from road dust	3	153.5	15.03	769.00
2	Air pollution: loss of visibility, due to all pollutants attributable to motor vehicles	3.6	27.4	18.04	137.27
3	Air pollution: damage to agricultural crops, due to ozone attributable to motor vehicles	3.3	5.7	16.53	28.56
4	Air pollution: damages to materials, due to all pollutants attributable to motor vehicles	1	8	5.01	40.08
5	Air pollution: damage to forests, due to all pollutants attributable to motor vehicles	0.2	2	1.00	10.02
6	Climate change due to lifecycle emissions of greenhouse gases (U. S. damages only)	0	3.5	0.00	17.53
7	Noise from motor vehicles	0.5	15	2.50	75.15
8	Water pollution: health and environmental effects of leaking motor-fuel storage tanks	0.1	0.5	0.50	2.50
9	Water pollution: environmental and economic impacts of large oil spills	0.2	0.5	1.00	2.50
10	Water pollution: urban runoff polluted by oil from motor vehicles	0.1	0.5	0.50	2.50
	Total	**33.3**	**513.1**	**166.82**	**2570.50**

Table 28: Delucchi's cost summary converted into billions of 2006 ZAR

The assumptions made in Table 28 are that in 1991 the Rand Dollar exchange rate was R2.89 to the dollar and that the average consumer price inflation index from 1991 to 2005 was four percent.

In order to make the values slightly more realistic or relevant to the South African context, we can apply a factor to them that relates to the differences between the USA and South Africa.

In Table 30, a series of factors have been applied to the original values in Table 29. The first is the current South African GDP as a fraction of the US GDP. The second is the current estimated vehicle population in South Africa as a fraction of the vehicle population in the US. The third is the total estimated annual fuel consumption in South Africa as a fraction of the fuel consumed in the US, and the fourth is the estimated population of South Africa as a fraction of the population of the US. The respective values used in each scenario and the resultant factors applied are given below.

	GDP ($)	Vehicle Population	Population	Fuel consumption (l)
RSA	4.914E+11[34]	6875645[35]	44,344,136[36]	2.8087E+10[37]
US	1.175E+13[59]	248984865.8[58]	295,734,134[61]	1.78E+11[59]
RSA/US	0.041821277	0.027614711	0.14994595	0.1577936

Table 29: Conversion Factors

In Table 30 the factors derived in Table 29 are applied to the totals listed in Table 28.

[34] https://www.cia.gov/cia/publications/factbook/rankorder/2001rank.html

[35] see Table 14

[36] http://www.cia.gov/cia/publications/factbook/rankorder/2119rank.html

[37] http://www.eldforum.org/safrica.htm assumption: one barrel holds 42 US gallons (standard crude oil barrel)

[38] http://www.mathcimauctions.com/usmr/us2.html - values adjusted to 2005 by applying an assumed 2% growth rate

[39] http://www.infoplease.com/ipa/A0004727.html

	Original Val's		GDP		Veh Pop		Pop		Fuel Cons	
Section	Low	High	Low	High	Low	High	Low	High	Low	High
1a	83.66	1334.59	3.5	55.81	2.31	36.85	12.54	200.12	13.2	210.59
1b	11.52	85.67	0.48	3.58	0.32	2.37	1.73	12.85	1.82	13.52
1c	11.52	65.13	0.48	2.72	0.32	1.8	1.73	9.77	1.82	10.28
1d	15.03	769	0.63	32.16	0.42	21.24	2.25	115.31	2.37	121.34
2	18.04	137.27	0.75	5.74	0.5	3.79	2.7	20.58	2.85	21.66
3	16.53	28.56	0.69	1.19	0.46	0.79	2.48	4.28	2.61	4.51
4	5.01	40.08	0.21	1.68	0.14	1.11	0.75	6.01	0.79	6.32
5	1	10.02	0.04	0.42	0.03	0.28	0.15	1.5	0.16	1.58
6	0	17.53	0	0.73	0	0.48	0	2.63	0	2.77
7	2.5	75.15	0.1	3.14	0.07	2.08	0.38	11.27	0.4	11.86
8	0.5	2.5	0.02	0.1	0.01	0.07	0.08	0.38	0.08	0.4
9	1	2.5	0.04	0.1	0.03	0.07	0.15	0.38	0.16	0.4
10	0.5	2.5	0.02	0.1	0.01	0.07	0.08	0.38	0.08	0.4
	166.82	**2570.5**	**6.98**	**107.5**	**4.61**	**70.98**	**25.01**	**385.44**	**26.32**	**405.61**

Table 30: Adjusted totals for pollution costs (billions of 2006 ZAR)

Charting the results yields the following:

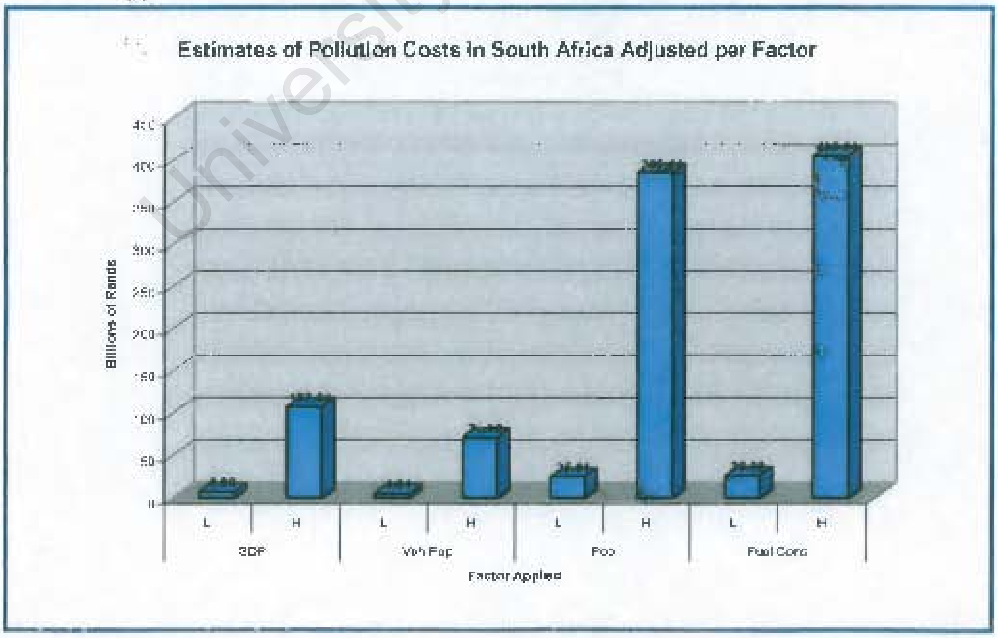

Figure 29: Estimates of Pollution Costs in South Africa Adjusted per Factor

Figure 29 indicates that there are relatively strong relationships between GDP and Vehicle Population and between Population and Fuel Consumption respectively. However, no further conclusive relationships can be drawn beyond this. The only result that can be said to have been found is that the environmental costs of pollution due to the use of ranges between R4.61 billion and R405 billion.

These figures are for the environmental costs of the total spectrum of use of motor vehicles in South Africa. However, we are primarily concerned with two facets of motor vehicles use in this report. These are speeding and the additional congestion resulting from accidents caused by speeding vehicles. The premise is that, should ISA be implemented in South Africa, then it holds the potential to eliminate these sources of pollution. This quantity is of interest here.

It was previously determined that on UK and Australian roads, between 20 and 50% of vehicles travel above the speed limit, and the Australian study showed that of these, between four and 11% exceeded the speed limit by more than 10km/h. The UK study found that an average of 15% of cars and light delivery vehicles travelled above 10mph over the speed limit. It was concluded by both studies that the incidence of speeding varied with the category of road, and both studies found that the prevalence of speeding increased the higher order of the road[40].

It was also found that ISA had the potential to decrease speeds by between four and 13%, and Adaptive Cruise Control (ACC) type ISA could lower all speeds to below the speed limit, as is shown in Figures 30 and 31 taken from a trial conducted in Tilburg (Besseling and can Boxtel, 2003).

[40] See section 3.2.2: Fuel consumption

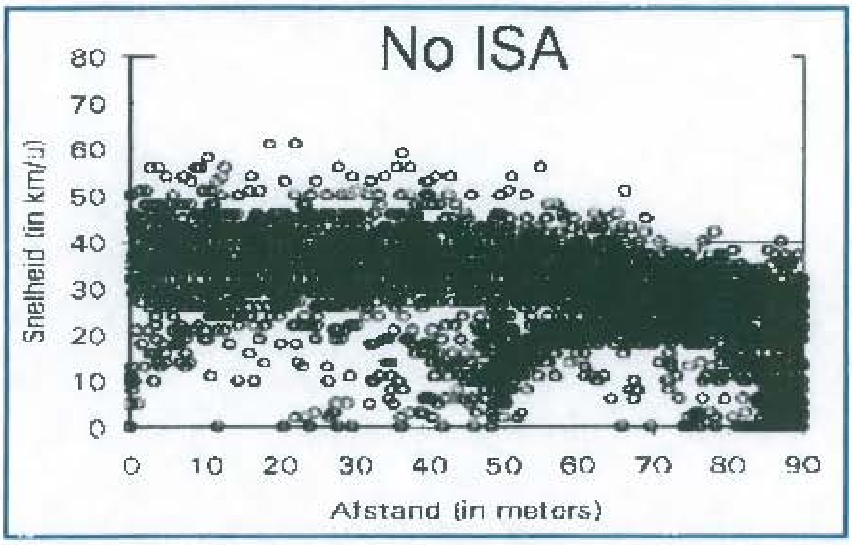

Figure 30: Speeds prior to the implementation of ISA

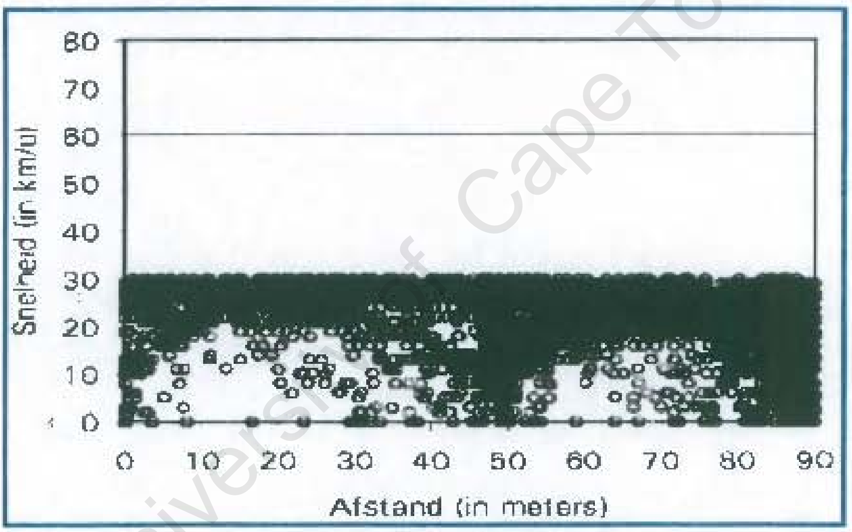

Figure 31: Speeds after the implementation of ISA

The figures clearly illustrate the dramatic potential ISA has for lowering speeds on a road.

A study completed by E.H. Pechan & Associates, Inc. (1997) investigated the effect on emissions of increasing the speed limit on roads in the USA from 55mph to 65mph. The study found that increasing the speed limit by 10mph would lead to an increase of six percent in NOx emissions, two percent in VOC emissions and seven percent in CO emissions. For the average vehicle, CO accounts for 85 to 90% of the emissions bulk, VOC's make up between five and seven percent and NO's between three and five percent.

So for every 100 grams of emissions at 55mph, these increases correspond to a five gram (or five percent) increase in emissions bulk. It stands to reason therefore, that a 10mph speed decrease would result in a five percent saving in emissions.

Considering that the majority of road users speeding, are travelling at under 10mph (±16km/h) over the speed limit, it would be reasonable to assume that should all road users speeding be forced to travel at or below the speed limit, there would also be a five percent emissions saving for that proportion of road users.

Using the range of speeders discussed previously of between 20 and 50%, Table 31 can be generated:

Percentage motorists speeding	potential emissions saving (%)
20	1.04
50	2.56

Table 31: Potential emissions savings assuming a five percent decrease in bulk emissions per vehicle

Applying these percentages to the results obtained from Delucchi's (1998) study yields the following findings:

%motorists speeding	potential % emissions saving	Delucchi min	Delucchi max
20	1.04	0.048021	4.21875
50	2.56	0.118205	10.38462

Table 32: Potential emissions savings applied to Delucchi's (1998) results in billions of ZAR

Table 32 shows that the range of possible savings from lowered emissions as a result of lowered average speeds could be between R48 million and R10.4 billion annually. This is still a large range of values, but it reflects the large variety of inputs and factors that govern emissions and pollution caused by automobiles.

3.5. Infrastructure Costs

3.5.1. The Cost of Speed Enforcement

The cost of enforcing the speed limits can be broken down into a number of categories. These are:

- Infrastructural costs such as traffic calming projects and devices, speed cameras, signage and the maintenance and operational costs of these.
- The deployment costs of the law officials who carry out the duties related the enforcement of speed restrictions, and the administrative costs of that portion of the traffic service devoted to speed restriction enforcement.
- The administrative costs associated with the processing and issuing of fines as well as the costs of any outsourced service providers involved in the administration of this service.
- The costs associated with the legal and juristic systems put in place to deal with non-payments of fines, the issuing of subpoenas, and the court and related criminal procedures required to convict offenders

Quantifying these costs is complicated by the diversity of the various National, Provincial and Municipal Departments involved in the delivery and funding of the various aspects of traffic enforcement. Furthermore, these costs often form part of larger budgetary allocations and information regarding their precise amounts is therefore not readily available.

However, the average provincial budgetary allocation for road traffic management is on the order of R250 million annually (therefore, the figure nationally would be approximately R2,25 billion). Of the 525 000 notices issued during phase 2 of the Arrive Alive Campaign held February 1998 to April 1998, approximately 299 000 (57%) were for speeding[41].

Data issued by the Road traffic Management Corporation (RTMC) in their 2005 Road Traffic Report yielded the information presented in Table 33:

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[41] http://www.transport.gov.za/projects/arrive/closer.html

Number of	GA	KZ	WC	EC	MP	NW	NC	RSA
Roadblocks	0	1,314		148	100	103	62	1,727
Vehicles stopped	10,830	187,468	1,678	0	12,199	23,521	10,830	246,524
Alcohol prosecutions	156	535	53	173	56	34	0	1,007
Vehicle defects	239,000	8,784	615	0	1,334	2,088	155	251,976
Vehicles suspended	0	649	39	271	119	140	14	1,232
Documentation	0	5,313	25	0	0	0	226	5,564
Overloading	0	1,065	998	0	131	0	42	2,236
General operations	0	6,991	0	0	0	0	6,991	13982
Speed	260,223	32,708	3,141	4,008	3,566	652	304,298	608596
Moving violations	0	2,745	443	0	559	0	26	3,773
Other offences	0	2,396	183	0	12,002	116,617	1,727	132,925

Table 33: RTMC traffic offences for 2005

Although the Free State and Limpopo provinces did not forward any data in time for publication of the report, the information still provides some useful insights into the proportions of traffic fines issued nationally. The chart below is based on the data presented in Table 33:

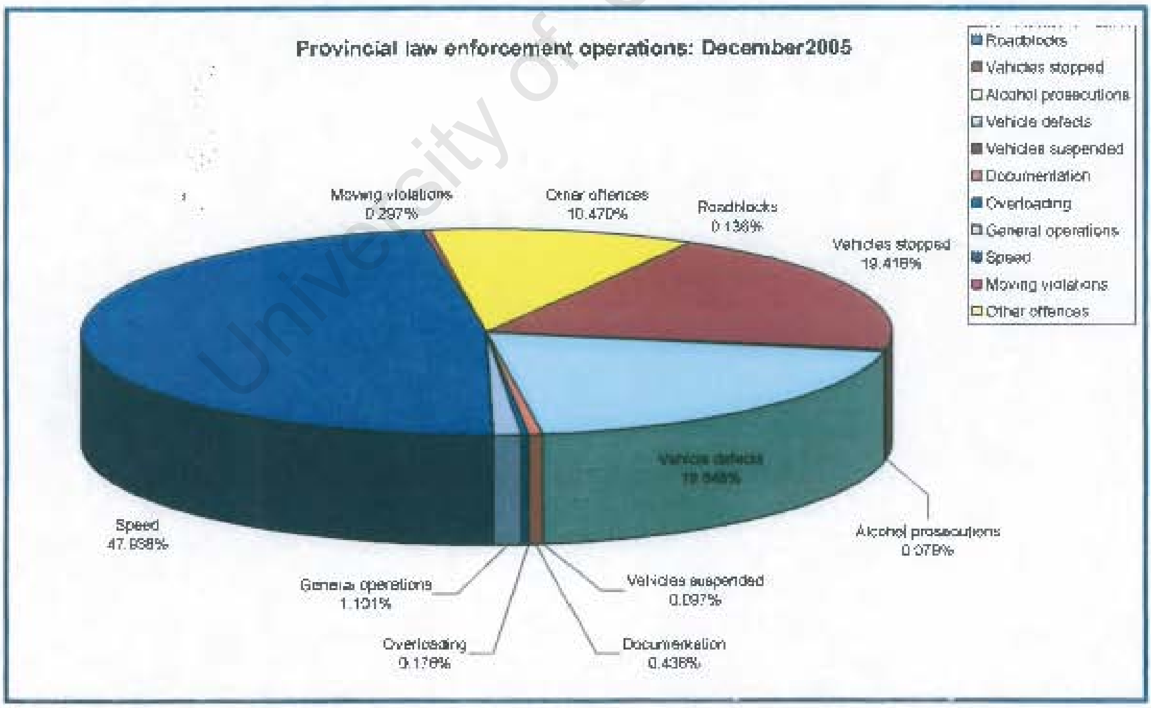

Figure 32: Provincial law enforcement operations: December 2005

Figure 32 clearly shows that nearly 50% of the violations recorded during December 2005 were for speeding. This value is similar to that reported by Arrive Alive. The implication is that as the majority of fines issued is for speeding, the majority of time and money spent in enforcing and administering road traffic goes towards monitoring speed. Although it is a crude assessment of the expenses towards law enforcement, without any further information, the best estimate that can be made based upon the information at hand is that by eliminating speeding, ISA could potentially save R1.125 billion of public funds devoted to traffic law enforcement annually.

This figure would account for time spent by all personnel and all moneys spent on the administration, equipment and plant used in enforcing the speed limits.

3.5.2. The Cost of Infrastructure

The cost of infrastructure not included in the cost of speed enforcement discussed previously in section 3.5.1, but still employed in the enforcement of speed, includes physical infrastructure such as speed camera's and traffic calming measures.

These improvements have been kept apart from the other costs of enforcement discussed in section 3.5.1 because they constitute permanent road fixtures and upgrades as opposed to ongoing expenses to deliver the service.

A cost benefit analysis undertaken on behalf of the UK Home Office Police Research Group by Andrew Hooke, Jim Knox and David Portas in 1996 found that speed camera's cost £12,500 per site and that there was an recurrent annual cost of £8,500 per site.

In June 1996, a British Pound cost approximately R6,71, and so the conversion indicates that these devices cost approximately R83 875 per site with an annual cost of R57 035 per site. Using An average inflation of 11% over the period 1996 to 2006, these values would have increases to approximately R265 000 for installation and R180 000 for ongoing maintenance. Although these values seem very large, a quick calculation shows that any particular site only has to generate one fine a day to cover its recurrent costs (assuming that the average speeding ticket costs R500).

It was not possible to source reliable data as to the number of speed camera's currently operating in South Africa, and so it is not possible to determine what potential savings ISA could offer the authorities in terms of the installation and continual maintenance of these sites.

Similarly, the cost of traffic calming varies from country to country, from city to city, and even from project to project. Traffic calming devices such as speed humps can range in cost from R5000 to R15 000, and a traffic circle or a roundabout can cost in excess of R200 000 (even up to R1 000 000). Another factor is that traffic calming is often implemented as a package of measures, designed to lower speed and address excessive traffic volumes. This affects the price of the individual devices as the package cost is often lower than the individual device.

It was also not possible to ascertain the scope of traffic calming projects currently underway in South Africa, and so it is difficult to speculate as to annual expenditure on traffic calming.

However, full implementation of ACC type ISA would eliminate the need for traffic calming measures. It has also been noted in much of the literature, that traffic calming devices incorporating vertical deflections increase wear on vehicles, they increase ambient noise due to the repeated acceleration and deceleration cycles they introduce, they increase emissions levels due to the repeated acceleration they introduce and they create difficulties for larger vehicles such as busses and trucks.

This last point has seen traffic calming devices mostly excluded from higher order roads such as collectors and distributors. The irony is that the majority of accidents occur on these roads, which often fall within a 5 to 10 minute radius from the journey origin. This is often cited as being the most dangerous time for a motorist, as this is when accidents are most likely to occur.

The major benefit of ISA is that it will not be constrained in this manner, and the severity of the speed restriction can easily be lessened further up the road hierarchy to suit conditions. This is in contrast to physical alterations to the road, which are very difficult to engineer for a certain speed, and even if installed correctly, does not guarantee that it will be used optimally by the passing motorist.

Traffic calming measures also increase the cost of maintenance on roads due to the complexity they add to construction techniques. Resurfacing a road with speed bumps or speed tables is more expensive and to make matters worse, these pavements suffer increased loads due to the increased acceleration and deceleration cycles they experience.

Fortunately, on the majority of roads where calming measures have been introduced this is not problematic as they mostly carry light passenger vehicles.

3.6. Resume

In the literature review, we considered the effects of speed in relation to safety, operating costs and the environment. It was accepted that ISA is a speed reduction measure, and so any of its benefits could be quantified by determining firstly to what extent ISA would affect vehicle speeds, and secondly what the effects of speed are. A simple calculation would then yield reasonable estimates for the effects of ISA.

Some of the findings are listed below:

- There is a direct link between speed and the incidence of road accidents.
- There is a direct link between speed and the severity of road accidents.
- Speed limits are effective in increasing or decreasing the travelled speeds on a road.

It can be concluded from the above three points that speed limits play an important role in regulating the incidence and severity of road accidents. Moreover, improving the adherence to speed limits would greatly improve the efficacy of speed limits.

ISA by its very nature is aimed at improving adherence to posted speed limits, and so it can be said with some degree of confidence that ISA would have a direct influence on the incidence and the severity of road accidents.

An attempt was made to estimate the value of this benefit to South Africa. It was found that, when a road accident occurs, the costs created are borne by a range of parties, and that in general, the costs borne by society as a whole outweighs the costs borne by the individual.

An initial estimate for the total annual cost of road accidents as a result of speed was calculated by using the N.D.o.T. (National Department of Transport) assertion that speed is the primary causal factor of 30% of road accidents, and applying it to the C.S.I.R.'s estimation that road accidents cost the country approximately R38 billion per year. This calculation yielded a result of R11.4 billion. It is a crude estimate, but useful in that it gives us some sense of the magnitude of the problem.

A further estimate was derived by considering the findings of a study conducted by Reynolds (1956) in the United Kingdom during the early 1950's. It was accepted from the outset that the actual values derived by Reynolds would be of little relevance today, but that the method he used to arrive at those figures might be of value.

Reynolds considered the following as contributing to the costs of road accidents:

- Damage to property;
- Medical costs associated with the treatment of casualties;
- Administrative insurance costs which can be ascribed to the occurrence of accidents; and
- The net reduction in output of goods and service due to the loss of output from people who have been killed

In addition, Reynolds mentions a set of costs that he claims cannot be measured or estimated accurately, but that does contribute to the overall costs of road accidents:

- Administrative costs due to the occurrence of accidents, incurred by the police, the government and lawyers. These cannot be separated from the cost incurred during the performance of their other duties.
- The economic effects of a smaller population: With the existence of road accidents the population of Great Britain will be slightly smaller and of a slightly different age/sex occupational structure.
- The effect of transfers of income within the community: With the occurrence of accidents, income is transferred from the rest of the community in compensation to those who suffer loss from the accidents, without any necessary change in the resources at the disposal of the community. It is impossible to estimate this change.

The proportions of the values derived by Reynolds was considered and it was found that the immediate costs of road accidents (those costs that cannot be attributed to a loss of output of injured or deceased peoples) accounts for approximately 50% of the total costs of road accidents.

It was also noted that the RAF (Road Accident Fund), set up by the South African government and funded by levies incorporated into the fuel price, settled approximately R5,5 billion worth of claims during the 2004/2005 financial year.

A further estimate was made by combining the assertion made by the spokesperson for the Automobile Association of South Africa, Mr Gary Ronald, that fatal accidents costs the country approximately R400 000 each with the number of fatalities on South African Roads as given by the CSIR of 11 616. This yielded an annual value of R5 622 144 000 after accounting for inflationary effects.

Another estimate, the costs per accident and per injury, derived from values for New Zealand given in a paper by Barnett et al (1998) is given below:

	Fatal	Serious	Minor
Accident	R9 770 816.62	R863 501.37	R61 522.65
Injury	R8 234 570.49	R706 600.41	R45 868.96

These values have been converted to Rands and incorporates inflationary effects and currency fluctuations. When further combined with NDoT accident statistics the values for 1998 are as follows:

	Killed	Seriously injured	Slightly injured
Number of cases	9068	36246	84358
Cost per injury	R 6,016,920	R 516,306	R 33,516
Totals	R 54,561,430,560.00	R 18,714,027,276.00	R 2,827,342,728.00

Summing the totals gives a figure of R 76,102,800,564.00. Applying the NDoT's estimate that speed accounts for approximately 30% of road accidents yields a value of R 25,367,600,188.00. This value differs significantly from the initial estimate as derived from the CSIR and the NDoT's statistics of R 11,400,000,000.00. This may be due to the the scope of factors included into the assessment, but it is impossible to verify without further information as to the scope of the NDoT's study.

It was noted that none of the estimates included costs incurred because of incident-induced congestion. This was covered in a later section. The cost of accident-induced congestion was found to be dependent upon a number of factors. Amongst these are:

- The costs associated with time delay due to congestion
- The additional fuel consumed due to congestion
- The additional operating costs due to congestion
- The additional environmental costs due to the congestion

An investigation was done into these costs.

The first exercise was to determine the extent of incident induced congestion delay. Two types of delay were considered. These were congestion near the incident in the same lane or carriageway and congestion in the opposing lane or carriageway because of "rubbernecking".

Results from two American studies were combined with South African accident statistics to estimate the extent of delay locally. A result of 291 972 920 vehicle hours annually was arrived at. A further finding was that "rubbernecking" accounted for 2% of the total delay.

A further calculation, an extrapolation of Canadian and American data, showed that the total costs of time delay could amount to around R75 891 715 annually. If this value is combined with the total number of vehicle hours, this would equate to approximately R0,26 per vehicle hour.

Two values for the possible fuel consumption savings resulting from an eradication of speeding on roads due to the implantation of ISA were found. The first was calculated based upon a 0.1L/100km reduction in consumption resulting in an annual saving of 160 967 000 litres of fuel per year. This translates to a value of R1 094 575 600 at a fuel price of R6,80 per litre. A second value was calculated based upon an 8% reduction in consumption. The resultant saving was R7 180 415 936 per year.

The cost of the additional fuel consumed as a result of incident induced congestion because of accidents caused by excessive speed was calculated at R3 584 774.10 per year. This was for a petroleum price of R5, 90 per litre as of the 2005.

The additional maintenance costs of vehicles because of incident-induced delay was derived from National Department of Transport figures and calculated as a percentage of the fuel costs. The findings are shown in the table below:

	Servicing and repair costs (% of fuel costs)	Tyre Costs (% of fuel costs)	Total cost (c/km)
Petrol Vehicles	44.47	20.19	82.68
Diesel Vehicles	69.03	28.11	83.85

These costs were found to increase the fuel costs by 64.7% bringing the total operating costs to R5 902 688.97.

A similar calculation was applied to the fuel savings derived from the eradication of speeding vehicles. The operational costs savings were found to be between R11 861 329 084 and R14 225 122 010.

An in-depth look into the relationship between vehicle speed and the effects on the environment was undertaken. This was done so as to determine to what extent ISA would either benefit or worsen the effect of automobiles on the environment.

The question that needed to be answered was, accepting that ISA, even in its most severe application, could not eliminate vehicular emissions and pollution entirely, how would the elimination of speeding translate into a decrease in overall vehicular emissions?

An initial estimation, based upon the cost ratio's derived from studies done by Transport Canada and Shrank and Lomax of Texas A&M University, yielded a cost of R2 529 724 for the environmental costs of incident induced congestion, where the primary cause of the incident was excessive speed. A further finding was that the possible savings from the implementation of ISA due to reduction in average travelling speed was between R5 083 426 750 and R6 096 480 861.

A very comprehensive study by Delucchi et al (see Appendix 5) was also considered. The study addresses a very wide range of the generalised impacts of automobile usage in the USA on the environment, and attempts to present its findings in US dollars. The results are presented as a range of values from low to high. An attempt was made to apply these findings to the South African context. After the application of various factors specifically derived for this report, the finding was that the cost of automobile usage in South Africa on the environment ranged between R4.61 billion and R405 billion.

The potential savings resulting from the introduction of ISA was presented for two cases. The first case assumed that 20% of motorists travelled in excess of the speed limit and the second case assumed that 50% of motorists travelled in excess of the speed limit. For each case, the calculations were done for the low and high range of the findings from Delucchi's study. The results are presented below:

%motorists speeding	potential % emissions saving	Delucchi min	Delucchi max
20	1.04	0.048021	4.21875
50	2.56	0.118205	10.38462

The potential savings was calculated to be between R48 million and R10,4 billion annually.

The cost of infrastructure was considered from two perspectives. Firstly, the cost of the administrative, manpower and institutional infrastructure devoted to enforcing adherence to the speed limits, and secondly, the cost of the physical infrastructure installed to enforce the speed limits.

It was found that nearly 50% of resources devoted to traffic management went towards enforcing the speed limits. This finding was made based upon the proportion of fines issued for traffic offences. This finding translated into a cost of R1,125 billion annually spent on enforcing the posted speed limits.

The scope of the physical infrastructure put in place to enforce speed limits was limited to speed cameras and traffic calming measures. It was not possible to determine the extent of the infrastructure that has been installed or is currently being installed. However, it was estimated that a speed camera costs approximately R265 000 to install and R180 000 annually to operate and maintain.

Table 34 summarises the findings of the literature report:

Category	Cost Item	Value Range
Road Accidents	Cost of road accidents caused by excessive speed	R11 400 000 000 R5 622 144 000 R25 367 600 000
Time Delay	Costs of time delay as a result of accidents caused by excessive speed	R75 891 000
Operating costs	The additional vehicle operating costs because of incident-induced delay caused by incidents resulting from excessive speed	R5 902 000
	The additional vehicle operating costs as a result of speeding	R11 861 329 000 R14 225 122 000
Environmental Costs	The cost of damages to the environment because of incident-induced delay caused by incidents resulting from excessive speed	R2 529 000
	The cost of damages to the environment because of the additional pollutants resulting from excessive speed	R5 083 426 000 R6 096 480 000 R48 000 000 R10 400 000 000
Infrastructural Costs	The cost of the enforcement of speed limits	R1 125 000 000
	The cost of infrastructure installed to enforce the speed limit	unknown
Total Potential Savings	Maximum	R51 202 046 000
	Minimum	R18 740 797 000

Table 34: Summary of potential annual cost savings offered by ISA

It was not possible to determine values for the cost of infrastructure installed to enforce the speed limit.

As can be seen, there is a range of possible totals presented for certain of the cost sectors. The charts below present the maximum and minimum combinations of savings as per the table above. The maximum savings that can be achieved by implementing ISA in South Africa was calculated as R51 202 046 000 and the minimum savings as R18 740 797 000.

The charts show that under both scenario's, the additional cost operating costs as a result of speeding and the cost of road accidents are the greatest contributors to the total potential savings ISA could offer. Together they contribute 93.3% of the total savings in the maximum savings scenario and 77.3% in the minimum savings scenario.

It can be concluded from this that by far the largest cost to the country because of speeding is due to the increased operating costs of vehicles and due to accidents caused by speeding motorists.

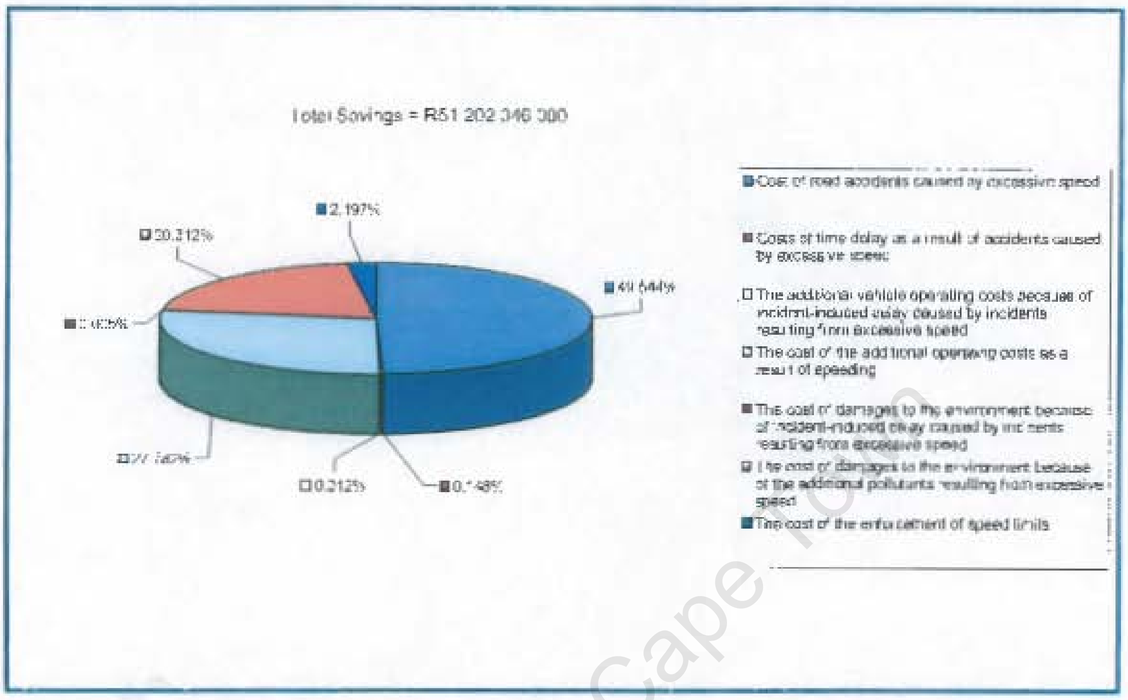

Figure 33: Maximum saving scenario

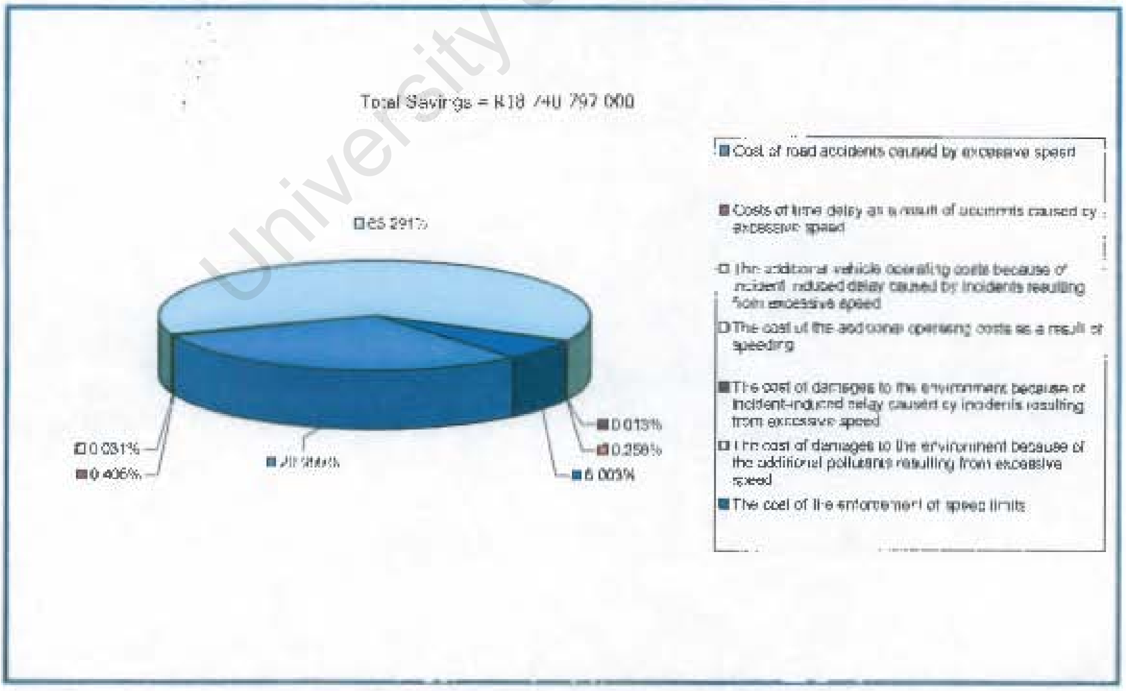

Figure 34: Minimum saving scenario

4. CONCLUSIONS

The stated aim of this dissertation was to find, list, quantify, and where possible, provide monetary estimates of all of the benefits that Intelligent Speed Adaptation (ISA) might hold for South Africa. The conclusions listed here are, therefore, a distillation of the findings and a summation of the monetary values of those benefits that were identified.

1. Various forms of ISA can be implemented, each with its own set of advantages and disadvantages. Since ISA can only affect the vehicles speed, the maximum benefit that ISA can achieve is to lower speeds to the posted speed limit. Inappropriate speeds below the speed limit cannot be regulated, and in these cases, amending the limits to more appropriate levels is the only solution.

2. The different types or levels of ISA have been found to have differing levels of influence on vehicle speeds. Additionally, the efficacy of ISA has been shown to vary with the rate of ISA penetration into the vehicle fleet. The maximum benefit that could possibly be derived from ISA would therefore be achieved on a network with 100% penetration of the most intrusive form of ISA, this being fuel regulating or ACC type ISA systems.

3. User acceptance of ISA increases with exposure to the system. Acceptance, however, decreases with the level of intrusiveness into driver control. There is also evidence to suggest that the public is at least open to the concepts driving the technology, and that through education and awareness programmes negative opinions may be swayed regarding ISA.

4. ISA has the potential to provide savings in the direct costs of road accidents, in the costs attributed to the time delay resulting from road accidents and in the associated additional operating and environmental costs resulting from this time delay. Further savings could be expected from the general lowering of travel speeds to below the speed limits. These savings are primarily from lowered operating costs and lowered environmental damages. Additionally, ISA can provide savings from the release of resources dedicated to the enforcement of speed limits and the costs of infrastructure directly aimed at controlling vehicle speeds.

5. The direct costs of road accidents caused by speeding in South Africa is as much as R26,4 billion annually. In addition, nearly 292 million vehicle hours annually are spent in traffic congestion caused by road accidents resulting from excessive speed. The cost of this time delay amounts to nearly R76 million annually. The additional vehicle operating costs because of this time delay amounts nearly R6 million annually, and the additional cost of damages to the environment is estimated to be approximately R2.5 million annually.

   In total, therefore, speeding costs South Africa nearly R26.5 billion per year.

6. ISA has the potential to offer South Africa substantial annual savings. The maximum savings that can be achieved by implementing ISA in South Africa was calculated as R51.2 billion and the minimum savings as R18.7 billion annually.

   The maximum value is made up of the R26.5 billion cost attributed to road accidents, an additional R24.6 billion in savings from lowered vehicle operating costs and environmental damages, and a saving of at least R1.1 million annually (conservatively) in infrastructural and enforcement costs.

7. The largest savings in both the maximum and minimum savings scenario's are due to the additional operating costs as a result of speeding and the direct cost of road accidents. Together, these contribute between 77% and 93% of the savings identified.

8. Very little research has been done to establish the potential ISA has in South Africa. There is no data on user perceptions, or how well ISA systems would perform in terms of actual speed reduction in South Africa. No concerted effort has been made to establish a feasible implementation strategy for this country. Furthermore, the question of how ISA would fit into the policy, legal and regulatory framework governing transportation in South Africa must still be investigated.

The conclusions drawn in this report have confirmed that speeding costs South Africa very large sums of money every year. But beyond the monetary costs are those costs that cannot be measured or costed. The wounds that speeding leaves on our society and on our country go well beyond fuel consumption and enforcement costs, extending into the lives of those disabled by speeding motorists and those who have lost loved ones.

This report confirms that ISA has the potential to eliminate much of the damage caused by speeding. The full ramifications of the elimination of speeding cannot be fully understood prior to its implementation.

5. RECOMMENDATIONS

The following recommendations are made in relation to the findings and conclusions that were drawn in this report:

1. It is recommended that ISA be implemented in South Africa. South Africa has excessive problems due to speeding and road accidents, as is shown by the very large annual cost of road accidents caused by speed. Road accidents have been shown to be one of the largest contributors to the cost of speeding in South Africa.

2. Other countries, most notably in Europe, have made great strides in developing and understanding ISA technologies, and with the current interest in the application of intelligent transport systems in South Africa, it is recommended that the possibilities that ISA type technologies hold for the country are actively promoted, so that interest in and awareness of the technology is stimulated.

3. Much still needs to be done in terms of researching the effects of this technology in South Africa, its advantages and disadvantages and developing a sound strategy for implementation. This scope of this report did not allow for a more thorough analysis of the benefits of implementing ISA in South Africa, and did not include an evaluation of the costs of ISA. It is therefore recommended that actual field-testing of ISA systems be done. These tests could yield data on system performances as well as user perceptions and attitudes towards the technology.

4. It is recommended that research be done into the implications South Africa's legal, policy and regulatory frameworks may hold for bringing ISA to South Africa. This will provide results that will inform any implementation strategies that may be developed.

5. The results from this study could be further refined and then form the basis of an in-depth cost benefit analysis, that would then further be used to develop an appropriate implementation strategy for South Africa.

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APPENDICES

Contents

Appendix 1:

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Table 3. Summary of the effects of raising or lowering speed limits.

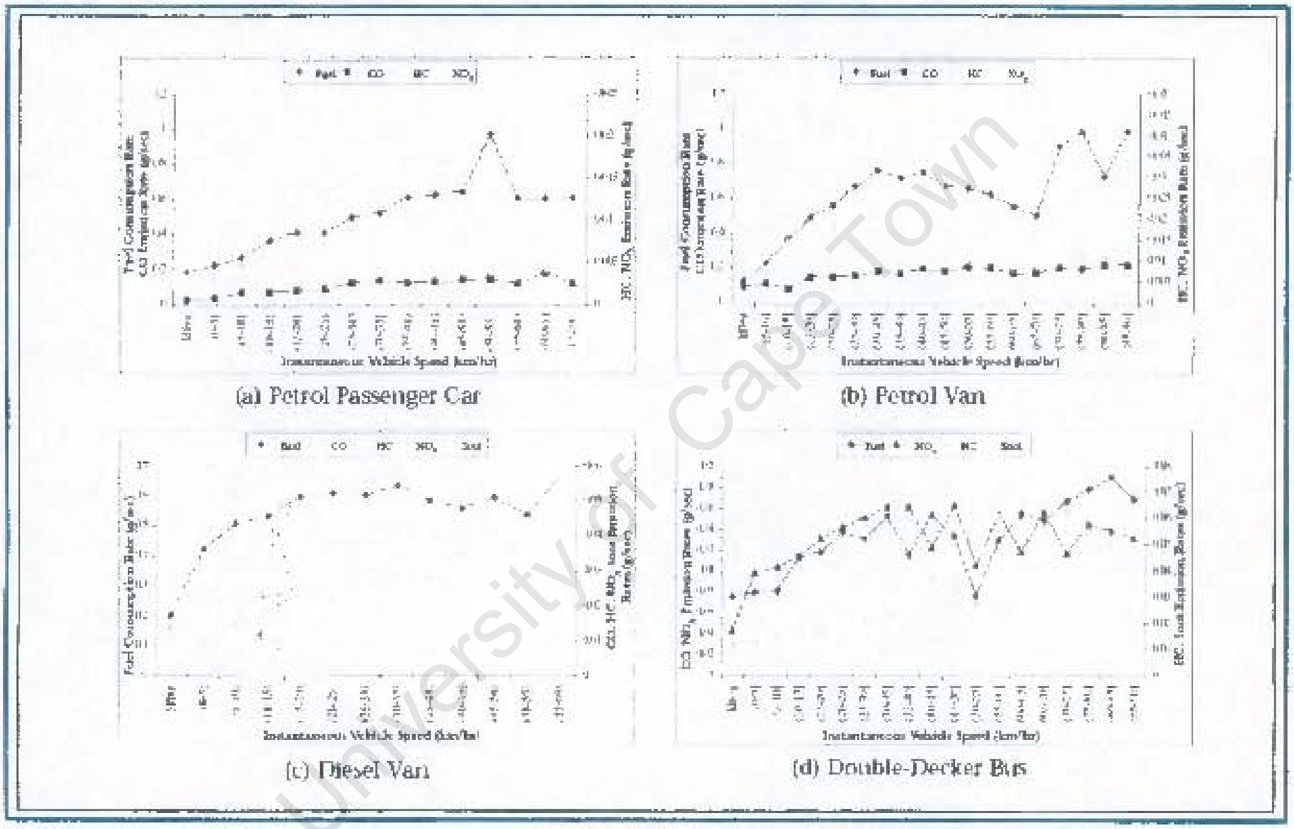
Reference	Country	Change	Results
Speed Limit Decreases			
Nilsson (1990)	Sweden	110 km/h to 90 km/h (68 mi/h to 56 mi/h)	Speeds declined by 14 km/h Fatal crashes declined by 21%
Engel (1990)	Denmark	60 km/h to 50 km/h (37 mi/h to 31 mi/h)	Fatal crashes declined by 24% Injury crashes declined by 9%
Peltola (1991)	UK	100 km/h to 80 km/h (62 mi/h to 50 mi/h)	Speeds declined by 4 km/h Crashes declined by 14%
Sliogeris (1992)	Australia	110 km/h to 100 km/h (68 mi/h to 62 mi/h)	Injury crashes declined by 19%
Finch et al. (1994)	Switzerland	130 km/h to 120 km/h (81 mi/h to 75 mi/h)	Speeds declined by 5 km/h Fatal crashes declined by 12%
Scharping (1994)	Germany	60 km/h to 50 km/h (37 mi/h to 31 mi/h)	Crashes declined by 20%
Newstead and Mullan (1996)	Australia	5-20 km/h decreases (3-12 mi/h decreases)	No significant change (4% increase relative to sites not changed)
Parker (1997)	USA 22 states	5-20 mi/h decreases (8-32 km/h decreases)	No significant changes

Speed Limit Increases			
NHTSA (1989)	USA	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Fatal crashes increased by 21%
McKnight, Kleinand Tippetts (1990),	USA	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Fatal crashes increased by 22% Speeding increased by 48%
Garber and Graham (1990)	USA (40 States)	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Fatalities increased by 15% Decrease or no effect in12 States
Streff and Schultz (1991)	USA (Michigan)	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Fatal and injury crashes increased significantly on rural freeways
Pant, Adhami and Niehaus (1992)	USA (Ohio)	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Injury and property damage crashes increased but not fatal crashes
Sliogeris (1992)	Australia	100 km/h to 110 km/h (62 mi/h to 68 mi/h)	Injury crashes increased by 25%
Lave and Elias (1994)	USA (40 states)	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Statewide fatality rates decreased 3-5% (Significant in 14 of 40 States)
Iowa Safety Task Force (1996)	USA (Iowa)	55 mi/h to 65 mi/h (89 km/h to 105 km/h)	Fatal crashes increased by 36%
Parker (1992)	USA (Michigan)	Various	No significant changes
Newstead and Mullan (1996)	Australia (Victoria)	5-20 km/h increases (3-12 mi/h increases)	Crashes increased overall by 8% 35% decline in zones raised from 60-80
Parker (1997)	USA 22 states	5-15 mi/h (8-24 km/h)	No significant changes

Appendix 2

Tong H.Y., Hung W.T, Cheung, C.S.; 2000; On-Road Motor Vehicle Emissions and Fuel Consumption in Urban Driving Conditions; J. Air & Waste Manage. Assoc. 50:543-554:

Emissions and fuel consumption factors against instantaneous vehicle speed.



(a) Petrol Passenger Car

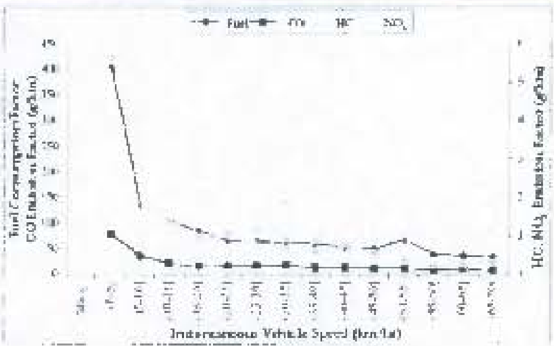
(b) Petrol Van

(c) Diesel Van

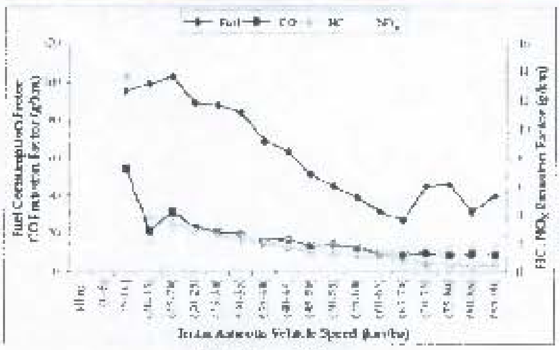
(d) Double-Decker Bus

Appendix 2 cont.

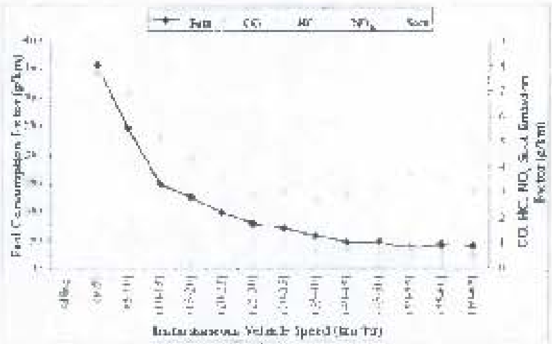
Emissions and fuel consumption rates against instantaneous vehicle speed.



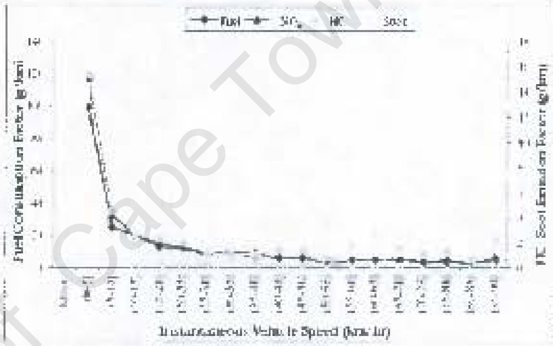
(a) Petrol Passenger Car



(b) Petrol Van



(c) Diesel Van



(d) Double-Decker Bus

Appendix 3

6.1.1. Determination of South African Vehicle Population

The National Association of Automobile Manufacturers of South Africa (NAAMSA) provides statistics for new vehicle sales. The following quotation was taken from their website[42]: "During 2005, South Africa was probably the best performing market internationally. Calendar 2005 represented another outstanding and record year for the South African new vehicle manufacturing industry with both domestic sales and production rising to all time highs. Initial indications are that the magnitude of 2005 sales is in the order of 565 018 - some 25,7% up on 2004. For the year 2004, NAAMSA reported sales improved by a remarkable 22,0% to reach 449 603 vehicles compared to the 368 470 units sold during 2003." However, final vehicle sales for 2005 reached 618028

Table 1 lists the data outlined in the National Association of Automobile Manufacturers of South Africa's (NAAMSA) 4th quarterly report for 2002[43]. The values show that for 2001 the total number of new vehicles sold was 382529. For 2002 the number of vehicles sold was 363184[†].

The figures quoted above assert that from 2001 through 2005, the national vehicle population increased by 2128804 new vehicles. Combining this value with the National Department of Transports value for the national vehicle population in 2000 of 6 049 964 would bring the total number of vehicles on South Africa's roads at the end of 2005 to 8178768. This value, however, does not take into account vehicle retirements or scrapping.

In the absence of reliable data for scrappage rates for South Africa, a figure of 4% per annum was assumed to apply locally. A 2006 report[44] investigating the state of the US vehicle fleet released by R. L. Polk & Co, a US based research organisation, found that during 2005 scrappage rates had declined across vehicle types to around 3% and that the median age of the vehicle population varied between 9 years for cars and 6.5 years for light trucks (see figures 1 and 2).

42 http://www.naamsa.co.za/

43 http://www.naamsa.co.za/papers/2002_4thquarter/schedule.htm

† These values are calculated by the addition of the relevant totals for the local market, which do not include exports.

44 http://www.greencarcongress.com/2006/02/us_vehicle_flee.html

INDUSTRY VEHICLE SALES, EXPORT AND IMPORT DATA : 1995 - 2005											
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	ACTUAL	ACTUAL	ACTUAL	ACTUAL	ACTUAL	ACTUAL	ACTUAL	ACTUAL	PROJ	PROJ	PROJ
PASSENGER CARS											
Domestically Produced											
Local Sales	233512	231616	215784	174870	159944	172373	172052	163474	165000	170000	175000
Exports (CBU)	8976	3743	10458	18342	52347	58204	97599	113025	126000	138000	150000
Sub-Total	242488	235359	226242	193212	212291	230577	269651	276499	291000	308000	325000
CBU Imports											
NAAMSA	7246	18268	23978	28951	29426	51749	67008	68128	70000	75000	85000
Non-NAAMSA	15059	23500	28000	31000	25000	10000	12500	10000	11000	12000	13000
Sub-Total	22305	41768	51978	59951	54426	61749	79508	78128	81000	87000	98000
TOTAL LOCAL MARKET	255817	273384	267762	234821	214370	234122	251560	241602	246000	257000	273000
LIGHT COMMERCIAL VEHICLES											
Domestically Produced											
Local Sales	128397	129575	113992	99778	96169	105235	113111	101956	104000	108000	112000
Exports	6356	7125	8000	6806	6581	9148	10229	11699	12000	14000	20000
Sub-Total	134753	136700	121992	106584	102750	114383	123340	113655	116000	122000	132000

INDUSTRY VEHICLE SALES, EXPORT AND IMPORT DATA : 1995 – 2005 Continued											
	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
	ACTUAL	**ACTUAL**	**ACTUAL**	**ACTUAL**	**ACTUAL**	**ACTUAL**	**ACTUAL**	**ACTUAL**	**PROJ**	**PROJ**	**PROJ**
CBU Imports											
NAAMSA							2035	2791	2800	2900	3000
Non-NAAMSA	3000	3500	3762	4100	3500	3000	2500	2500	2500	2600	2700
Sub-Total	3000	3500	3762	4100	3500	3000	4535	5291	5300	5500	5700
LOCAL MARKET	131397	133075	117754	103878	99669	108235	117646	107247	109300	113500	117700
MEDIUM AND HEAVY COMMERCIAL VEHICLES											
Domestically Produced	11803	13567	12759	11511	10236	11725	12693	13705	14500	15000	16000
Exports	432	685	1111	748	788	679	465	582	600	700	800
Imports	950	1050	1000	1300	1500	550	630	630	630	3000	3300
MCV/HCV MARKET	12753	14617	13759	12811	11736	12275	13323	14335	15130	18000	19300

Table 1: Industry vehicle sales, export and import data: 1995 - 2005[45]

[45] http://www.naamsa.co.za/papers/2002_4thquarter/schedule.htm

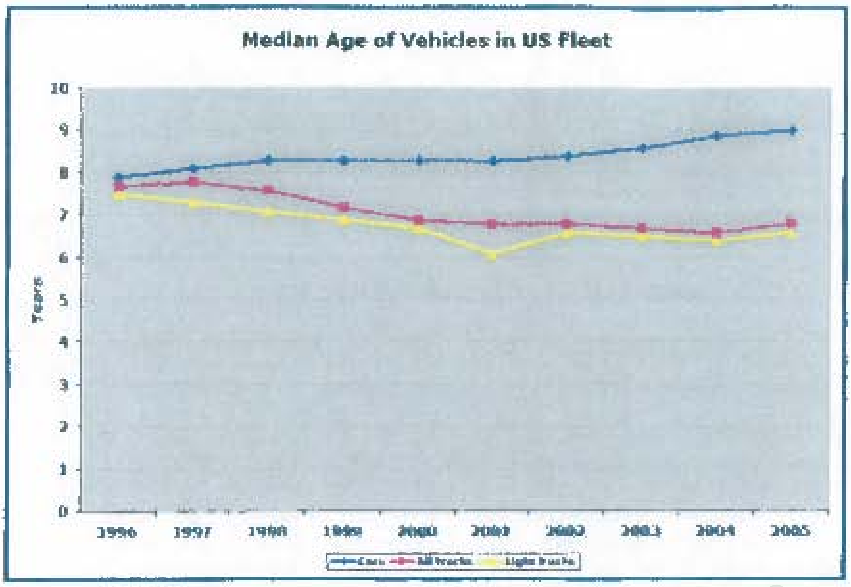


Figure 1: Median age of vehicles in US fleet

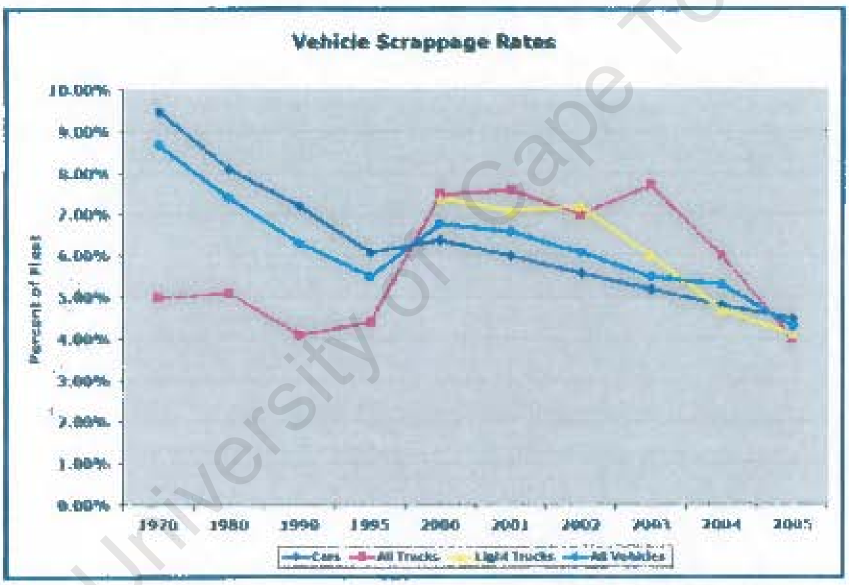


Figure 2 : Vehicle Scrappage Rates in the USA

If it is considered that the average age of the fleet in South Africa is generally higher than in the US, as can be seen in the table and figure[46] below, then it is fair to assume that the scrappage rates will be lower here than there.

[46] http://www.transport.gov.za/library/docs/stats/2001/statistics.html#2.4

Year	Cars	Minibuses	Commercial vehicles	Buses	Motorcycles
1985	7.4	6.5	7.3	7.7	5.2
1986	7.8	6.9	7.8	8.9	6.1
1987	8.1	7	8.1	9	6.8
1988	8.4	7.1	8.4	9.1	7.5
1989	8.7	7.1	8.6	9.6	8
1990	9	7.3	8.9	10	8.7
1991	9.2	7.6	9.2	10.1	9.5
1992	9.6	8	9.6	10.7	10.2

Table 2 Average age of vehicles in South Africa

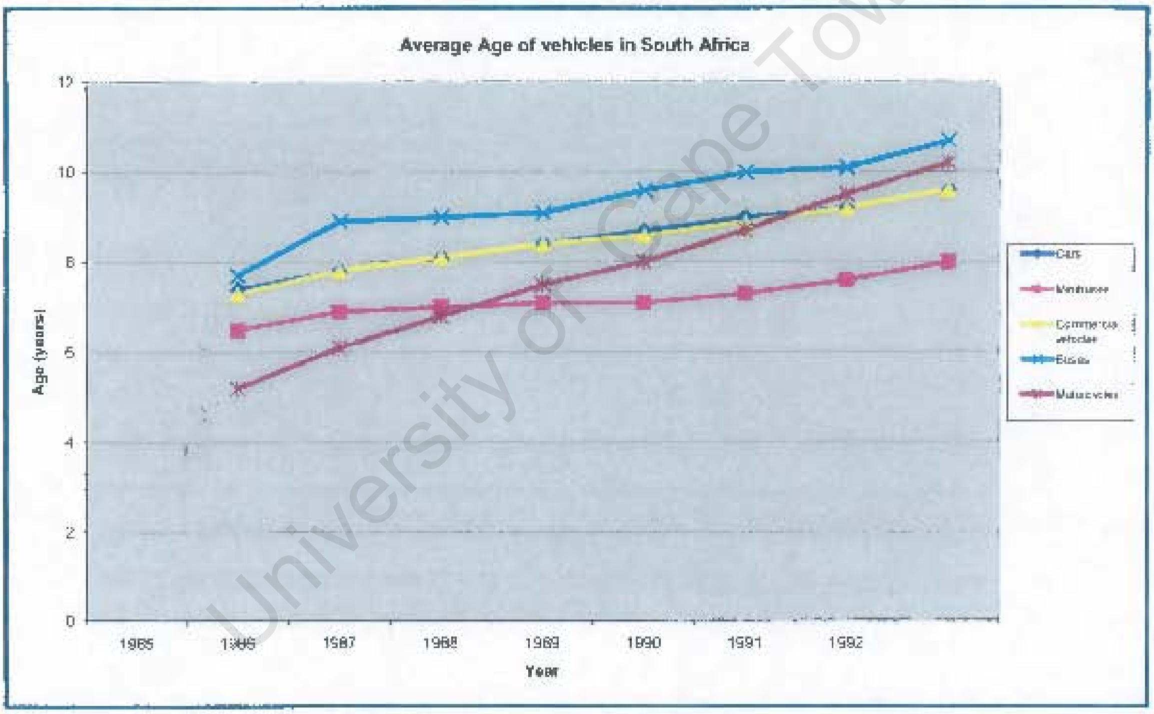


Figure 3: Average Age of Vehicles in South Africa

Applying the assumed scrappage rate of 3% per annum to the values obtained from the NAAMSA statistics gives the following set of results:

Year	Vehicle population	Vehicle population adjusted for scrappage	Annual vehicle sales
31/12/2000	6 049 964		
31/12/2001	6 049 964	5 868 465	382 529
31/12/2002	6 231 649	6 044 700	363 184
31/12/2003	6 413 170	6 220 775	368 470
31/12/2004	6 670 378	6 470 266	449 603
31/12/2005	7 088 294	6 875 645	618 028

Table 3: SA Vehicle population adjusted for scrappage

Appendix 4:

The UK Department for Transport, 2005, Transport Statistics Bulletin: Vehicle speeds in Great Britain 2005

Table 1 Vehicle speeds on non-built-up roads by road type and vehicle type: Great Britain: 2005

(a) Motorways[1] — miles per hour/per cent/number of vehicles

	Motor-cycles	Cars	Cars towing	Light goods[4]	Buses/coaches	Heavy goods vehicles[5] Rigid 2 axle[6]	Rigid 3 axle	Rigid 4 axle	Articulated 4 axles	Articulated 5+ axles
Under 50 mph	3	3	13	4	5	6	12	12	8	8
50-60 mph	16	12	53	14	45	46	81	87	90	91
60-65 mph	9	12	19	13	42	15	6	1	1	1
65-70 mph	13	17	9	18	5	14	1	0	1	0
70-75 mph	16	20	4	19	2	9	0	0	0	0
75-80 mph	16	17	1	15	0	5	0	0	0	0
80-90 mph	19	16	0	14	0	3	0	0	0	0
90 mph and over	7	3	0	3	0	1	0	0	0	0
Speed limit	70	70	60	70	70	n/a	60	60	60	60
% more than 10 mph over the limit	27	19	5	17	0	n/a	0	0	0	0
Average speed	72	71	57	70	59	61	54	53	54	54
Number observed ('000s)	2,536	455,408	3,482	58,594	2,493	27,556	2,661	1,747	8,606	42,381
(b) Dual carriageways[2]										
Under 30 mph	0	0	1	0	0	0	0	0	1	0
30-40 mph	1	0	1	0	1	1	2	1	1	0
40-50 mph	5	3	11	3	11	10	21	21	18	13
50-60 mph	16	15	51	17	49	48	74	77	78	86
60-65 mph	10	15	17	15	33	15	2	1	2	1
65-70 mph	13	19	8	18	4	11	0	0	1	0
70-80 mph	30	34	5	32	1	12	0	0	0	0
80 mph and over	25	13	0	14	0	3	0	0	0	0
Speed limit	70	70	60	70	60	n/a	50	50	50	50
% more than 10 mph over the limit	25	13	5	14	2	n/a	2	1	3	1
Average speed	71	69	56	69	57	60	52	52	53	53
Number observed ('000s)	312	43,568	330	4,816	200	2,141	252	188	518	2,494
(c) Single carriageways[3]										
Under 20 mph	2	0	2	0	0	1	1	1	1	0
20-30 mph	5	2	5	2	3	3	5	6	6	2
30-40 mph	13	14	17	14	21	18	24	25	21	19
40-50 mph	28	41	50	41	50	47	51	49	50	50
50-60 mph	29	32	23	31	23	26	18	20	21	28
60-65 mph	8	6	2	6	2	3	0	0	0	1
65-70 mph	5	2	0	3	0	1	0	0	0	0
70 mph and over	9	2	0	2	0	1	0	0	0	0
Speed limit	60	60	50	60	50	n/a	40	40	40	40
% more than 10 mph over the limit	8	2	3	2	3	n/a	19	20	22	28
Average speed	51	49	44	49	45	46	43	43	44	46
Number observed ('000s)	514	46,588	568	5,096	273	2,149	330	195	448	2,237

1 Average vehicle speeds from 27 motorway sites
2 Average vehicle speeds from 7 dual carriageway sites
3 Average traffic speeds from 26 single carriageway sites
4 Goods vehicles under 3.5 tonnes gross weight
5 Goods vehicles over 3.5 tonnes gross weight
6 Speed limit depends on rating which cannot be determined

Table 4 Vehicle speeds on non-built-up roads: Great Britain: 2000 - 2005

number/ miles per hour/*per cent*

		2000	2001	2002	2003	2004	2005
Motorways	Sites	26	26	27	27	27	27
	Observations (thousands)	54,686	104,119	534,820	465,941	561,368	605,465
	Average car speed	70	70	70	71	71	71
	% exceeding limit	*55*	*54*	*54*	*57*	*56*	*56*
	% exceeding limit by more than 10 mph	*17*	*18*	*18*	*20*	*19*	*19*
	Average motorcycle speed	70	70	71	72	72	72
	% exceeding limit	*54*	*54*	*57*	*59*	*59*	*59*
	% exceeding limit by more than 10 mph	*18*	*18*	*27*	*28*	*28*	*27*
	Average artic[1] speed	55	54	54	54	54	54
	Percent exceeding limit	*6*	*5*	*2*	*2*	*2*	*1*
	% exceeding limit by more than 10 mph	*0*	*0*	*0*	*0*	*0*	*0*
	Average bus/coach speed	60	60	60	59	59	59
	Percent exceeding limit	*4*	*4*	*6*	*4*	*2*	*3*
	% exceeding limit by more than 10 mph	*1*	*1*	*2*	*0*	*0*	*0*
Dual	Sites	4	4	7	7	7	7
carriageways	Observations (thousands)	6,933	9,167	38,913	48,055	56,889	54,908
	Average car speed	70	70	69	69	69	69
	Percent exceeding limit	*52*	*51*	*46*	*50*	*48*	*48*
	% exceeding limit by more than 10 mph	*13*	*13*	*14*	*15*	*14*	*13*
	Average motorcycle speed	67	68	70	69	68	71
	Percent exceeding limit	*38*	*35*	*53*	*50*	*48*	*55*
	% exceeding limit by more than 10 mph	*15*	*13*	*26*	*23*	*21*	*25*
	Average artic[1] speed	54	54	53	53	53	53
	Percent exceeding limit	*90*	*88*	*88*	*87*	*86*	*86*
	% exceeding limit by more than 10 mph	*4*	*4*	*3*	*2*	*2*	*2*
	Average bus/coach speed	59	59	57	58	58	57
	Percent exceeding limit	*49*	*49*	*39*	*39*	*40*	*39*
	% exceeding limit by more than 10 mph	*2*	*1*	*2*	*3*	*3*	*2*
Single	Sites	24	24	28	28	28	28
carriageways	Observations (thousands)	8,304	14,043	46,133	54,084	59,719	58,502
	Average car speed	45	45	47	48	48	49
	Percent exceeding limit	*9*	*9*	*8*	*9*	*10*	*11*
	% exceeding limit by more than 10 mph	*2*	*2*	*1*	*2*	*2*	*2*
	Average motorcycle speed	54	55	48	50	51	51
	Percent exceeding limit	*27*	*28*	*23*	*22*	*25*	*24*
	% exceeding limit by more than 10 mph	*15*	*14*	*11*	*9*	*10*	*9*
	Average artic[1] speed	45	44	43	45	46	46
	Percent exceeding limit	*76*	*76*	*65*	*74*	*79*	*78*
	% exceeding limit by more than 10 mph	*27*	*28*	*15*	*23*	*28*	*28*
	Average bus/coach speed	41	41	43	45	45	45
	Percent exceeding limit	*22*	*23*	*16*	*23*	*25*	*26*
	% exceeding limit by more than 10 mph	*2*	*2*	*2*	*3*	*3*	*3*

[1] artic = articulated heavy goods vehicles

Appendix 5:

6.1.2. A summary and analysis of:

Delucchi, M; 1998; Report #9 in the series: The Annualized Social Cost of Motor-Vehicle Use in the United States, based on 1990-1991 Data: Summary Of The Non-monetary Externalities Of Motor Vehicle Use

1. The cost of the health effects of air pollution from motor vehicles

The health effects due to air pollution are naturally of pivotal concern when estimating the costs of vehicle emissions. Delucchi estimated the effects of a specific, "marginal" change in pollution. The methodology entailed analysing the actual pollution, and what pollution there would have been had there been a 10% or a 100% reduction in motor vehicle related emissions. This is especially relevant to this report, since motor vehicle emissions are directly related to vehicle speed (see Appendix 2). Delucchi's findings are summarised in the tables below:

Cost item	Low	High
particulate emissions from vehicles	16.7	266.4
all other pollutants from vehicles	2.3	17.1
all pollutants from upstream processes	2.3	13
road dust	3	153.5

Table 1: Summary of the cost of the health effects of air pollution from motor vehicles

Emission	Ambient	United States		All urban areas		Los Angeles	
	pollutant	low	high	low	high	low	high
CO	CO	0.01	0.09	0.01	0.1	0.03	0.18
NOx	nitrate PM10	0.96	15.53	1.31	21.17	6.02	75.11
	NO2	0.14	0.68	0.18	0.91	0.52	2.62
Total for NOx		1.1	16.21	1.5	22.08	6.54	77.73
PM2.5	PM2.5	3.22	45.22	6.53	88.79	41.93	405.29
PM2.5-10	PM2.5-10	0.27	2.95	0.63	6.2	4.69	29.77
Total for PM10		0.6	15.13	1.45	31.69	12.35	155.58
SOx	sulfate PM10	2.8	22.6	4.4	35.28	33.53	209.88
VOC	organic PM10	0.1	0.99	0.13	1.25	0.52	4.29

VOC+NOx	ozone	0.01	0.1	0.02	0.12	0.05	0.39

Table 2: The Health Cost Per Kg Of Motor-Vehicle And Related Upstream And Road-Dust Emissions, Based On A 10% Reduction In Direct Motor-Vehicle Emissions, Related Upstream Emissions, Paved-Road-Dust Emissions, And Unpaved-Road-Dust Emissions† ‡

2. The cost of reduced visibility due to particulate air pollution from motor vehicles

Particles and gases in the atmosphere absorb and scatter light, thereby reducing visibility. Delucchi mentions a number of Willingness to Pay (WTP) studies[47] conducted throughout the USA that attempts to ascertain what value people place on air quality and the reasons for this. The costs of reduced visibility are estimated based upon empirical data collected for residential property values. These values are then correlated with values for related total suspended particulate data for those homes. It is believed that motor vehicles play a significant role in contributing to the levels of suspended particulate matter. This is because those particles primarily responsible for scattering light have approximately the same diameter as the wavelength of light, 0.5μm and most particles produced by the combustion of fuel, as well as particles of suspended road dust are between 0.1 and 1μm in diameter. Since fuel consumption is directly related to engine load (see Appendix 2), and since it was also shown earlier that congestion increases fuel consumption, it can be said with some confidence that ISA or similar speed influencing measures would have an effect on the levels of suspended particulate matter.

Table 3 provides an outline of Delucchi's findings:

[47] E. T. Loehman, S. Park, and D. Boldt, "Willingness to Pay for Gains and Losses in Visibility and Health," Land Economics 70(4): 478-498, November (1994); G. McClelland, W. Schulze, D. Waldman, J. Irwin, D. Schenk, T. Stewart, L. Deck, and M. Thayer, Valuing Eastern Visibility: A Field Test of the Contingent Valuation Method, U. S. E. P. A. Cooperative Agreement #CR-815183-01-2, prepared for the U. S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, Washington, D. C., June (1991); L. G. Chestnut and R. D. Rowe, Preservation Values for Visibility Protection at the National Parks, prepared for the U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Economic Analysis Branch, Research Triangle Park, North Carolina, February 16 (1990b).

† 1990 Emissions, 1991$/Kg-Emitted

‡ Each $/kg value is equal to the total calculated health damages attributable to the pollutant and source, divided by emissions of the pollutant from the source.

Emissions source	$/kg-PM10(a)		$/kg-NOx(b)		$/kg-SOx(c)		$/kg-VOCs(d)	
	Low	High	Low	High	Low	High	Low	High
MVs	0.4	3.9	0.19	1.11	0.89	3.97	0.01	0.05
MVs + U	0.37	3.47	0.17	1.04	0.36	1.35	0.01	0.04
MVs + U + RDP	0.32	2.07	0.17	1.04	0.36	1.35	0.01	0.04
MVs + U + RDP +RDU	0.1	0.81	0.17	1.04	0.36	1.35	0.01	0.04

Table 3: The Visibility Cost Per Kg Of Motor-Vehicle And Related Emissions, Based On A 10% Reduction In Emissions (1990 Emissions, 1991$/Kg-Emitted)

MVs = motor vehicles; U = upstream emissions related to motor-vehicle use (e.g., from petroleum refineries); RDP = road dust from paved roads; RDU = road dust from unpaved roads; PM10 = particulate matter of aerodynamic diameter of 10 microns or less; NOx = nitrogen oxides; SOx = sulfur oxides; VOCs = volatile organic compounds.

Note that in all cases, the year of the analysis is 1990 (i.e., 1990 data for emissions, air quality, and income), but the year of the dollars is 1991.

(a): Equal to the dollar cost of light extinction caused by 10% of the primary ambient PM10 attributable to motor vehicles, divided by 10% of PM10 emissions attributable to motor vehicles. Primary or direct PM is PM that is emitted as such, as distinguished from PM that is formed in the atmosphere.

(b): NOx emissions can become ambient NO2 or form particulate nitrate aerosols. The $/kg estimate here is equal to the dollar cost of light extinction caused by 10% of the ambient NO2 and 10% of the ambient particulate nitrate attributable to motor vehicles, divided by 10% of NOx emissions attributable to motor vehicles.

(c): SOx emissions can form particulate sulfate aerosols, which scatter light and reduce visibility. The $/kg estimate here is equal to the dollar cost of light extinction caused by 10% of the ambient particulate sulfate attributable to motor vehicles, divided by 10% of SOx emissions attributable to motor vehicles.

(d): VOC emissions can form secondary organic aerosols, which scatter light and reduce visibility. The $/kg estimate here is equal to the dollar cost of light extinction caused by

10% of the ambient organic aerosol attributed to motor vehicles, divided by 10% of VOC emissions

3. The cost of crop losses caused by ozone air pollution from motor vehicles

Ozone is formed in the troposphere when sunlight reacts with the oxides of nitrogen (NOx) and volatile organic compounds (VOC) released into the atmosphere by the burning of fossil fuels in internal combustion engines. Ozone enters leaves through the stomata (one of the minute pores in the epidermis of a leaf or stem through which gases and water vapour pass[48]) during normal gaseous exchange. Ozone is a strong oxidant, and amongst the many symptoms it causes are chlorosis (the yellowing or whitening of normally green plant tissue because of a decreased amount of chlorophyll) and necrosis (the unprogrammed death of cells and living tissue). Other symptoms include flecking, stippling, bronzing and reddening[49]. Ozone is by far the greatest cause of crop losses caused by air pollution. Delucchi estimates that the costs of crop losses due to the effects of ozone amounts to between $3 billion and $6 billion per year. The table below outlines Delucchi's findings:

Case IIA: 10% reduction[d]	$/1000-VMT				$/kg-[VOCs+NOx]a			
	Direct emissions[b]		Direct + upstream[c]		Direct emissions[b]		Direct + upstream[c]	
	Low	High	Low	High	Low	High	Low	High
LDGAs	0.99	1.77	1.13	1.91	0.19	0.29	0.17	0.26
LDGTs	1.67	2.97	1.91	3.21	0.2	0.31	0.18	0.27
HDGVs	3.99	6.56	4.57	7.18	0.14	0.23	0.13	0.21
All gasoline vehicles	1.16	2.08	1.33	2.24	0.19	0.29	0.17	0.26
LDDAs	0.37	0.57	0.4	7.44	0.21	0.33	0.19	3.47
LDDTs	0.13	0.22	0.2	0.28	0.21	0.33	0.14	0.2
HDDVs	3.4	5.74	3.69	6.02	0.19	0.32	0.17	0.28
All diesel vehicles	2.69	4.53	2.93	4.76	0.19	0.32	0.17	0.28
All gasoline, diesel	1.29	2.28	1.46	2.45	0.19	0.3	0.17	0.26

[48] http://www.answers.com

[49] http://www.ars.usda.gov/Main/docs.htm?docid=8453

vehicles								
Case IIB: 100% reduction[e]	**1.37**	**2.51**	**1.53**	**2.68**	**0.2**	**0.33**	**0.18**	**0.29**

Table 4: The Change In Welfare In The Crop Market Due To A 10% Or 100% Reduction In Motor-Vehicle Related Emissions (1990 Emissions, 1991$/1000-Vmt And 1991$/Kg-[Nox+Vocs])

LDGA = light-duty gasoline auto; LDGT = light-duty gasoline truck; HDGV = heavy-duty gasoline vehicle; LDDA = light-duty diesel auto; LDDT = light-duty diesel truck; HDDV = heavy-duty diesel vehicle; VMT = vehicle-miles of travel.

These results include the effect of ozone on all crops, and the effects of pollutants other than ozone.

a: Includes a minor amount of damage (5-10%) attributable to pollutants other than ozone, the pollutant formed from NOx and VOC emissions.

b: Direct emissions are tailpipe and evaporative emissions from motor vehicles.

c: Upstream emissions include emissions from the production of motor fuels, the servicing of motor vehicles, the production of crude oil used to make motor fuel, the production of motor vehicles, and so on. See Report #10 for details.

d: Case IIA is a 10% reduction in emissions of VOCs and NOx.

e: Case IIB is a 100% reduction in emissions of VOCs and NOx.

4. The cost of material damage caused by air pollution from motor vehicles

Oxidant, particulate and acid air pollution is able to soil and damage many man made materials and structures. This may leave surfaces or materials blemished or unsightly and in some cases may leave materials structurally vulnerable.

Delucchi reviewed a number of studies and found that damage from all sources of pollution ranged in the order to $5 billion to $30 billion in 1991-dollar prices for the USA. He estimated that emissions from motor vehicles contributed between 20% and 40% of these values. He therefore concluded that the cost of material damage caused by air pollution from motor vehicle emissions amounted to between $1 billion and $8 billion in 1991-dollar prices for the USA at the time of the release of the report.

5. The cost of forest damage caused by air pollution from motor vehicles

Ozone and acid pollution can damage forests in similar ways as reported for crop damages above. From an anthropogenic perspective, forests provide wood and are important recreational areas. In addition, forests are very important for their aesthetic qualities in and around urban centres. However, forests are also very important natural habitats for many animals, and play an important role in sustaining a large variety of ecosystems.

In South Africa, we do not have very many naturally densely forested areas. This is in contrast to the USA where coniferous, softwood and hardwood forests are common. As a result, the vast majority of wood products used in South Africa are sourced from commercially run forestry.

It is important to distinguish between natural forests and forestry, in that the losses incurred by our natural forests, which are primarily in more remote areas as opposed to near urban centres would be considerably lower than in the USA, where many cities are located near naturally heavily wooded regions.

Delucchi, using an approximation that motor vehicles contribute 30% to 40% of the total emissions damage to forests, concluded that forestry damages due to emissions from motor vehicles amounted to between $0.2 billion and $2 billion in 1991.

However, for the reasons outlined above these figures may be of no value in the South African context. At the Workshop On Impacts Of Air Pollution In Southern Africa held in Lusaka in 2002, van Tienhoven[50] presented an overview of the impacts of air pollution in South Africa. His presentation focussed on a number of affected sectors, amongst which were commercial forestry and natural ecosystems.

[50] van Tienhoven, M; 2002; Impacts of air pollution in South Africa; Presentation to the Workshop On Impacts Of Air Pollution In Southern Africa, Lusaka; Proceedings of the Workshop On Impacts Of Air Pollution In Southern Africa

With reference to commercial forestry, he cited two studies, the first by Olbrich in 1993[51] and another by Carlson in 1994[52], both of which could not find a direct causal link between pollutant exposure and tree damage.

The figure below shows the maximum modelled one-hour surface ozone over Southern Africa for the period 10 to 14 November 2000[53]. The figure clearly demonstrates that at that time the presence of surface ozone was very limited across most of the South Africa, with the majority of surface ozone being found in the far northern reaches of the Limpopo province, Mpumalanga and Kwazulu-Natal.

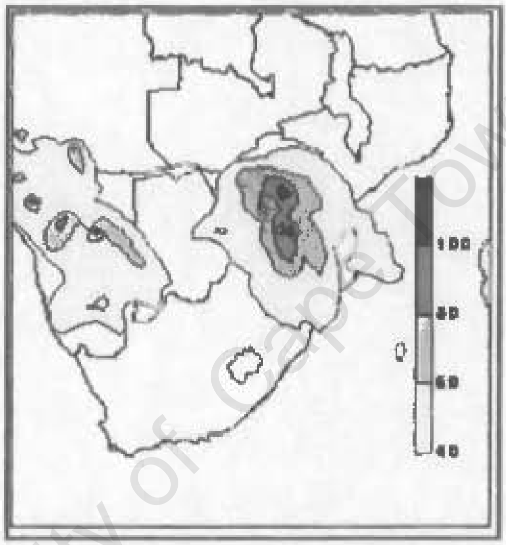


Figure 1: Maximum modelled one-hour surface ozone over Southern Africa for the period 10 to 14 November 2000

In contrast however, Van Tienhoven (1999)[54] asserts that "At a regional scale, ozone is emerging as the pollutant of major concern. Although high ozone levels may be a natural feature of the region, anthropogenic contributions through land use change and industrial and vehicle emissions could raise ozone concentrations to levels that may affect crop

[51] Olbrich, K.A. 1993. Patterns of shoot growth, needle growth and foliar symptom development in fertilised and unfertilised P. patula. Report to the Department of Water Affairs and Forestry. Report No 665.

[52] Carlson, C.A. 1994. An assessment of the risk posed by the gaseous pollutant ozone to commercial forests in the Eastern Transvaal. Report to the Department of Water Affairs and Forestry. Report FOR-DEA 754. CSIR, Pretoria.

[53] APINA: Air Pollution Information Network – Africa; Air pollution impacts on crops and ecosystems in southern Africa; http://www.sei.se APINA.org

[54] Van Tienhoven, A M; 1999; Status of Air Pollution in South Africa; Proceedings of the 11th World Clean Air and Environment Congress

production" He presents the following data regarding the total pollutant concentrations and sources in South Africa:

Source	CO_2	CH_4	N_2O	CO	NO_x	NMVOC	SO_2
Energy (electricity, industrial, domestic, mining & refineries)	238 554	751	7	1 660	1 221	88	1 695
Transport	31 390	39	5	2 707	995	569	37
Industrial processes (excludes energy)	23 461	4	2	28	13	194	28
Agriculture, land use change & forestry[35]	- 20 614	1 064	61	1 286	39		
Waste (landfills, effluent and sewage treatment)		380	3				

Table 5: Main sources and amounts of air pollutants emitted in South Africa in 1990 in kilotons (10^9 g) (from South Africa NSOER, 1999)

The table below gives an indication of pollutant concentrations detected in the Highveld:

	Maximum hourly mean concentrations			Maximum daily mean concentrations			Maximum monthly mean concentrations		
	SO_2 (ppb)	NO_x (ppb)	O_3 (ppb)	SO_2 (ppb)	NO_x (ppb)	O_3 (ppb)	SO_2 (ppb)	NO_x (ppb)	O_3 (ppb)
Bedworth Park	105	370	95.1	22.6	130.9	31.9	14.6	73.5	22.3
Elandsfontein	125	157	110	29.1	28.7	48.8	12.1	12.5	33.3
Makalu	131	150	90.2	25.5	56.4	40	12.5	25.3	28.7
Palmer	277	228	85.3	51.2	38.4	63.6	12.5	9.2	40.9
Verkykkop	63.8	87.7	76.8	17.2	15.3	56.2	5.8	6.3	38.8
South African guideline	300	800	120	100	400	-	50	300	-

Table 6: Maximum mean concentrations of pollutants on the Highveld in 1994

It is useful to compare the data to examples of foreign cities in order to get some perspective of the problems we face in South Africa:

The following image is a representation of ozone concentrations in parts per billion over the California basin in 1997:

[35] The negative CO_2 value for agriculture, land use and forestry indicates the carbon that is taken up by woodlands and forest and so represents a net uptake of carbon rather than release of carbon

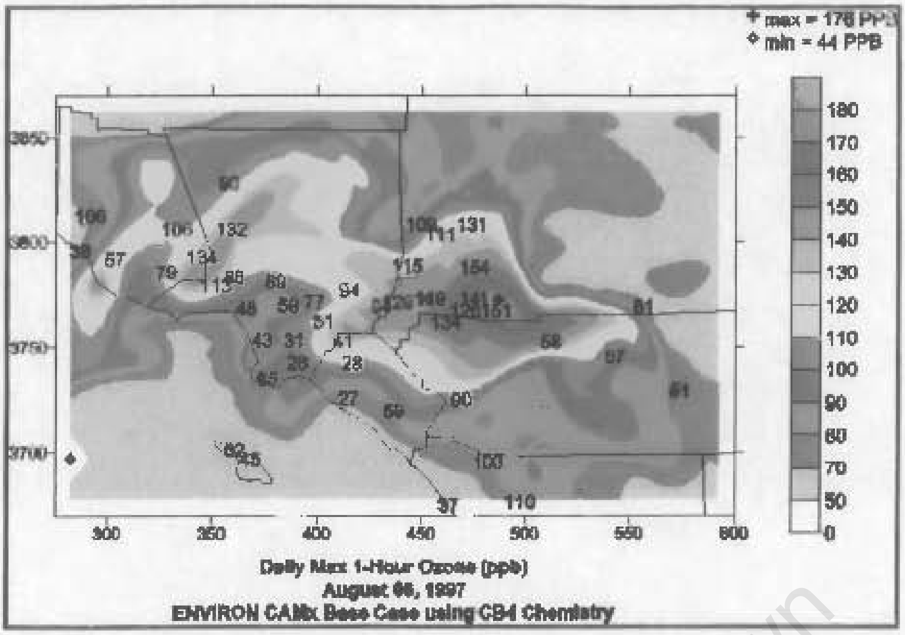


Figure 2: An example of CAMx output as an isopleth map showing ozone concentrations over Los Angeles[56]

From the image it is apparent that peak hourly concentrations are in excess of 151 ppb. This value is far greater than the maximum given for the Highveld stations noted in Table 6, Bedforview, at 95.1 ppb. The example would seem to indicate that the problem is not as severe in South Africa as it is elsewhere in the world.

However, it may be that the growth in the vehicle population in South Africa from approximately 5 million vehicles in 1994[57] to 8,2 million vehicles at the end of 2005 would have in the interim significantly increased the levels of ground level ozone and other pollutants, although no recently collected data could be sourced to verify this.

[56] Yarwood G. (2002). Introduction to CAMx. CAMx Training Course for CAPIA, 15-19 April 2002,Durban, South Africa.

[57] The value for vehicle population in 1994 was roughly estimated by scaling the growth obtained between 1998 and 2005 as given in Section 2.3.3.1 down to 1994 levels.

6. Climate change damage costs due to lifecycle CO_2-equivalent emissions of greenhouse gases from motor vehicles

Delucchi estimates that emissions from motor vehicles attributes approximately 30% of all CO_2-equivalent greenhouse gasses in the USA. He presents the following data for the global costs of greenhouse gasses with respect to global warming:

	Damage %	with respect to	1991$/ton-C	1991$/ton-$CO_2$
Cline (1992) (2.5oC short-term warming)	1.0 – 2.0	world GDP	4 – 40	1.1 –11
Cline (1992) (10oC long-term warming)	6.0 –12.0	world GDP	220?	60?
Nordhaus (1993)	1.33	world output	5 – 22	1.4 – 5.8
Nordhaus (1991)	0.25 – 2.0	world output	0.3 – 71	0.1 – 19
Ayres & Walters (1991)	2.1 – 2.4	GWI	40 – 46	11 – 13
Fankhauser (1994)e	n.e.	n.e.	6 – 66	1.7– 18
Titus (1992)	n.e.	n.e.	40 - 530 (165)	11 - 143 (45)
Pearce et al. (1992)	1 – 3	GWP	9 – 28	2.5 – 7.7
Hohmeyer (1996)	n.e.	n.e.	800	220
CEC (1992)	n.e.	n.e.	30	8.2
Montgomery (1991)	0.5	GNP	n.e.	n.e.
Tol (1995)	1.9	world GDP	n.e.	n.e.
Tol (1999)	n.e.	n.e.	9 – 180	3 – 50
Goodland & El Serafy (1998)	n.e.	n.e.	23	6.2
Tol (2003a)	n.e.	n.e.	1 – 20	0.3 – 5
Tol (2003b)	-2.3 – 2.7	World GDP	~ 4 – 40	~ 1 – 10
Pearce (2003)	n.e.	n.e.	3 – 32	1 – 9

Table 7: Summary Of Estimates Of Global Damage Cost Of Global Warming

GWI = gross world income; GWP = gross world product; GNP = gross national product; GDP = gross domestic product; n.e. = not estimated; C = carbon; CO_2 = carbon dioxide; CEC = California Energy Commission.

To estimate the US contribution to the values in the table, Delucchi uses the following formula:

$$DT_{US} = DT_W \cdot \frac{D_{US}}{D_W} = DT_W \cdot \frac{\frac{D_{US}}{GDP_{US}}}{\frac{D_W}{GDP_W}} \cdot \frac{GDP_{US}}{GDP_W}$$

Where:

DT = dollar damages from climate change, in the U. S. or in the world, per ton of carbon equivalent emitted

D = dollar damages form climate change, in the U. S. or the world

GDP = gross domestic (or world) product

subscript US = United States

subscript W = world

This formula however, cannot readily be adapted to calculate the South African contribution without knowing what the dollar damages from climate change in South Africa (DSA) are. As an estimate, we can calculate DSA as follows:

$$D_{SA} = D_{US} \cdot \frac{GDP_{SA}}{GDP_{US}}$$

The resultant formula, including the substitution mentioned above would now take the following form:

$$DT_{SA} = DT_W \cdot \frac{\left(D_{US} \cdot \frac{GDP_{SA}}{GDP_W}\right)}{D_W} = DT_W \cdot \frac{\frac{\left(D_{US} \cdot \frac{GDP_{SA}}{GDP_W}\right)}{GDP_{SA}}}{\frac{D_W}{GDP_W}} \cdot \frac{GDP_{SA}}{GDP_W}$$

Where:

DT = dollar damages from climate change, in the U. S., South Africa or in the world, per ton of carbon equivalent emitted

D = dollar damages form climate change, in the U. S., South Africa or the world

GDP = gross domestic product for the U. S., South Africa or the world

subscript US = United States

subscript SA = South Africa

subscript W = world

7. The external cost of noise from motor vehicles

Noise can be extremely disruptive in its influence on surrounding areas. Noise affects sleep, it disrupts activities, it can hinder work, it can impede learning, and it has been known to cause stress. The model used to calculate the costs assumes that the dollar cost of noise is equal to the fraction of annualised housing value lost per excess decibel. This fraction is multiplied by: the annualised value of housing units exposed to motor-vehicle noise above a threshold (P), the density of housing units exposed to motor-vehicle noise above a threshold (M); the amount of motor-vehicle noise over a threshold (AN); and a scaling factor to account for costs in non-residential areas ((To+Ti)/Ti).

The estimates for the costs of noise produced by Delucchi are distributed between a high value and a low value, and are based upon the costs per 1000 vehicle miles travelled and distributed between the varying types of vehicles and classes of roads, as is shown below:

	Interstate	Other freeways	Principal arterials	Minor arterials	Collectors	Local roads
Base case						
LDAs	2.96	4.25	1.18	0.57	0.07	0.00
MDTs	8.50	13.20	7.02	5.37	1.05	0.00
HDTs	16.69	30.80	20.07	29.93	4.93	0.00
Buses	6.36	9.77	7.18	6.42	1.22	0.00
Motorcycles	17.15	27.03	8.71	4.67	0.56	0.00
Low-cost case						
LDAs	0.11	0.18	0.04	0.01	0.00	0.00
MDTs	0.40	0.66	0.32	0.18	0.01	0.00
HDTs	0.81	1.62	1.22	1.77	0.06	0.00
Buses	0.35	0.58	0.38	0.22	0.00	0.00
Motorcycles	0.66	1.13	0.27	0.09	0.00	0.00
High-cost case						
LDAs	40.11	56.02	16.20	9.35	6.04	0.44
MDTs	114.76	173.38	96.05	84.93	78.84	12.13
HDTs	225.61	404.82	269.27	414.17	319.22	92.04
Buses	86.15	128.60	98.66	105.33	108.00	12.84
Motorcycles	232.47	355.73	119.64	76.65	50.08	2.73

Figure 3: Vehicle noise costs per 1000 vehicle miles travelled by vehicle type and road category

Using the values given above, Delucchi obtains total costs ranging between $0.4 billion and $50 billion. Delucchi however asserts that the highest figure is to be regarded with a fair amount of scepticism, and estimates the actual costs to be between $10 billion and $20 billion. Delucchi notes that this correlates well with findings from a number of studies conducted in Europe and the USA from 1975 to 1991 as reviewed by Verhoef (1994) and Rothengatter (1990).

8. Health and environmental impacts of leaking motor-fuel storage tanks

Motor fuel, and the oils and chemicals used in the production of motor fuels, are very often stored in large underground or aboveground tanks before being shipped by truck or pipeline to their final destinations.

These tanks, in certain instances may leak. Leaked fuels, oils or chemicals pollute groundwater, cause health problems and damage property. Modelling the effects of leaked fuels would involve a number of steps. One would have to know the tank population of the country and be able to reliably estimate the quantities of leaked fuels emanating from them. The location and the quantity of the leaks could then be matched to that of areas with significant populations of people and properties, and important natural habitats and groundwater deposits (where these are accurately known). Assumptions can then be made regarding the most likely fate of the leaking fuels and what the damages due to their presence may amount to.

However, quantifying the value of these damages is very difficult because of the large number of unknown variables and their respective uncertainties, the cumulative effects of which may render any derived totals wholly unrealistic.

Consequently, Delucchi has resorted to supposition to estimate what the costs may be. He notes that a study undertaken in 1987 by DeLuchi et al[58] estimated the costs to be between $0.3 billion and $1 billion for property damages and between $0.3 billion and $2 billion for damages due to health problems and excess mortality. This figure, he notes, was derived based upon an estimate that at least 100 000 fuel tanks were leaking across the USA during the early to mid eighties.

Delucchi, however, notes that stricter legislation enacted after this study and the more refined monitoring procedures implemented as a result may have dramatically reduced the number of leaking fuel tanks in the interim. In addition, a number of cleanup programmes have been put in place and this may have reduced any damages even further. Delucchi estimates 1997-dollar value damages to be less than $1 billion per year.

In order to have any use of the above value for the South African scenario, it becomes necessary to know what the ratio of fuel tanks in South Africa to the USA might be. However, in the absence of this data, a crude estimation could be made by accepting that all of Delucchi's assumptions regarding legislation and monitoring of these facilities are applicable in South Africa, and then by multiplying the his estimated costs by the ratio of

[58] M. A. DeLuchi, D. Sperling, and R. A. Johnston, A Comparative Analysis of Future Transportation Fuels, UCB/ITS/RR-87-13, Institute of Transportation Studies, University of California, Berkeley, California, October (1987).

vehicles operating in the USA to that operating in South Africa. This ratio can be taken as a crude estimate of the ratio of US demand for fuel (and hence demand for storage) versus the corresponding South African demand. However, the assumption that is made here is that the storage policies and volumes (something that is of national interest and may differ quite dramatically depending on the economic and political situation of the country) may be significantly different for the USA as opposed to South Africa.

9. Environmental and economic impacts of large oil spills

Delucchi estimates the costs of oil spills in terms of dollar costs per barrel of oil produced. He uses a value of $0.10 per barrel of oil produced. This value was obtained from estimates made in previous studies, most notably by Stevens and Peterson (1993)[59] and by Behrens et al. (1992)[60].

Using an estimate based on the number of barrels of oil produced is problematic for the South African case. This is because South Africa has virtually no crude oil production facilities (notwithstanding Sasol's coal to oil technologies and the natural gas to oil industry at Mosgas) and so the vast majority of oil used in South Africa is imported. As a result, the majority of the risk related to any potential marine oil-spill disasters would come from tankers carrying oil of origin elsewhere than South Africa. Additionally, many of the tankers passing our coastline are carrying oil not destined for our markets. The risk of an oil spill, however, is still carried by South Africa.

Another approach would be to quantify the risk of an oil spill on South African shores in terms of the volumes of crude oil being shipped to South Africa. These volumes can then be related to the costs of the measures in place to prevent a spill (where these are borne by South African motorists or companies), the costs of any continual cleanup operations, the costs of any rehabilitation programmes due to oil spills and the damages to the environment due to previous oil spills.

59 B. Stevens and T. Peterson, Estimating the Net Social Benefits of Reduced Oil Spills, Appendix H of A Cost-Benefit Analysis of Selected Transportation Policies, Transportation Policy Impacts Hearing, 1993 California Transportation Energy Analysis Report, California Energy Commission, Sacramento, California, October 12 (1993).

60 C. E. Behrens, J. E. Blodgett, M. R. Lee, J. L. Moore, L. Parker, External Costs of Oil Used in Transportation, 92-574 ENR, Congressional Research Service, Environment and Natural Resources Policy Division, Washington, D. C., June (1992).

The critical question would be of course whether ISA would have any significant impact on these costs. This can be otherwise phrased as: would ISA diminish the risk of an oil spill on South African shores to any meaningful extent? If one considers that the vast majority of tankers travelling along our coastline are not necessarily bound for our harbours, then it is reasonable to assume that implementing ISA in South Africa may not have any significant impact on the risk of any of these tankers spilling oil and soiling our coast. The figure below gives an overview of oil tanker shipping routes globally and highlights where some of the largest oils spills have occurred in the past.

Figure 4: Oil tanker shipping routes and historically major oil spills61

Tragically, South Africa has suffered large oil spills in the past, and our entire coastline is continuously under threat from very large and ultra large tankers en route to and from primarily American markets. It would therefore be reasonable to assume that since the shipping of oil to other parts of the world cannot be affected by implementing ISA locally, that ISA would not significantly diminish the risk (and consequently the costs) of large oil spills in South Africa.

[61] http://faculty.uaeu.ac.ae/fhowari/images/env-geology/env_sc/POLLUTION%20IN%20THE%20MARINE%20ENVIRONMENT.htm

10. Other water pollution related to motor-vehicle use: urban runoff polluted by oil from motor vehicles, and nitrogen deposition

Delucchi's study considered the costs of motor vehicle use in general. This report is considering the possible impacts an ISA system might have in South Africa. So whereas Delucchi's study listed impacts in general, this study must limit itself essentially to impacts because of a reduction in speed, simply because ISA is a broad-spectrum speed reduction measure.

With regards to other forms or sources of water pollution as a result of the use of motor vehicles, ISA can only be shown to impact if it can be shown that either speed affects oil pollution and nitrogen deposition in urban runoff, or that ISA would lower the overall use of motor vehicles, thereby lowering the incidence of oil pollution and nitrogen deposition in urban runoff.

Because ISA's overarching intentions are not to lower the overall use of motor vehicles, but instead to ensure the responsible use of motor vehicles, one cannot say that ISA would lower the incidence of oil pollution and nitrogen deposition in urban runoff. It is also unlikely that speed plays any significant role in polluting urban runoff. As a result, it can be said that ISA would not have any effect on the levels of pollution in urban runoff because of the use of motor vehicles.

11. Non-monetary costs due to net crimes related to using or having motor-vehicle goods, services, or infrastructure

Similar to section 10 above, ISA would not have any impact on the incidence crime, and therefore cannot be said to have any effect whatsoever on any of the non-monetary costs related to criminal activity associated with the use or possession of motor-vehicle goods, services or infrastructure.

12. Pain, suffering, and other non-monetary costs due to fires related to using or having motor-vehicle goods, services, or infrastructure

The same argument put forward in section 10 holds for this section as well. ISA cannot be said to have any impact on the occurrence of fires whether due to mechanical problems or other (road accidents have already been accounted for). The next step is to apply Delucchi's findings to the South African context. The following table is a distillation of a table Delucchi provides as a summary. Only the sections covered above are included.

Section	Cost Item	Low	High	% Δ
1a	Air pollution: human mortality and morbidity due to particulate emissions from vehicles	16.7	266.4	1595.2
1b	Air pollution: human mortality and morbidity due to all other pollutants from vehicles	2.3	17.1	743.5
1c	Air pollution: human mortality and morbidity, due to all pollutants from upstream processes	2.3	13.0	565.2
1d	Air pollution: human mortality and morbidity from road dust	3.0	153.5	5116.7
2	Air pollution: loss of visibility, due to all pollutants attributable to motor vehicles	3.6	27.4	761.1
3	Air pollution: damage to agricultural crops, due to ozone attributable to motor vehicles	3.3	5.7	172.7
4	Air pollution: damages to materials, due to all pollutants attributable to motor vehicles	1.0	8.0	800.0
5	Air pollution: damage to forests, due to all pollutants attributable to motor vehicles	0.2	2.0	1000.0
6	Climate change due to lifecycle emissions of greenhouse gases (U. S. damages only)	0.0	3.5	N/A
7	Noise from motor vehicles	0.5	15.0	3000.0
8	Water pollution: health and environmental effects of leaking motor-fuel storage tanks	0.1	0.5	500.0
9	Water pollution: environmental and economic impacts of large oil spills	0.2	0.5	250.0
10	Water pollution: urban runoff polluted by oil from motor vehicles	0.1	0.5	500.0
	Total	**33.3**	**513.1**	**1540.8**

Table 8: Summary of Delucchi's findings[62]

Instead of a single estimate, Delucchi provides arrange of values for costs between high and low. I have included the percentage increase from low to high in the last column as a

62 Values are for billions of 1991 US dollars

further illustration of the range of each set of values. The difference between high and low is 1272%.