BRINGING YOU UP TO SPEED:

A Health and Economic Model of the Effects of Raising the Speed Limit on New Zealand State Highways and Motorways from 100km/h to 110km/h.

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CONTENTS

ABSTRACT

Introduction – International road safety philosophies are wide ranging, from Sweden's vision zero, a goal of no road deaths or serious injuries to the unlimited speed zones of Germany's autobahn (1,2). Australia has raised their speed limits on highways in multiple states (3) and Great Britain aims to implement a speed increase to 80mph (129km/hour) on motorways by 2013 (4).

Aim – Our objective was to address the public health impact of a speed limit increase from 100km/h to 110km/h on all New Zealand state highways and separately on motorways only.

Methods – We conducted a systematic review of the literature (including grey literature), augmenting our findings with expert testimony from the private sector and Ministry officials. In addition, we collated existing data on speed surveys, congestion, vehicle kilometres travelled, accident demographics, the social costs of accidents, long-term rehabilitation costs and entitlement benefits from the Ministry of Transport, New Zealand Transport Agency and Accident and Compensation Corporation. We used Nilsson's internationally recognised power model adapted by Elvik (5) to determine the projected increase in accidents, injuries and fatalities with an increase in speed. The estimated mean increase in speed and accidents were then entered in to an economic model which included factors such as: time-saved, congestion, fuel tax revenue, the social cost of accidents, vehicle operating costs, vehicle emissions and changing speed signs.

Results – Based on the results of the Saskatchewan Study,(6) a 10km/h speed limit increase would result in a 4km/h increase in mean speed from the current 96.36km/h to 100.36km/h (7). According to Elvik's (5) power model, a 4km/h increase in mean speed would result in an additional 35.4 fatal, 110.6 serious, and 171 minor injury crashes per annum if the speed limit increase was applied to all 100km/h state highways. If the speed limit increase was applied to 100km/h motorways alone, we would expect an additional 1.2 fatal, 3.5 serious and 16.5 minor injury crashes per annum. The economic cost of increasing the limit to 110km/h on all state highways is 107 million NZD per annum (in 2011 prices, GST exclusive). Conversely, if we were to limit the increase to motorways, the change would result in a net savings of 22 million NZD per annum.

Conclusion – We found a net economic benefit to society of increasing the speed limit to 110km/h on motorways. However, we recommend that any potential change be implemented concurrently with road safety measures such as increasing speed surveillance, and adopting a variable speed increase, keeping a 100km/h limit on trucks and all vehicles in inclement weather. Our findings also need to be viewed taking into consideration the ethical implications of the loss of human life and the increase in emissions such a change would cause.

Section 1: INTRODUCTION AND BACKGROUND

The laws and regulations surrounding traffic control can have a very significant impact on a population's health, economy and environment. The briefing for this public health project was for our group to quantify how these variables would be affected by a specific change to New Zealand's speed limit. Our group chose to define this change as an increase in the speed limit from 100km/hour to 110km/hour on certain roads. We considered the implications of applying this change only to motorways and then we also included all state highways currently at 100km/hour. This proposal has generated a great deal of media and public interest in recent years. We believe this is mostly because due to the comparatively low quality of New Zealand's roads, the current speed limit on these roads is relatively low compared with limits on motorways and state highways in other OECD countries. We believed it would be worthwhile investigating the feasibility of implementing this change. During the course of the project we examined how safe our roads are with the current speed limit before predicting how the number of accidents and casualties would change with the new speed limit. This required us to estimate what the change in actual speed would be if the limit was set at 110km/hour. We also calculated the economic and environmental consequences of this change in speed limit.

1.1: Method

We narrowed down a list of potential research questions to form a research project. The four questions we focussed on were:

1. How does New Zealand rank internationally in terms of road safety and who is involved in road traffic accidents on New Zealand roads?
2. What are the relationships between vehicle speeds and speed limits?
3. What are the relationships between vehicle speeds, deaths and injuries?
4. What are the long term economic implications of changes in speed limits?

Understanding the background and demographics of crashes and speeding in New Zealand is crucial to our understanding of the topic as a whole. We required comprehensive background knowledge to be able to go on to investigate the effect of a change in speed limit.

To answer our research questions we completed a literature review in a range of search engines and databases (see appendices 2, 3 and 7). We conducted interviews with experts and officials and collated existing data. We then combined our findings to model the effects of an increase in speed limit. The mean increase in speed was then used in a Power Model along with NZTA crash data from 2006-2010 to calculate the projected increase in accidents, injuries and fatalities. This projected increased was then put into an economic model to estimate whether a change in speed limit would result in a net financial benefit or cost. Within this model the social cost of accidents and injuries, the projected time saved, the change in fuel consumption and the change in vehicle emissions were considered.

For the purposes of the model of the increase in speed limit we had to make some assumptions (see appendix 1).

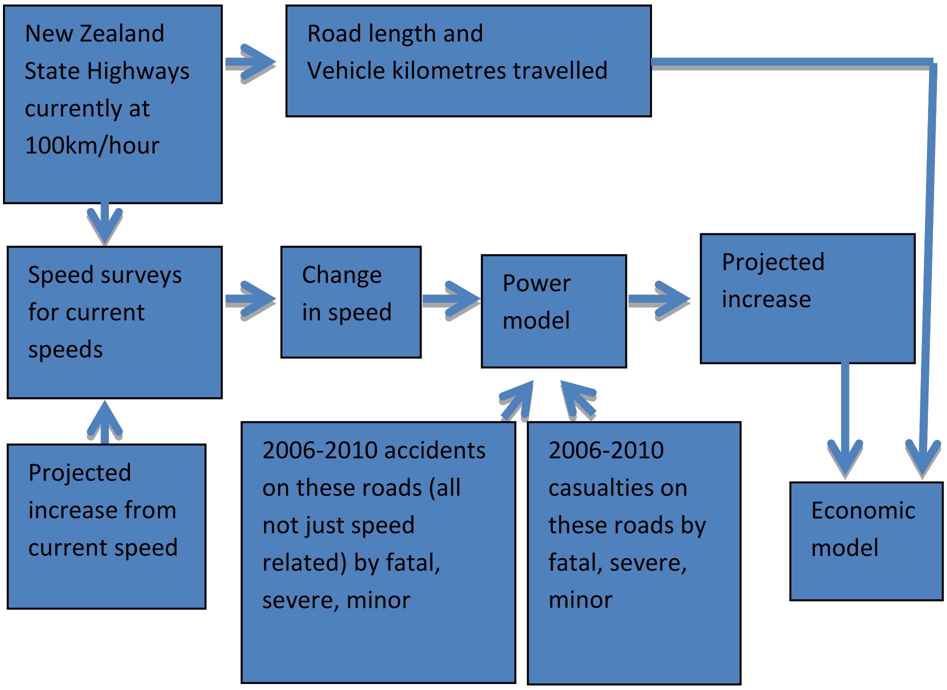

Figure 1: *Flow Diagram Illustrating Research Method.*

1.2: Road Selection Process

Before we could begin the modelling process we had to select which roads to model an increase in speed limit on. The design speed of a road is the maximum speed for which the road is designed (8). A large proportion of New Zealand open roads were built with a design speed of 80km/hour (8). Since the construction of New Zealand roads, many have been modified to increase that speed to 100km/hour (8).

The New Zealand geography poses great difficulty for road building. New Zealand roads are described in the literature as *"challenging"* and *"unforgiving"* (8,9). This is due to road side hazards such as ditches and fences, roads having to negotiate mountainous country resulting in tight turns and narrow roads, and variable weather conditions including rain, ice and snow.

"The roading system in New Zealand is not built to safely sustain vehicle speeds over 100 km/h." (p.4, 8). This view was reflected in personal correspondence we had with staff at both the New Zealand Transport Agency (NZTA) and the New Zealand Ministry of Transport (MoT with comments including *"There are no roads in New Zealand at present that would be suitable for a speed limit of 110 km/h."* (10).

New Zealand's main cities, especially Auckland, contain the nation's motorways and divided state highways. Only 5% on New Zealand state highway is median divided (11). The majority of the remaining state highways throughout New Zealand are two-lane, two-way roads. Due to the nature of these roads, the risk of head on crashes is dramatically increased. Vehicles can cross the centreline and emerge in the path of oncoming traffic either accidently or when overtaking. Vehicle speed plays a large role in the outcome of the crashes that result (8).

All information about State Highways is held by NZTA but this authority does not have information about local authority roads (roads managed by local government). Due to time constraints and difficulty obtaining data on local authority roads, we chose to limit the road selection to state highways.

Road selection for the modelling of an increase in speed limit was difficult. We initially attempted to model the situation on Auckland motorways which had a design speed equal to or greater than 110km/hour. This was done using NZTA data (12) that divided Auckland motorways into 100m segments. Segments to be included were limited to those with an environmental speed of at least 110km/hour. Environmental speed is thought to be a reasonable estimate of the 85th percentile speed and is comparable with design speed (12). Additionally the preceding 500m segment had to have a design speed of at least 110km/hour as having separate speed limits for 100m segments is not feasible. Also, as increasing the approach speed for a tight curve for which the speed is constrained is inappropriate, segments with negotiation speeds of less than 105km/hour for the tightest 30m of curve were excluded. These 3 criteria were met by 44% of Auckland's motorway.

Unfortunately we received the data set late in the project and it did not include many of the categories we would require for the model. Matching each 100m road segment to other data that we did not have personal access to (and may not exist for such specific road segments) was beyond our logistical capabilities given the time frame within which we were working. Another issue was that the number of accidents occurring on this limited part of motorway was low, 17 fatal accidents occurred over the 2006-2010 period. This low number raised concern around the statistical significance of any projected increase in crashes. As a result we decided to continue with a more hypothetical situation. We have modelled the increase in speed limit on all motorways and separately on all state highways (inclusive of motorways) that currently have a 100km/hour speed limit in New Zealand.

State highways are *"roads in New Zealand that form a nationally strategic purpose in moving people and goods nationwide"*. Motorways are *"access-controlled, high-speed roads that normally have 'grade-separated intersections' - which means they have overbridges (or underpasses)"* (13).

1.3: Demographics of Road Traffic Accidents

Before any changes are made to New Zealand speed limits, it is important that we have an understanding of how safe our roads currently are. Road traffic injuries currently represent a major cause of death and disability in New Zealand. Age standardized mortality and demographic data from the Ministry of Health (MOH) suggests that 9.5 deaths per 100,000 people were due to road traffic accidents (RTA) in 2009 (14). Using this figure, it can be shown that RTAs were responsible for 2.3% of the total age standardized deaths in New Zealand (14).

The MOH has statistics showing which groups of people are most affected by RTAs. Age standardised mortality rates due to RTAs in 2009 were 2.4 times higher for men than women and 2.3 times higher for Maori than non-Maori (14). Among Maori, almost half of all fatalities were those under 25 (14). While the burden of RTAs is more evenly distributed across age groups in the non-Maori population, compared to Maori, almost one third of non-Maori male deaths were in those under 25 (14). Data from 2010 shows that 69% of RTA fatalities were car occupants, 13% were motorcyclists, 9% were pedestrians, 3% were cyclists and 6% were 'other' (15). Of the 375 total road fatalities in 2010, 69% occurred on rural roads, 29% on urban roads and 1.9% on motorways (15) .

Comparing New Zealand's RTA statistics to international examples is a useful way of evaluating how safe our roads are. The International Road Traffic Accident Database (IRTAD) provides information on road accidents and exposures for 29 countries and presents this data in a standardised format. The 29 countries are largely high income countries. While this common income profile is useful for this report's purposes, it should be noted that most of the burden of RTAs rests with lower and middle income countries (16).

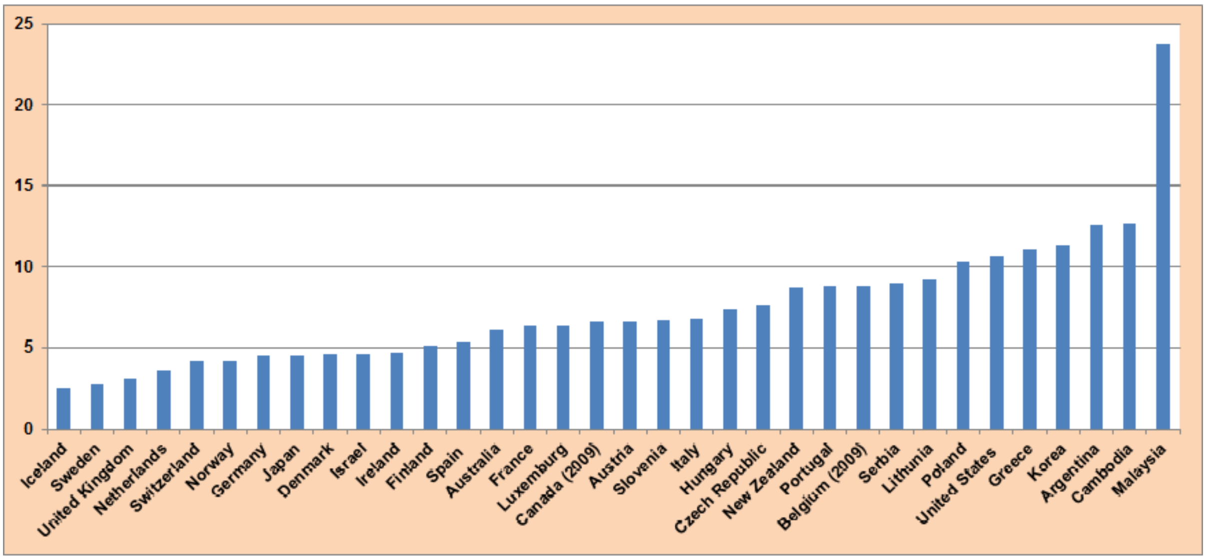

Figure 2. *Road fatalities per 100 000 people in 2010 (2)*

Figure 2 shows the road fatalities per 100,000 people, 2010. This graph suggests that New Zealand has a relatively high road fatality rate compared to other IRTAD countries. However, the data in this figure does not take into account the number of cars and distance travelled for each country. It is interesting to note that this figure decreased by more than 60% between 1970 and 2010. This is despite a threefold increase in the number of vehicles in New Zealand (15).

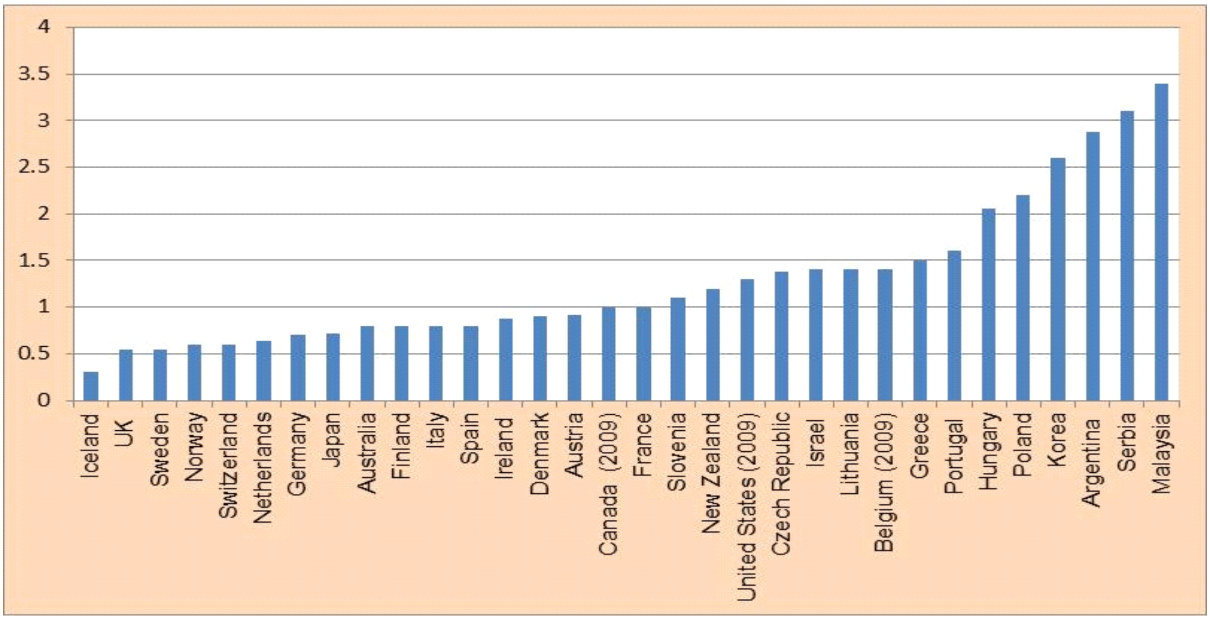

Figure 3. *Road Fatalities per 10,000 registered vehicles in 2010* (15)

Figure 3 shows the road fatalities per 10,000 vehicles, 2010. The more favourable ranking of New Zealand in this figure suggests that some of the difference in mortality rate is due to the fact that New Zealand has a relatively high level of vehicle ownership.

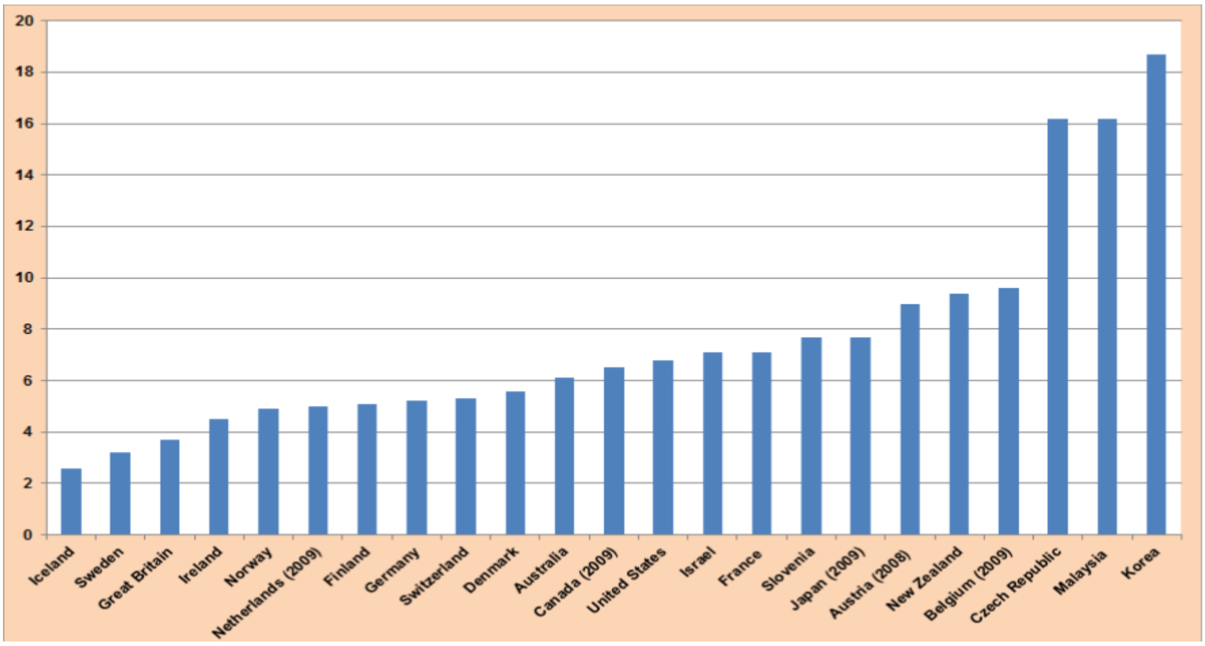

Figure 4. *Road fatalities per billion vehicles-kilometres in 2010* (15).

A third way to make international comparisons in terms of road safety is to look at the road fatalities per billion vehicles-kilometres, as in Figure 4 above. However, not all of the IRTAD countries collect this data.

There are some significant limitations to the application of this data. Consideration of fatality risk using these measures doesn't take into account many variables which can affect fatality rates. For example,population type (age, gender, density, age and gender of license holders, average income), vehicle fleet (distribution of vehicles by type and age), traffic flow by road type, metereology (rain fall, snow levels, ice, sunlight hours), quality of emergency health care, traffic safety measures (seat belt usage, alcohol tolerance, speed limits, drivers license age requirement, road quality, policing levels etc.) (17). Researchers such as Yves Page have used statistical models to account for these variables and rank countries in terms of their overall safety. However, none of these studies include New Zealand in their models.

1.4: Other Countries as Case Studies

Having seen where New Zealand sits internationally, it is interesting to examine some countries that have different philosophies on speed limits and their consequences. We have explored two countries, Sweden and Germany, in more depth because they have unique policies that result in low accident, injury and fatality rates.

Vision Zero

Vision zero is a road safety philosophy adopted by the Swedish Parliament in 1997. It declares that a target of zero road deaths or serious injuries within the road transport system should be the ethical norm and ultimate goal of the transport policy by 2020 (18).

The vision acknowledges that vehicles, road users and infrastructure are interrelated, and so a shared responsibility exists between traffic planners and road users. As a result, the design and function of the road transport system has been adapted to meet the requirements as stated in 'Vision Zero' (2,18).

Vision Zero promotes a road system where the amount of biomechanical energy cannot exceed human tolerance. This has become the basic parameter to which road and vehicle design is based. Speed limits are subsequently set on the basis of the human body's endurance at the moment of the collision (19,20). With this in mind it has been calculated that the speed limit should not exceed 50km/h at intersections with possible side impacts between cars, and should not exceed 70km/h on roads where there is a risk of frontal impacts between cars (including rural roads). Speeds over 100km/h can be tolerated if the infrastructure is designed to prevent both frontal and side impacts (20). This is a unique concept that could be applied to New Zealand in some places however it may not be geographically and fiscally possible to change the majority of roads in New Zealand to fit the guidelines of 100km/h roads in Vision Zero.

According to statistical data the strategy has been successful. In 1997, when Sweden started to implement the principles of Vision Zero there was a total of 541 road deaths. Over a decade later this number had fallen to 266 in 2010, which is a 50.8% drop in fatalities (21). Although it is unlikely that all fatalities and serious injuries can be avoided, Sweden is one of the safest countries when it comes to road safety. It has been shown that by adopting the basic principles of Vision Zero, road accident fatalities can be significantly reduced (22). Increasing the speed limit to 110km/h as proposed would be going against these basic principles – is it a step in the wrong direction for New Zealand?

German Autobahn System

Germany's autobahns are the nationally coordinated motorway system. They are famous for being some of the few public roads in the world without blanket speed limits for cars and motorcycles. Currently, 52% of the German motorways do not have a speed limit, 15% have temporary speed limits due to weather or traffic conditions and 33% have permanent speed limits. On unlimited sections there is an advisory limit of 130 km/h but this is not strictly enforced (1).

The accident, injury and death rates on the Autobahn are relatively low. In 2009, the Autobahn carried a third of all Germany's traffic, but crashes along the autobahn accounted for only 6% of Germany's injury related accidents, and less than 12% of national traffic fatalities . In fact, the annual fatality rate (2.7 per billion km in 2009) is consistently lower than that of most other superhighway systems, including Denmark, Belgium, Austria, and the US interstates. However it is important to realise the Autobahns are highly engineered roads with little interaction of traffic

This data indicates that whilst comparatively safe, Germany can still make further progress in terms of motorway safety. Given that the quality of vehicles and infrastructure is relatively good the best measure to improve road safety is likely to be in the introduction of mandatory speed limits. There is clear evidence for the effectiveness of implementing speed limits on the autobahn. In December 2002 a 130km/h limit was introduced on a 62km section of the autobahn. As a result the number of injury related accidents decreased by 48% and the number of casualties decreased by 57% over the next 3 years (23), indicating that speed free zones have a negative effect on road safety.

Section 2: POSTED SPEED LIMITS vs ACTUAL CAR SPEEDS

Having established where New Zealand stands internationally in terms of road safety, we moved on to considering what would actually happen if the speed limit were to be increased from 100 to 110km/h.

It is important when exploring a potential change in speed limit to consider what effects on actual traffic speed a particular change will have.

This part of the report will focus on actual vehicle speeds with respect to speed limits and the potential change in mean speed when altering the speed limit.

New Zealand introduced their first speed limit, known as the ‘Speeding Infringement System’ in 1971. Over the following 40 years changes have been added to this, including roadside suspensions for excessive speed, increasing fees for speeding infringements and penalties for dangerous driving (24).

The New Zealand Land Transport Safety Authority (LTSA) developed a set of guidelines and procedures which are used when setting or altering a speed limit, called Speed Limits New Zealand (SLNZ) (25). These guidelines take into account several factors of the road, such as the current speed limit, the character and function of the road, vehicle activity and past crash data

We looked at current speed limits for existing roads and the actual speed cars were travelling at within this current speed limit. We also examined how much this actual speed could change when the speed limit is altered, based on international literature. We focused on the mean speed of cars, as well as the 85th percentile speed, which is the speed that 85% of cars are travelling at, or below. We also looked at the range of speed (the difference between the fastest cars and the slowest) and how this is affected by speed limit changes

2.1: Method

We conducted a literature review (appendix 2), then concentrated on several key studies which appeared to be the most relevant to our research interests.

New Zealand speed data was obtained from the New Zealand Speed Survey, conducted by the MoT (7). Free speeds were attained in the speed survey when the vehicle was unimpeded by the presence of other vehicles or by environmental features such as traffic lights, intersections, hills, corners or road works. Measuring the speeds of unimpeded vehicles allows the survey to measure the drivers’ choice of speed within a given speed limit.

The survey is conducted annually throughout randomly selected sites around New Zealand to provide a national speed profile estimate. The surveys are carried out in an unobtrusive manner to ensure speeds measured are minimally affected by survey procedures. 13, 132 open road cars were surveyed at 68 open road sites.

***Table 1**. New Zealand Speed Survey Data 2002-2011*(7)

Year	Mean Speed (km/h)	85th Percentile Speed (km/h)	% of Cars Speeding
2002	99.1	107	43.00%
2003	98.0	105	39.00%
2004	97.8	105	39.00%
2005	97.1	104	36.00%
2006	96.4	103	32.00%
2007	96.3	103	29.00%
2008	96.6	103	30.00%
2009	96.3	103	29.00%
2010	96.2	103	29.00%
2011	96.5	103	31.00%

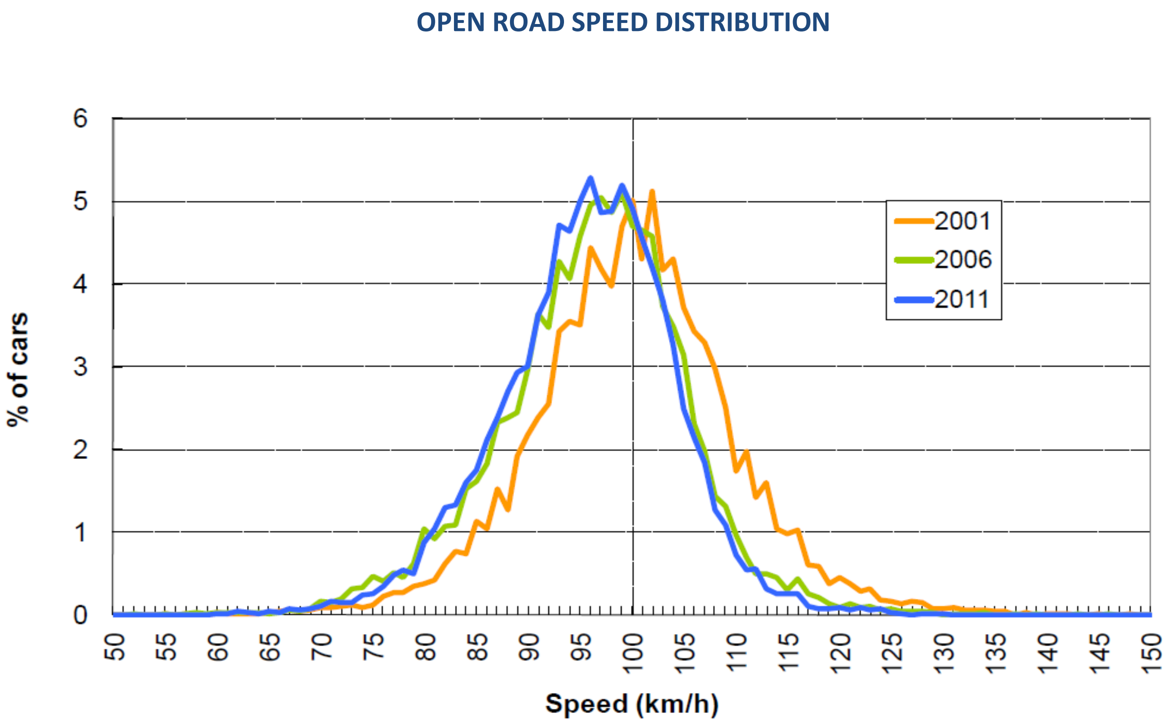

***Figure 5.** Open Road Speed Distribution, New Zealand Speed Survey* (7)

Table 1 and Figure 5 above demonstrate the mean speeds, 85th percentile speeds and the distribution of speeds over the previous 10 years. In the case of this analysis an average of data from between 2006-2010 has been used. The average speed over this 5 year period was 96.36km/h and the average 85th percentile speed was 103km/h (7).

The Saskatchewan study (6) was the primary piece of international literature that was used to predict the changes to actual speeds if a speed limit change were to be implemented in New Zealand. It consisted of a major effort in collecting various spot speed studies conducted throughout the Saskatchewan province of Canada. Only free-flowing vehicle speeds, defined as vehicles having greater than 3 seconds between cars, were used for this analysis. Free flowing traffic is uninhibited by other vehicles and speed is therefore solely determined by the driver, based on the speed limit and their confidence.

The Saskatchewan study(6) looked at a change in speed limit from 100km/h to 110km/h which is the same change that our study is proposing. All locations were representative of typical conditions on highway sections. The speed data detection devices used in the study have a relatively low level of error at 0.11-1.1km/h either side of the true speed, giving the speed data that they collected a high degree of precision.

Table 2. *Speed Survey Data from Saskatchewan Study- Passenger Cars only included in data* (6).

	Before (100km/h)	After (110km/h)	Change Before and After
Mean Speed (km/h)	108	112	+4 km/h
85th Percentile Speed (km/h)	115	119	+4 km/h
% of Cars Speeding	83	57	-26 %
Speed Differential	15	16	+1

'Before' refers to when the speed limit was 100km/h (ie. Before speed limit change) and 'after' refers to when the speed limit has become 110km/h (ie. After the speed limit change).
The speed limit change had only been in effect for approximately 4 months at the conclusion of the data collection. Because of this the data only displays initial results of the speed limit increase. More definitive trends may have appeared as time passed and additional data was collected.

SPEED DISTRIBUTION (LIDAR ONLY)

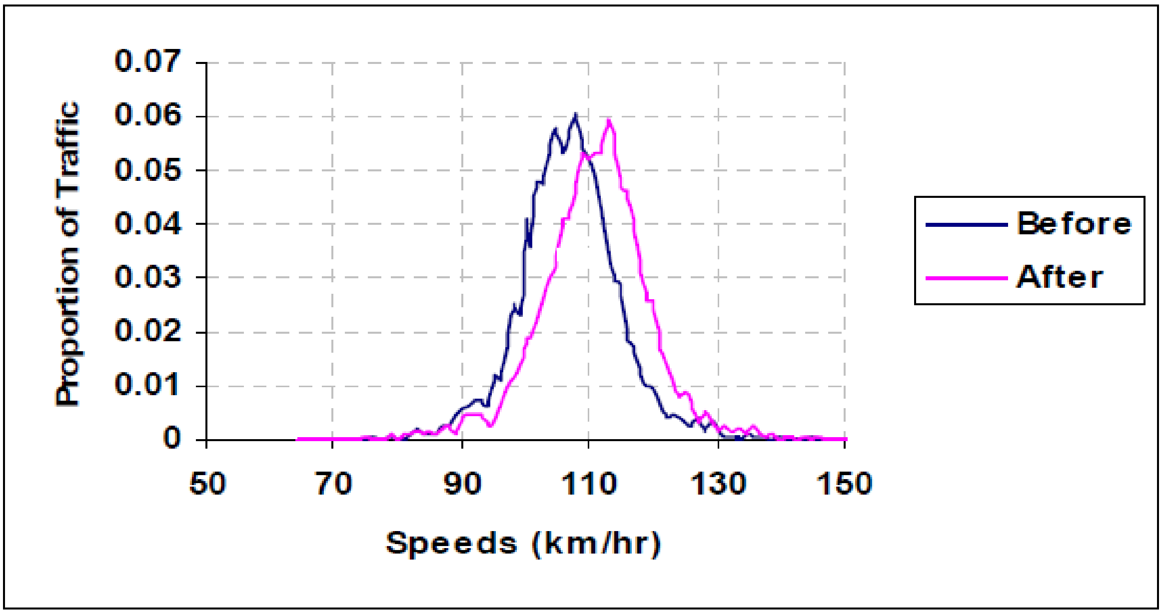

Figure 6. *Speed Distribution before and after speed limit change using Laser Technology to record speeds* (6).

SPEED DISTRIBUTION (PERMANENT RECORDING STATIONS ONLY)

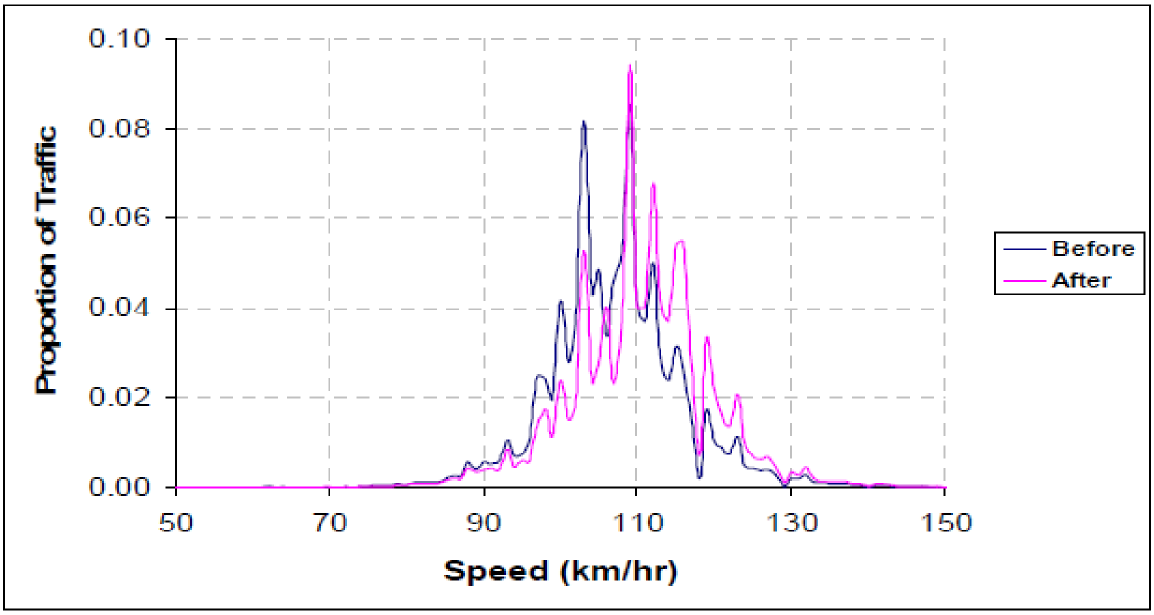

Figure 7. *Distribution of speeds before and after speed limit change recorded using permanent recording stations* (6).

Figures 6 and 7 above both demonstrate that following a change in speed limit from 100km/h to 110km/h the distribution of vehicle speeds tends to broaden. This is due to some vehicles continuing to go at a similar speed to those travelled prior to the change and other vehicles increasing their speed with the speed limit increase (6).

2.2: Summary of Other International Literature Findings with Regard to Changes in Speed:

Table 3*. Mean Speed Increases Observed from Raising Speed Limit from 55 to 65 MPH (88.5Km/hour to 104.6Km/hour). Reviewed by Stuster et al.* (26)

Study	MPH	KM/H
Brown *et al*. (1990)	2.4	3.9
Freedman and Esterlitz (1990)	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

A study by Finch *et al.* (27) analyzed the changes in speeds from raising and lowering speed limits reported in a number of international studies. This study found that the change in mean traffic speed is roughly one-fourth of the change in the posted limit.

Reigo Ude (28) assessed seasonal speed limit changes on Estonian roads. This experiment involved sections of road which met requirements of specified conditions having speed limit increases from 90 to 100, 110 and 120. Speed monitoring stations reported the changes in speed and concluded that if the speed limit is raised, changes of 1.5-2 km/h would occur per 5km/h speed limit change.

An additional study by Agent (29) looked at the changes in 85^{th} percentile speeds on rural interstates and 4 lane-parkways in Kentucky when the speed limit changed from 65mph to 70 mph. No average speeds were reported for the change in speed limit but the 85^{th} percentile speeds increased by 1.3mph and 2mph on rural interstates and 4 lane- parkways respectively.

This international data that we reviewed supports the Saskatchewan data with average speed changes ranging from 0.3-8km/h. When the results from these studies are averaged there is found to be an increase in speed between 3.88-4.95km/h.

2.3: Discussion

As shown by the international literature, increasing speed limits results in an increase in the mean speed that vehicles travel at on state highways and motorways. For the purposes of this study we assume that the mean increase in speed is 4km per hour. This was the finding of the Saskatchewan Study (6) and is approximately consistent with the findings of the other studies discussed. We will apply this to the New Zealand speed survey data in order to predict the mean speed increase resulting from an increase in the open road speed limit from 100km/h to 110km/h. As stated above, the mean speed in New Zealand for 2006-2010 was 96.36km/h. Thus, the mean speed would be projected to increase to 100.36km/h. The 85^{th} percentile speed would increase from 103km/h to 107km/h and the distribution range of vehicle speeds would also increase.

We chose to base our projected speed changes on the Saskatchewan study we assessed this study to have produced the most reliable data. The data produced by this study was also the most relatable to the situation we are modelling as it involved the same change in speed limit on relatively similar roads.

2.4: Psychology of Speeding

Looking at the potential reasons why people speed, Blincoe (30) reported that there are four types of drivers. There are conformers, who report they never exceed speed limits, deterred drivers, who are put off from speeding by the presence of cameras, manipulators, who slow only at camera locations, and defiers, who exceed limits regardless of cameras.

Blincoe (30) found that conformers were the least likely to state that prosecutions had deterred them probably because they thought they were already law abiding. The deterred drivers were most likely to express opinions to avoid further speeding. Their speeding would be most likely to be accidental. Manipulators and defiers often reported they had deliberately exceeded speed limits.

Demographic factors such as financial position and ability to pay fines also influence whether people speed. The value an individual places on their money and time as well as fuel costs may factor. Fuel consumption tends to increase as speed increases, thus the nation's economic situation and the price of petrol may be large considerations for some people. The condition of the road and the weather may determine whether a person will speed or not. The number of people in the car, which can affect both peer pressure to speed and safety concerns around speeding, may influence a driver's speed choice. A driver's mental state, intoxication, level of concentration, driving for the thrill, 'testing out a new car' and pure ignorance of the speed limit are all other factors which may contribute to speeding. Overconfidence is a significant factor involved in speeding; drivers tend to have an 'it won't happen to me' attitude around collisions.

2.5: Limitations

This literature review on the changes in average speed when the posted speed limit is changed is limited by the nature of the study type itself. Information from a literature review is limited by the quality of the studies included. Additionally New Zealand has a maximum speed limit of 100 km/h. To our knowledge no studies have been done testing a speed limit of 110 km/h in New Zealand, so all of the research we were able to access and analyse came from international studies. International studies will feature many influencing factors that are different from those found on New Zealand roads. Such factors could affect drivers' response to changing speed limits. Many of the studies reviewed use a change of 55 miles per hour to 65 miles per hour, (88.5Km/hour to 104.6Km/hour). This is different from the proposed change of 100 to 110 km/h; however the relationship shown by these studies is still supportive of the 4km/h change in mean speed we project would occur.

2.6: Conclusion

By using the average speed increase of 4km per hour found by the Saskatchewan Study and applying it to the data that has been collected by New Zealand speed surveys, a new open road average speed can be extrapolated. If the open road speed limit were to increase from 100km/h to 110km/h, the projected average speed would move from 96.36km/h to 100.36km/h. This is well below the new posted speed limit. We estimated that the 85th percentile would shift from 103km/h to 107km/h, which would still be below the new posted speed limit. The distribution of driver speeds would be slightly increased.

Section 3: THE EFFECT OF SPEED

To make an informed decision on whether it would be appropriate to increase the speed limit we needed to consider what effect the 4km/h increase in mean speed discussed in Section 2 would have on road safety. In order to do this we needed to assess what kind of impact the proposed increase would have on road traffic accidents and casualties. With this in mind, we completed a literature review and critical analysis of the current literature. Based on this analysis we modelled the effect of an increase in speed using a modified version of Nilsson's Power Model (5). We formed an estimate of the change in the number of road traffic accidents and casualties that would occur if the proposed speed limit change was implemented.

3.1: The Relationship Between Speed and Crashes

"It is difficult to think of any other risk factor that has a more powerful impact on accidents or injuries than speed" (p.3, 31)

An increase in speed results in an increase in collisions through a multitude of factors. These include: increased stopping distance, increased probability of exceeding the critical speed on a curve, an increase in rear end collisions if the driver has not accounted for their increase in speed by increasing their following distance, reduced time available to detect and respond to hazards in the driving environment, and reduced time to avoid hazards once they are seen (reviewed in (8)). As the mean speed for all vehicles is projected to increase, all cause crashes were considered when modelling the effect of the proposed increase in speed limit (see section 3.5).

Not only does the number of collisions increase with higher speeds but the severity of injury arising from a collision also increases. At higher speeds more collisions occur and these collisions have more severe outcomes.

We have briefly looked at crashes in which speed was considered a factor in order to gain an appreciation of the effect of speeding on crashes. The definition of 'speeding' used in this report is adopted from the MoT definition. Speeding is driving "too fast for the conditions". This definition incorporates both driving faster than the legal speed limit and driving at an inappropriate speed for the conditions (32).

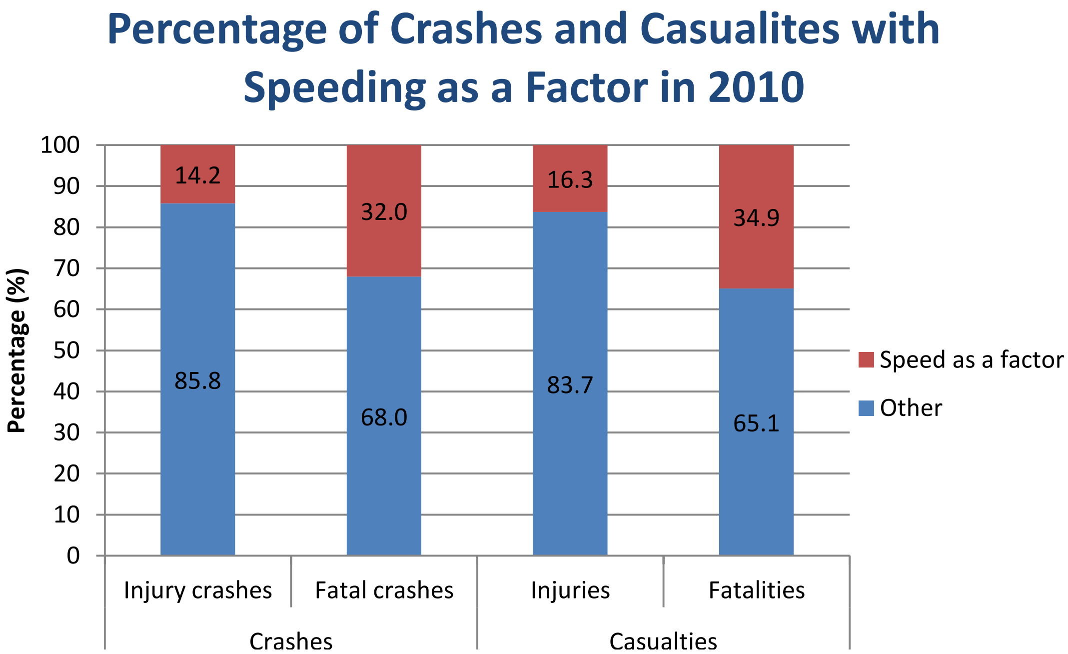

Figure 8. *Percentage of Crashes and Casualties with Speeding as a Factor in 2010. Graph data source* (33,34)

Graph 4 above displays the proportion of RTA crashes and casualties in New Zealand in 2010 in which speeding was a factor in the cause of the accident. As shown, speed was a factor in 32% of fatal crashes and 14.2% of crashes that resulted in injury. The casualties of speed related crashes, that is the people who were injured or killed, accounted for 34.9% of RTA fatalities and 16.3% of RTA injuries in 2010.

The risk of collision associated with speeding is comparable with collision risk associated with driving while under the influence of alcohol (35). Kloeden *et al.* (35)found that travelling at 5 km/h above a 60 km/h limit increases the risk of crash involvement to the same degree as driving with a blood alcohol concentration of 0.05. This is the legal blood alcohol limit in most OECD countries for example Australia with the exception of New Zealand.

Driving at 80kmh in a 60kmh zone is the equivalent of being 4 times over the legal blood alcohol limit (35). This is the level of intoxication you would reach after 8 standard drinks if you weighed 73kg. At this level an individual may experience severe motor impairment, loss of consciousness and memory blackout (35).

3.2: Bodily Tolerance

"The human body usually has no capacity to cushion the effects of a crash once it occurs, and so is left to the mercy of the physical forces that are at play to determine the severity of the resulting injury."(p.21, 8)

By the laws of physics, the impact in a crash increases with an increased travel speed. This increased impact substantially increases the severity of any injuries resulting from that crash. Regardless of whether speed is a factor in causing a crash, the speed the vehicle was travelling at will influence the severity of the crash (8). The more kinetic energy there is prior to collision, the greater the chance that the impact will be more than the human body can tolerate (5). Given that kinetic energy is proportional to the square of speed, higher speeds result in a decreased likelihood of crash survival.

The risk of injury for elderly people involved in collisions is generally a lot higher than the risk for younger people, because of their greater frailty. For instance a male driver aged between 70 and 80 has 3 times the likelihood of being killed in a crash of the same impact compared with a 20 year old (reviewed in (8)). This is particularly significant from a public health perspective given New Zealand's aging population.

3.3: 'NATURAL EXPERIMENTS': Past Changes In Speed Limits In New Zealand

1973

On the 4th December 1973 the New Zealand government implemented a 50mph (80.47km/h) open road speed limit. This was meant primarily as a fuel saving measure during the international oil crisis of 1973 (Frith & Toomath, 1982).

Frith and Toomath (36) looked at all roads which had a speed limit of 55mph (88.51km/h) or 60mph (96.56km/h) prior to the change in 1973. Speed checks conducted at locations throughout the country before and after its introduction showed a general reduction in average operating speeds of between 8mph (12.86km/h) and 10mph (16.09km/h). It also showed a reduction in the spread of speeds. In addition, there was a substantial reduction in the proportion of vehicles travelling at extremely high speeds, accompanied by a statistically significant reduction in the 85th percentile speed. In the latter part of the after period speeds tended to stabilise at about 3-5mph below previous speeds.

It was concluded that there was a reduction in road traffic accidents in the year following the change in speed limit on open roads.

- There was a 37.2% decrease in fatalities
- There was a 24.2% decrease in serious injuries
- There was a 21.9% decrease in minor injuries
- There was a 22.5% decrease in accidents

As shown above, the decrease in speed resulted in a decrease in RTAs with the most significant decrease in fatalities and the smallest decrease in minor injuries. This is consistent with the change predicted by Nilsson's model (37) which is discussed later.

1985

The open-road speed limit was increased from 80km/h to 100km/h in 1985. Speeds prior to the increase had been high therefore there were no subsequent changes in crashes. These findings suggest that speed limit increases or decreases are only likely to change crash rates if they are accompanied by mean speed changes (reviewed in (8)). This reinforces that, when looking at a projected change in accidents, we need to look at the change in mean speed rather than the change in speed limits when considering the effect on road safety and accidents.

3.4: The Current Situation in New Zealand

The graph below shows the total fatal crashes and casualties in New Zealand in 2010 and the proportion of those that involved speed as a factor in the crash.

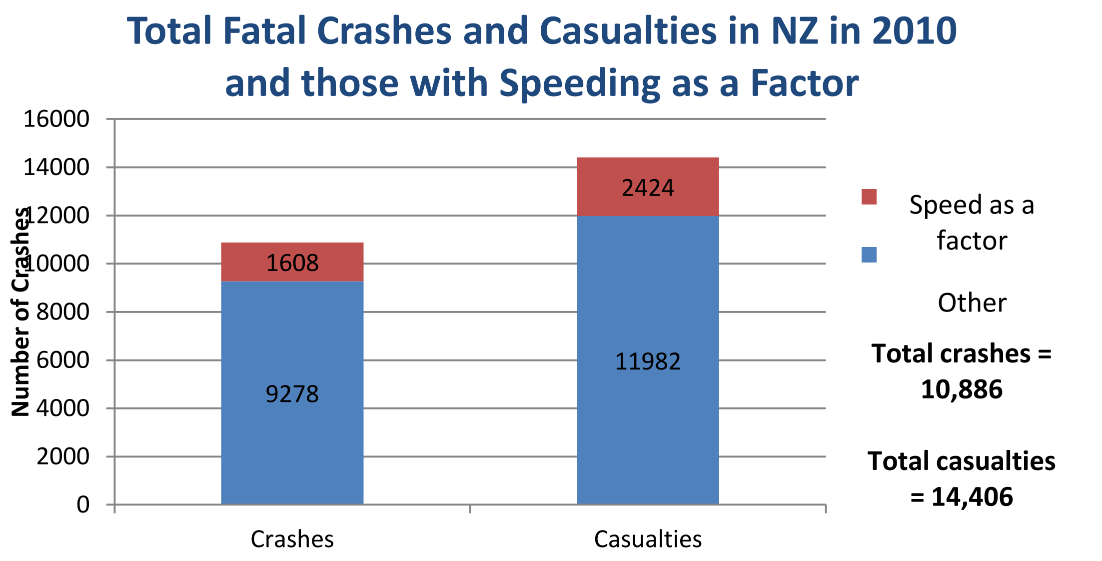

Figure 9. *Total Fatal Crashes and Casualties in New Zealand in 2010 and those with Speeding as a Factor*
In this graph a multiple fatality crash is counted as one crash but multiple casualties.
Graph: data source (33,34)

3.5: Inequalities

As there is such a strong relationship between speed and crash rates and the severity of crashes, we were concerned about the effect this would have on certain population groups.

The graph in Appendix 6 is showing speed-related fatalities by age, ethnicity and gender; crashes were classified by police as speeding or going too fast for the conditions. Young men are overrepresented in the data, especially young Maori men which is evident even in this non-age standardised data. If there is an increase in the speed limit, based on the current data, more Maori will die because they are already disproportionately represented in road crash fatalities. This is not a favourable outcome for Maori and an important public health issue that needs to be considered.

The European Transport Safety Council estimated that fatalities on Europe's roads would drop by 40–50% if every car owner were to upgrade their vehicle to safest in its class (38). We could make the assumption that this estimation can be applied to New Zealand's population. This demonstrates the disproportionate effect that crashes have on the lower socioeconomic groups, as the newer car models are expensive but consequently safer.

3.6: Modelling the Effect of a Change in Speed Limit on Road Crashes

From the information discussed in earlier segments of section 3 it can be appreciated that an increase in the speed vehicles travel will result in more crashes. For our purposes, we wished to form a numerical estimate of what this increase would be. Many models have been put forward over the years to approximate the relationship between speed and road safety. The models are not all the same but they all indicate that an increase in traffic speed results in an increase in crash rates (reviewed in (8)).

Studies examining the relationship between speed and crash rate can be separated into two groups: (39)

1. Individual vehicle level
2. Average speed at road section level.

The relationship between individual vehicle speed and crash rate was determined to be exponential for individual vehicles that increase their speed. This was mainly deduced based on work by Kloeden *et al*. (35), (reviewed in (39)).

However for our purposes, it is the second relationship that is more valuable. This has been looked at in two main ways over the years.

1. Before and after studies where the average speed and crash rate are analysed before and after a speed limit change. A comparable group is included to control for factors other than speed that could affect crash rate. Nilsson's 1982 (40)study is an example of this.
2. Cross sectional studies where different roads are compared and analysis is carried out to determine the variance in crash frequency that is due to the difference in average speed between the roads. The work done by Baruya (41) is an example of this.

Providing that there is a consequent change in speed, almost universally these studies have shown that increasing a speed limit increases crash rates while decreasing a speed limit may decrease crash rates (8,39).

3.7: Nilsson's Power Model (40,42)

Nilsson's power model describes a relationship between changes in mean speed and consequent changes in accidents and accident victims through six power functions (40,42). Nilsson developed his power model on Swedish rural roads following speed limit changes between 90 and 110km/hour. Roads with an unchanged speed limit of 90 km/h were used as control locations (40,42). He found that a decrease in speed limit with a decrease in average speed resulted in a consequent reduction in the number of crashes. As Nilsson found that the severe crashes increased more than overall crashes with an increase in speed limit, he allocated a larger power to more severe crashes than overall crashes. Since this time, other models have been proposed and Nilsson's model has been modified. However Nilsson's power model is still commonly referred to in recent international literature (16,39,43)

3.8: Elvik's Adaptations (5,31)

In 2004 Elvik *et al*. (31) evaluated the Power Model proposed by Nilsson using conventional and regression meta-analysis. They concluded that *"The Power Model has a number of attractive features. It is parsimonious, simple, elegant and general. It yields results that make sense"* (p.6, 31)

To be included in Elvik's 2004 meta-analysis, a study had to state the relative change in speed and the relative change in the number of accidents or accident victims. 98 studies, containing 460 estimates of the effects of changes in speed were included in the meta-analysis.

It was found that the power model was supported by the results. The exponents found to best match the pooled studies were similar to Nilsson's.

In 2009 an updated analysis of the power model was put forward (5). The accumulated total of evaluated studies was 115, with 526 estimates of effect. The main questions addressed in the analysis were whether the power model described the relationship between speed changes and road safety adequately and whether a revision of the values of the exponents was justified. The exponents were modified and the model was refined to include a version applicable to urban roads and a version applicable to freeways and rural roads. This is due to findings that traffic environment is an important *'moderating variable'* and the effects of an increase in speed tend to be lower in urban areas than rural areas and freeways.

3.9: Alternative models

There has been discussion around whether the mean speed provides an adequate representation of speed for modelling purposes. The concern is that the proportion of vehicles travelling at excessive speed and the degree of variation in speed needs to be accounted for (39,41). This seems to apply more to urban roads than rural roads. As noted by Cameron *et al*. (37), Nilsson's power model and Elvik's subsequent meta-analysis (5)make the assumption that the change in crashes and casualties can be estimated using the change in mean travel speed only. On further analysis, Cameron *et al.* (37) concluded that *"on rural highways, the mean speed is adequate to represent the influence of speeds on crashes"* and that using mean speed changes with the power model gives a good indication of the consequences of speed changes. Taylor *et al*. (44) had similar findings concluding that for rural road casualty crashes the incorporation of other speed parameters added no additional information.

3.10: Chosen model

We have chosen to use the rural roads/freeways exponents from Elvik's 2009 (5) adaptation of the Nilsson Power model. Below is the equation from Elvik's 2009 model (5). The exponents can be found in Appendix 4.

$$(\text{X after}/\text{X before}) = (\text{speed after}/\text{speed before})^{Y}$$

X= Accidents or number of accident victims at a given level of severity (fatal, serious, minor)
Y= exponent

Equation source: (5)

3.11: What will happen if speed limits on state highways currently at 100km/hour are changed to 110km/hour?

Data for collisions and casualties on state highways with a speed limit of 100km/hour at the time of the collision over the period 2006-2010 was obtained from the Crash Analysis System (CAS) through personal data request (12,34). The projected increase in crashes and casualties was calculated by applying Elvik's 2009 (5) adapted version of Nilsson's power model to these numbers. The results are in Tables 4 and 5 below.

Table 4: Projected 5 year increase in crashes and casualties by severity for all state highways with 100km/hour speed limits.

2006-2010 (before) refers to a 5 year period prior to the speed limit change. Projected (5 years) (after) refers to the modelled increase in crashes and casualties that would be expected a 5 year period if the speed limit were to be increased.
Data source: Power (best estimate) (p.58, 5)*, Crashes and casualties for 2006-2010 (before)* (12)

Projected 5 year increase in crashes and casualties by severity for all state highways with 100km/hour speed limits.					
Number of…	2006-2010 (before)	Power (best estimate)	Projected (5 year total) (after)	Change (5 year total, nearest whole)	% increase (1dp)
Crashes					
Fatal	743	4.1	877.83	135	18.2%
Serious	2,587	2.6	2,875.56	289	11.2%
Minor	9,303	1.1	9,728.67	426	4.6%
Total crashes	12,633		13,482.06	850	6.7%
Casualties					
Fatalities	859	4.6	1,035.73	177	20.6%
Serious injuries	3,612	3.5	4,164.58	553	15.3%
Minor injuries	14,592	1.4	15,447.00	855	5.9%
Total casualties	19,063		20,647.31	1,565	8.2%

Table 5: Projected 5 year increase in crashes and casualties by severity for all motorways with 100km/hour speed limits.

2006-2010 (before) refers to a 5 year period prior to the speed limit change. Projected (5 years) (after) refers to the modelled increase in crashes and casualties that would be expected a 5 year period if the speed limit were to be increased.

Data source: Power (best estimate) (p.58, 5)*, Crashes and casualties for 2006-2010 (before)* (12)

Projected 5 year increase in crashes and casualties by severity for all motorways with 100km/hour speed limits.					
Number of…	2006-2010 (before)	Power (best estimate)	Projected (5 year total) (after)	Change (5 years total, nearest whole)	% increase (1dp)
Crashes					
Fatal	32	4.1	37.81	6	18.2%
Serious	155	2.6	172.28	17	11.2%
Minor	1,802	1.1	1,884.45	82	4.6%
Total crashes	1,989		2,094.54	105	6.7%
Casualties					
Fatalities	37	4.6	44.61	8	20.6%
Serious injuries	199	3.5	229.44	30	15.3%
Minor injuries	2,466	1.4	2,610.49	144	5.9%
Total casualties	2,702		2,881.54	182	8.2%

Strengths of the model:

Like all models, the one we have used has strengths and weaknesses.

The estimates of power stem from the effects of speed change only as multivariate analysis was used to control for other road safety measures implemented. The majority of the evidence contributing to this model comes from before-and-after studies. This, in conjunction with the use of control roads, supports the notion that the changes in speed and not other variables caused the change in crashes and casualties. Elvik (5) undertook a comprehensive statistical analysis to detect publication bias, assess the analytic choices he made and to assess the quality of the primary studies. He concluded that none of these factors would have resulted in artefactial findings.

We are modelling for high speed roads only and thus using the rural road/freeway exponents should give the best estimate for our purposes. This is preferable to using an older model that does not acknowledge the difference between the relationship of mean speed change and safety on high speed verse low speed roads. In the studies included, initial mean speed on freeways was 104.3km/h and on rural roads 86.5km/h which fits well with our current mean speeds of 96km/hour and projected increase to 100km/hour.

The exponents have been updated to account for temporal changes. Elvik 2009(5) found that the exponents have shown a tendency to decrease over time. This means the effect of a change in speed on road safety has decreased. Improvements in safety devices such as seatbelts and airbags were proposed as a possible explanation for this weakened association. The exponents will be as close as possible to those estimated in recent high quality studies. Confidence intervals based on conventional meta-analysis are provided.

Meta-regression analysis has shown the Power Model can be applied in all countries. Thus it should be applicable to New Zealand. Personal correspondence with NZTA engineers has confirmed that this model is likely able to be applied to New Zealand roads (10,12).

Weaknesses of the model:

"Adopting the power model involves accepting a more crude approximation to the non linearity of the effects of speed than a more complex model will allow"(p.56, 5). As we are only trying to form an estimate however, the power model suffices.

Accident and speed data can be unreliable. As noted in by Elvik *et al*. in 2004(31), unreliable data tends to attenuate statistical relationships and therefore it is highly likely that the true effects of speed on road safety are underestimated. The authors felt that the conclusion validity could be particularly affected by speed measurement errors and incomplete and unreliable data on crashes and casualties. Reassuringly though, Elvik's own analysis of the data in 2004(31) found that the results were largely unchanged by separation of high and low quality studies. This indicates that the conclusion is not affected by study quality.

As the model is a 'rule of thumb' it inevitably can only provide us with an estimate. The specific environment of the roads in consideration is not incorporated into the model and may have an impact, *"the exact relationship between speed and crash frequency depends on the actual road and traffic characteristics including road width, junction density, and traffic flow"* (p.223, 39).

3.12: Other Limitations

Collisions involving trucks are included in the data. An increase in truck speed is expected despite differences between truck and car speeds. Given that we aim for an estimate only, we accept this limitation.

CAS data - the source of the crash data - is categorised by the speed limit at the time of a crash. The state highway speed limit could have changed on certain road segments since the crash occurred. Some crashes included in the model may have occurred in segments of road that no longer have a 100km/h speed limit. Additionally the forward projection does not take into account changes in traffic on the roads over time, however VKT have remained relatively constant in recent years (45).

Congestion will limit the time during which a speed limit change will result in a mean speed change. The model we have used does not take this into account as it is based on mean free speed. Additionally the average speed we are using is for all open roads. This incorporates roads that are not included in our model. Thus the speed we used may not represent the true speed of the roads we are modelling. While this is unlikely to have a large effect on the projection for all state highways, it may limit the accuracy of the model for motorways only. If the mean speed on motorways is greater than that on all state highways with a 100km/h speed limit then the projected increase in crashes would be greater for motorways, and vice versa.

Section 4: ECONOMICS

An economic consideration is crucial in any assessment that may alter the function of major transport networks. In order for any change to be considered viable it must not only be the ethical choice, but must also prove to be fiscally beneficial to society as a whole. There is no reason to institute change if it will only reduce national revenue, particularly in current volatile economic markets. If savings are made, this money can be spent on other areas such as healthcare, education or perhaps put back into improving roads to reduce the number of crashes and fatalities. In order to provide a comprehensive view of the effects of changing speed limits, the social costs of road traffic accidents, vehicle operating costs, fuel tax revenue, vehicle emissions and increased productivity from time saved were modelled (Figure 10). All calculations (excluding social costs) are based on vehicle and light commercial traffic only, as the speed limit increase is not applicable to trucks. This outcome is the crux of whether a change is practicable, in light of ethical consideration.

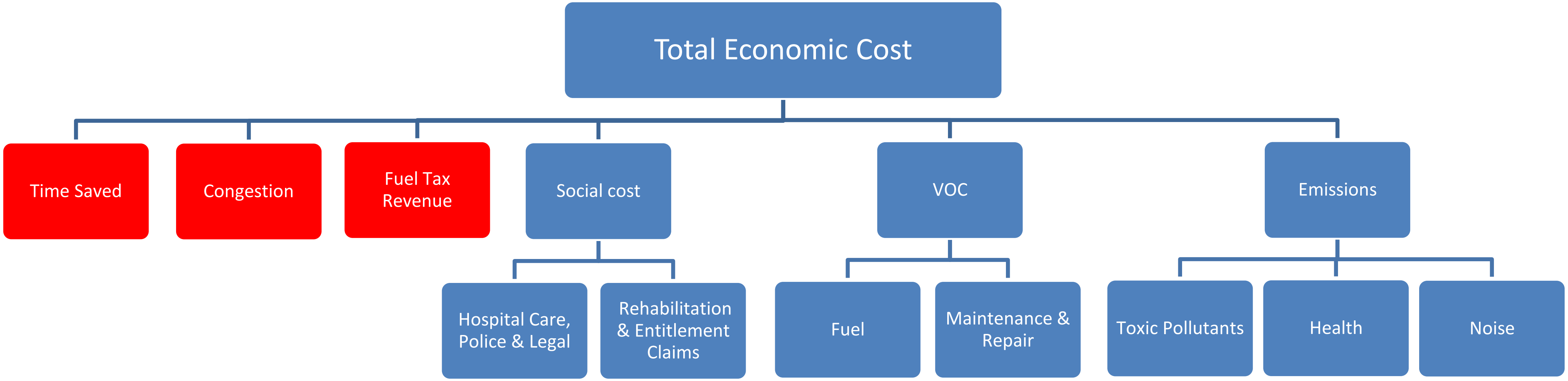

Figure 10: Economic model incorporating both additional costs (in blue) and cost savings (in red) to society as a result of increasing speed limits.

4.1: Social Cost of Road Traffic Accidents

Increasing speed limits is associated with increased road traffic accidents (RTAs), the cost of which is borne largely by society (the taxpayer), and to a lesser degree, traffic participants involved in the accident (31,46). The New Zealand MoT publishes an annual report on the social cost of road crashes and associated injuries (47). Their calculations include loss of life and life quality (derived from the value of statistical life), loss of output due to temporary incapacitation (estimated from average hourly earnings), medical costs (paramedics, hospital treatment and sub-acute follow-on costs), legal costs (crash investigation, imprisonment and court costs) and property damage (vehicle services and repair). In 2011, the total social cost of motor vehicle injury crashes was estimated at $3.03 billion (in 2011 prices, excluding property damage only (PDO) crashes and adjustments for non-reporting). Crashes with speed as a contributing factor represented 15% of all cause crashes and 29% of fatal crashes, which equated to 22% of the total social cost of accidents (social costs by injury type are broken down in Table 6 below).

Table 6: *Total social cost of crashes by injury type for all cause, speed as a contributing factor, speed on 100km/h state highways (SH), and speed on motorways (MW) only in 2011 prices in millions (Leung, 2012)*

Year	Fatalities				Serious Injuries				Minor Injuries			
	All Cause	Speed (Total)	Speed (SH)	Speed (MW)	All Cause	Speed (Total)	Speed (SH)	Speed (MW)	All Cause	Speed (Total)	Speed (SH)	Speed (MW)
2006	1,500	475	316	452	1,680	333	177	1.3	780	129	66	0.20
2007	1,630	500	357	458	1,670	370	206	8.2	850	136	69	0.17
2008	1,430	481	344	456	1,650	357	206	1.2	810	117	56	0.28
2009	1,460	437	309	423	1,540	279	158	0.79	750	105	50	0.15
2010	1,460	468	282	428	1,390	273	156	1.6	690	96	48	0.21
2011	1, 115	321	201	428	1,296	269	156	0.68	620	89	45	0.14

Note: Totals exclude PDO crashes and are not adjusted for non-reporting.

Speed-related crashes represent a disproportionate amount of the total social cost of RTAs because of the higher than average fatality rate associated with them (see figure 11 and Appendix 8). Fatality rates are important in the context of cost analysis because *"loss of life and/or life quality due to permanent impairments (accounts) for approximately 91 percent of the total social cost of injury crashes"* (pii, 47)

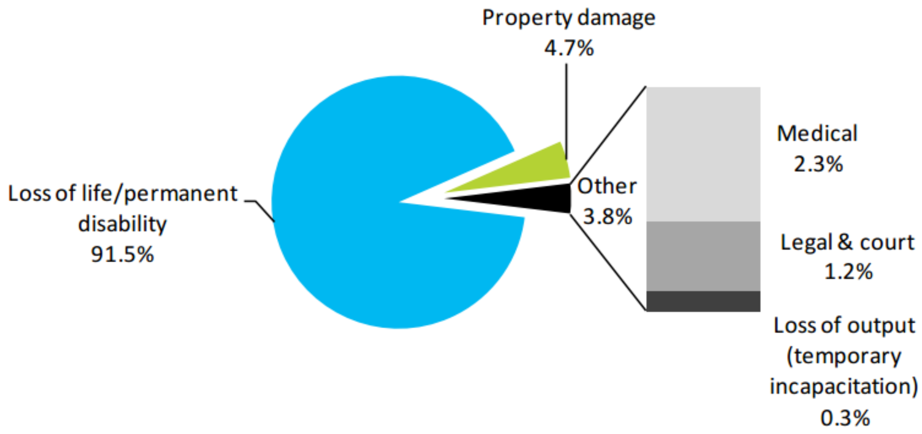

Figure 11: *Share of total cost of injury crashes in 2010 by cost component* (47)*. For a detailed cost component breakdown see Appendix 8.*

The cost of fatalities and permanent disabilities is based on the 1989-90 MoT's willingness-to-pay survey; a valuation technique used to "express pain and suffering from loss of life or life quality in dollar terms" (p.i, 54). The valuation survey essentially asked a group of New Zealanders what they were willing to pay to install a road safety measure that would result in the reduction of one premature death of a family member (55,56). The average figure was described as the 'value of statistical life' (VOSL) and determined, at that time, to be $2 million (56). Inflated to 2011 prices, the VOSL is now estimated at $3.67 million per fatality. While VOSL estimates are in common use internationally (46), there are many problems with this valuation method. For example, it has been shown that people have difficulty dealing with the abstract, small probabilities of traffic risks and that their responses are "critically dependent on how questions are presented, question order, payment vehicle (with tax-funded safety eliciting lower bids), and starting points for bidding" (p.171, 55). Consequently, VOSL estimates can differ significantly, ranging from $150,000 to $30 million USD (at 1997 prices; (46), creating highly heterogeneous valuations of the social costs of accidents (Table 7; (57). Time limitations prevented us from considering a range of valuations and approaches to test the sensitivity of the VOSL estimates.

Table 7: *Comparison of International Health-Care costs associated with road traffic accidents.*

Study	Year of data collection	Geographical location	Social cost model components	Cost per person	NZ value at time of study*	Inflated cost, to current 2011 NZ dollar valueᵠ
Maraste *et al.*(58)	1995	Sweden	Cost of care, short-term loss of production and loss of health	46,200 SEK	9,537.53	13, 829.42
Garcia-Altes & Puig-Junoy (59)	2007	Catalonia, Spain	Primary care, acute hospital care, emergency care, ambulances and transport, long-term care, and specialized care	3,855.38 Euros	6,970.18	7, 876.30
Pérez-Núñez *et al.*(60)	2007	Belize	Pre-hospital care, emergency room services, hospitalisation, ambulatory medical consultations, rehabilitation	169.60 USD	228.14	257.80
Naumann *et al.* (61)	2005	United States of America	Transport to hospital, emergency room, inpatient hospital costs, costs for re-admission, cost for rehabilitation, follow-up care, long-term medical costs, productivity losses	500 USD per licensed driver in USA	714.90	857.88
Riewpaiboon *et al.* (62)	2004	Thailand	Direct medical costs – prevention, detection, treatment, continuing care, rehabilitation and terminal care	102.20 USD	162.53	201.54
O'Connor *et al.* (63)	2007	Northern Queensland, Australia	Acute admission for casualties – including imaging, pathology, nursing, surgical care and intensive care	12,404 AUD	13,870.65	15, 673.83
Pérez-Núñez *et al.* (64)	2007	Jalisco, Mexico	Direct cost of all medical attention, for hospital-admitted patients	584.00 USD	785.58	659.92
Juillard *et al.*(65)	2005	Nigeria	Direct cost of treatment	39.40 USD-disabled 20.84 non-disabled	56.33 29.80	68.00 35.76

*Calculated using http://www.x-rates.com, historical exchange rates calculated as per exchange rate on 1st June of year of data collection (The date of 1st June used as this is an arbitrary midpoint of the year; and this is the corresponding date of data calculations in our present study).

ᵠ Calculated using http://www.rbnz.govt.nz/statistics/0135595.html, with inflation from date of data collection to 2011 dollar values. General Consumer Price Index (CPI); and Q2→Q2 defaults used (as date of calculation falls in the 2nd financial quarter).

Note: All studies calculated cost of RTAs per annum and either divided by the total population or by number of licensed drivers. Cost per person is highly heterogeneous due, in part, to only some of the studies including the cost of fatalities and differing values of statistical life for those that did. For currency conversions see Appendix X.

If we accept the New Zealand MoT's VOSL and social cost valuations as accurate estimates, then we are able to use their figures to approximate the increased social cost associated with increased speeds. If we raised the speed limit from 100km/h to 110km/h on all state highways in New Zealand, we would expect an increase in average speeds from 96.36km/h to 100.36km/h (6). According to Elvik's revision of Nilsson's power model (5), the 4km/h increase would result in an additional 35.4 fatal, 110.6 serious, and 171 minor injury crashes per annum. Based on the 2011 average social costs of injury-related accidents (Appendix 10), we estimate a yearly increase of $251,704,023 to the total social cost of RTAs (see Appendix 11 for calculations). If we were to only increase the speed limit on 100km/h motorways, we would expect an additional 1.2 fatal, 3.5 serious and 16.5 minor injury crashes per annum. This would result in a lesser yearly increase of $9,210,690 to the total social cost of RTAs (see Appendix 12 for calculations).

In 2010 there was an estimated 223,700 PDO crashes, valued at a further $0.61 billion (in 2011 prices; (47). Increasing speeds is also projected to increase PDO crashes by 6.29% (for calculation see equation in section 4.9 and exponent for PDO crashes in appendix 4; (5)).

Property damage only crashes are almost exclusively covered by private insurance. One of New Zealand's leading insurance companies reported repairing 51,930 vehicles for a total of $82,866,461 in the 2011 financial year (66). They could not filter out repairs due to malicious damage or weather/natural disasters from their data set (equal to approximately 10% of the total cost), which unfortunately rendered their figures unsuitable for our purposes. However, these figures do support the high estimates prepared by the MoT for PDO crashes, especially as they represent only one insurer and did not include RTA-related write off/total loss vehicle costs and non-vehicle property damages.

The MoT's model for quantifying the social cost of RTAs is reasonably comprehensive but may be improved upon by the addition of two components, long-term rehabilitation (e.g. physiotherapy) and entitlement claims (80% of salary for period of rehabilitation). The Accident and Compensation Corporation (ACC) provides the funding, through levies, for these two components. By using 2011 claims and projected estimates of spending based on injury type (67),p97) we were able to extrapolate average costs for long-term rehabilitation and entitlement claims for fatal, serious and minor RTAs (fatal RTAs include medical care costs only). As the ACC data also includes acute hospital care, we deducted the MoT's average cost of acute (hospital-based) medical care (2.3%, see Figure 11) from the ACC's figures. After this deduction, we found that the additional number of fatal RTAs associated with increasing the speed limit on all 100km/h state highways would cost an estimated $2,719,301 (See Appendix 13 for calculations). Serious and minor injury crashes were pooled together for a yearly increase of $6,081,927 which makes a total increase of $8,801,228 to the social cost of RTAs (see Appendix 13 for calculations; (67,68)). If we again reserve the speed limit change to 100km/h motorways only, then the increase in social cost is estimated at $92,180 for fatal RTAs and $539,696 for serious and minor RTAs, totalling an additional $631,876 to the yearly social cost of accidents (see Appendix 14 for calculations).

In conclusion, by expanding the MoT's social cost model to include ACC rehabilitation and entitlement claims, and calculating the projected increase in RTAs from increasing speeds, we estimate that increasing the speed limits on all 100km/h state highways would result in an 'additional' $260,505,251 to the total social cost of RTAs (see Appendix 13 for calculations). Limiting the speed limit change to 100km/h motorways would lead to an estimated $9,842,566 increase to the total social cost (see Appendix 14 for calculations).

4.2: Vehicle Operating Costs

Changes in speed impact upon a broader array of economic determinants than RTAs alone. Increased speeds result in altered vehicle operating costs (VOC), which are the direct expenditures imparted to the owner of a private motor vehicle (69). Operating costs can be broken down into: firstly 'fuel related costs', pertaining to the direct fuel consumption of vehicles; and secondly, costs related to the 'maintenance and repair' associated with keeping vehicles on the road (Equation 1).

Equation 1: Vehicle Operating Costs

Vehicle Operating Costs = Fuel Related Cost + Maintenance & Repair Costs

Fuel Related Costs: The cost associated with fuel consumption is related to three main variables. These variables include distance travelled, speed associated fuel consumption, and the direct price of fuel for the consumer (Equation 2).

Equation 2: Fuel Related Cost

Fuel Related Cost =
Speed Associated Fuel Consumption x Cost of Fuel (petrol + diesel) x Distance Travelled

Distance travelled

The distance travelled by a vehicle is directly related to the consumption of fuel, with increased distances consuming more fuel (70). The Vehicle Kilometres Travelled (VKT) on all 100km/h state highways in 2010 was 15,676,000,000km (71); whereas the corresponding VKT on New Zealand motorways alone was 4,419,628,812km (12).

Speed Associated Fuel Consumption

Fuel consumption is known to vary with vehicle speeds, with both very low and high speeds consuming the greatest amounts of fuel (72). Mid-range values between 40-65km/h typically result in the greatest fuel efficiency (72).

The Vehicle Emissions Prediction Model (VEPM) was used to calculate the fuel consumption at our speeds of interest (73). At a speed of 96.36km/h, the model showed a consumption of 10.16L/100km. At a speed of 100km/h, this consumption increased to a value of 10.32L/100km.

Using these values of fuel consumption, we have calculated that the 4km/h increase in average travelling velocity results in an extra 25,081,600 litres of fuel being consumed on state highways; and 7,071,406.1 litres on New Zealand motorways (refer to Appendix 15 for calculations).

It must be noted, that the VEPM only allows a maximum travelling velocity of 100.00 km/hr for calculation of speed associated fuel consumption. This therefore forms a conservative estimate of speed associated fuel consumption, as at our predicted increased velocity of 100.36km/h, we would expect even more fuel would be consumed.

Changes in velocity, both acceleration and deceleration, are known to have significant effects on vehicle fuel consumption (74). In their study, West *et al.* (75) explored this relationship, finding that the amount of fuel consumed was directly related to the rate at which a vehicle accelerated or decelerated. For the purpose of our calculations, we assumed that all vehicles were travelling at constant velocity.

Fuel Cost

The price of fuel differs between petrol and diesel, with diesel typically being sold at a lower price due to a lower demand for the fuel source (76). In 2011, the average price of petrol was $2.08 per litre (or $1.77 exclusive of GST) (77); with 91.5% of the New Zealand car fleet consuming petrol (78). This is compared to diesel, costing an average of $1.50 per litre in 2011 (or $1.28 exclusive of GST) (77); with only 8.5% of the New Zealand car fleet consuming diesel (78).

Our calculations have found that with a speed increase of 4km/h, there is an increase in fuel cost to the value of $43,349,783 on state highways; and an increase of $12,221,865 on New Zealand motorways – in 2011 New Zealand dollar values (refer to Appendix 16 for calculations).

Maintenance & Repair

With regard to vehicle operating costs, vehicle owners typically only perceive the fuel component of operating costs (79); however, the underlying costs of oil, tyres, maintenance, and cost of time spent on maintenance must also be considered (80). The NZTA has assigned a value of $0.11/km for all New Zealand vehicles, regardless of type (79).

The cost of maintenance and repair for distance travelled on all state highways equates $1,724,360,000 and for New Zealand motorways $486,159,169 (refer to Appendix 17 for calculations).

It is assumed that an increase in travelling velocity would result in a greater degree of 'wear and tear' on a vehicle, and thus a greater maintenance and repair cost. However, at present, differences in monetary values for maintenance and repair costs for our speeds of interest are not apparent in the literature. For this reason, we cannot assign differing values to the speeds of 96.36km/hr, and 100.36km/h. Thus, we have assumed that monetary values for maintenance and repair costs at these different speeds are the same.

Summary of VOC

As stated previously, VOC are the direct expenditures imparted to the owner of a private motor vehicle (81). There is an overall increase in VOC with a speed limit change from 100 to 110km/h, with associated average speed change from 96.36 km/h to 100.36km/h. Our projections estimate that the value of VOC would increase on state highways by $43,349,783, and increase by $12,221,865 on New Zealand motorways.

4.3: Revenue from Fuel Tax

The Association of British Drivers argues that an increase in road speed limit would result in a significant increase in tax revenue, due to increased fuel consumption, and thus an economic benefit to treasury (82).The current excise taxes imposed on fuel include (per litre of fuel) the National Land Transport Fund (48.52 cents), ACC Motor Vehicle Account (9.9 cents), Local Authorities Fuel Tax (0.66 cents), and the Petroleum or Engine Fuels Monitoring Levy (0.045 cents) (83).

In addition, Government Sales Tax (GST) is collected on the overall price of fuel including excise. The GST on excise amounts to 7.7 cents per litre (83). There is also an Emissions Trading Scheme charge, at a rate of 3 cents/L (83). Thus, the taxable revenue from petrol amounts to $0.6983 per litre.

There are no Excise Taxes on diesel; however GST remains included in the pump price (83). This means that at the average 2011 diesel price of $1.50/L, 22 cents/L is paid in GST. In addition to GST, the Emissions Trading Scheme charge of 3 cents/L still applies (83). Thus, taxable revenue from diesel equals $0.25 per litre. Instead of excise taxes, diesel vehicles are subject to Road User Charges. As these charges are based on kilometres travelled, changing speed limits will theoretically not impact upon these user fees.

Our calculations have found that a change in speed limits from 100 to 110km/h will result in a net gain of taxable revenue of $16,558,734 per annum for all state highways; and a gain of $5,119,306 for New Zealand motorways (see Appendix 18).

4.4: Implications of Vehicle Emissions

Health and Environmental Impacts

Along with the estimated fuel consumption; vehicle emissions, noise pollution and the resulting impact on health are expected to increase. Road traffic was the largest contributor to CO_2 emissions in New Zealand in 2007, at 33.6% (84). As well as the environmental effects of CO_2, there are vehicle emissions which impact on health. These include carbon monoxide (CO), oxides of nitrogen (NO_X), volatile organic compounds and particles such as smoke, tyre and break wear products. The emission output is altered by road type and traffic behaviour including idling, accelerating, decelerating, cruising, and congestion (85). This creates the relationship shown in Figure 11 between average vehicle speed and emissions, reflecting more congestion at lower speeds and greater work-rate of the engines at higher speeds (85).

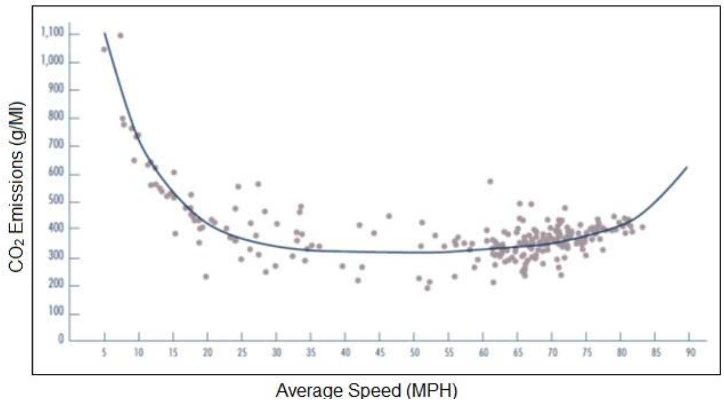

Figure 11. *Emission-speed plot of individual trips* (85).

Using the VEPM (73) an increase of 4km/h to the average speed of the New Zealand motor fleet would result in an overall increase in vehicle emissions (73). The figures used in the model applied a change of speed from 96.36km/h to 100km/h (as 100km/h was the upper limit of the prediction model). This change was modelled including only passenger cars and light commercial vehicles, and accounts for the difference between petrol and diesel vehicles. The VEPM (73) showed a 4.35% increase in CO, 1.82% increase in CO_2, 2.35% increase in NO compounds and 5.83% in particulate matter.

A wide range of important health effects result from motor vehicle use that are beyond the scope of RTAs. These other effects should be involved in the decision for road speed change. Studies around the world have shown an association between multiple indicators of air pollution and mortality, especially due to cardiopulmonary causes. These studies indicate the importance of solid particulate matter and ozone (86).

Economic Cost of Vehicle Emissions

If the speed increase was instituted on all New Zealand motorways, the increased emission values would produce a total economic cost of $980,155 per annum (see Appendix 19 for calculations). If all State Highways with a current 100km/h speed limit were affected, the economic cost would be $3,825,191 per annum. This cost was calculated using output from the VEPM and emissions costs from work by Cameron (3) with adjustments for inflation. Air pollution cost estimates were made on the basis of work by Cosgrove (87), who derived approximate environmental damage costs due to noxious emissions.

Noise Pollution

Increased noise pollution is unlikely to be of importance when increasing the speed limit to 110km/h. The untrained ear generally only detects noise level differences of 3 dB or more, which would require a doubling of traffic volume (72). With a real increase of 4km/h, it is unlikely that there will be any noticeable increase in noise pollution. As such, noise pollution was omitted from our calculations.

4.5: Speed Change Implementation Cost

Akin to vehicle emissions, physically changing road speed limits is a tangible cost. Unfortunately, we were unable to get concrete values from any source, national or local, with regard to what costs our proposed increase in speed limit would incur. We are, however, aware that there are costs that exist and must be considered before the implementation of such a change. In order to actually change a speed limit, a proposal must be submitted by a road controlling authority to persons that may be affected by the proposed speed limit (88). This process includes road side development and general road info surveys. The surveys and proposal then go out for consultation. If traffic calming measures or a pedestrian crossing are required, this requires additional consultations. The results of the consultations, surveys and proposal are then put forth to the regional Regulatory Management Committee who decides whether to enforce the change. If so, the local road controlling authority (local councils) would be responsible for changing the signs (or NZTA on the highway).

4.6: Congestion

"Widening roads to ease congestion is like trying to cure obesity by loosening your belt" - Roy Kienitz, executive director of the Surface Transportation Policy Project (89).

Congestion is when traffic demand slows the speed of the traffic stream. Increasing speed limits leads to a dispersion of traffic, resulting in a reduction in congestion (79,89). However, congestion is a self-limited equilibrium (89). Traffic grows when roads are not congested. This growth declines as congestion develops until equilibrium is reached. If roads are improved to increased capacity, traffic grows until a new equilibrium is achieved (Figure 12).

Induced demand is when consumption of a good increases in response to increased supply. This concept has been applied to the expansion of transportation systems and is referred to as induced traffic. Goodwin (90) found that an average road improvement increased the base traffic volume by 10% in the short term and 20% in the long term. The induced traffic as a result of the upgrade lessens the congestion reduction benefit (89). This will over-estimate the economic benefit of improving road congestion if induced traffic is not taken into account.

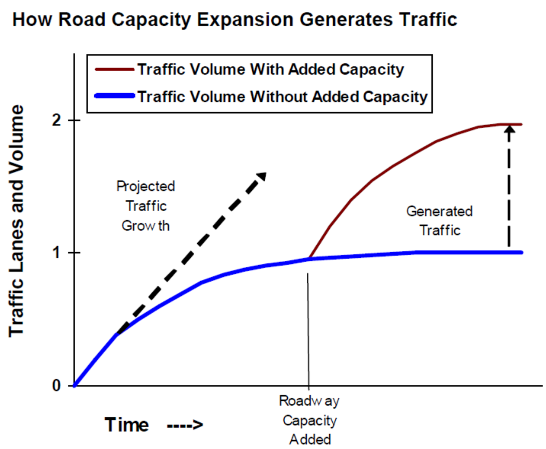

Figure 12: *Demonstrates the additional traffic induced due to road improvements to increase vehicle capacity.* (89)

With this in mind, it is unlikely that much long-term benefit will be gained in reducing congestion by increasing the speed limit to 110km.hr^{-1}, and have therefore selected to not include congestion in our calculations. Mobility, however, will be improved with more cars being able to travel on the roads in a given period as traffic demand increases to meet the increased capacity (89).

4.7: Economic Benefits of Time Savings

The primary advantage of increasing speed limits is time saved on the road. Through surveys, the NZTA have determined that New Zealanders value their time saved commuting on motorways and rural state highways at a rate of \$21.64/h and \$30.92/h, respectively (72); (in 2011 prices-see Appendix X for inflation calculation). Based on kilometres travelled on all 100km/h state highways by passenger cars and light commercial vehicles, we estimate the economic benefit due to time saved from increasing the speed limit to 110km/h to be \$183,518,563 (see Appendix 20) per annum (in

2011 prices; see Appendix 20). If the changes were applied only to motorways, the economic benefit due to time savings would be $39,559,027 per annum (see Appendix 20).

4.8: Total Economic Cost

By aggregating the cost components in our economic model, we conclude that a speed limit increase from 100km/h to 110km/h on all state highways would result in a net loss of 107 million NZD per annum (Table 8.a). Conversely, if the speed limit increase was confined to 100km/h motorways, we could expect net savings of 22 million NZD per annum (Table 8.b).

Tables 8.a and 8.b *Total economic cost of increasing speed limits on state highways or motorways alone.*

a. 100km/h State Highways

Cost Component		2011 NZD
Social Cost	MoT	$251,704,023.00
	Rehab/Entitl	$ 8,801,227.89
VOC-Fuel		$ 43,349,783.36
Emissions		$ 3,456,201.46
Time Saved		-$183,518,563.10
Fuel Tax Revenue		-$ 16,558,734.37
TOTAL COST		$ 107,233,938.24

b. 100km/h Motorways

Cost Component		2011 NZD
Social Cost	MoT	$ 9,210,690.00
	Rehab/Entitl	$ 631,875.56
VOC-Fuel		$ 12,221,864.73
Emissions		$ 948,247.76
Time Saved		-$39,559,026.89
Fuel Tax Revenue		-$ 5,119,305.55
TOTAL COST		-$ 21,665,654.39

The largest contributing component to the negative cost associated with increased speeds is the social cost of accidents (Figure 9). As previously stated, approximately 90% of the MoT's social cost is derived from the loss of life or permanent disability. Therefore, each additional fatality that would invariably occur if the speed limits were raised automatically increases the total cost by 3.67 million (see Section 4.1 for a discussion on the VOSL)The major benefit to society of increasing speed limits is derived from time saved commuting, which should also have a positive impact on congestion (Figure 12). However, the advantages of road improvement measures, such as higher speeds, are often less effective and of a shorter duration than expected due to induced traffic (see section 4.6).

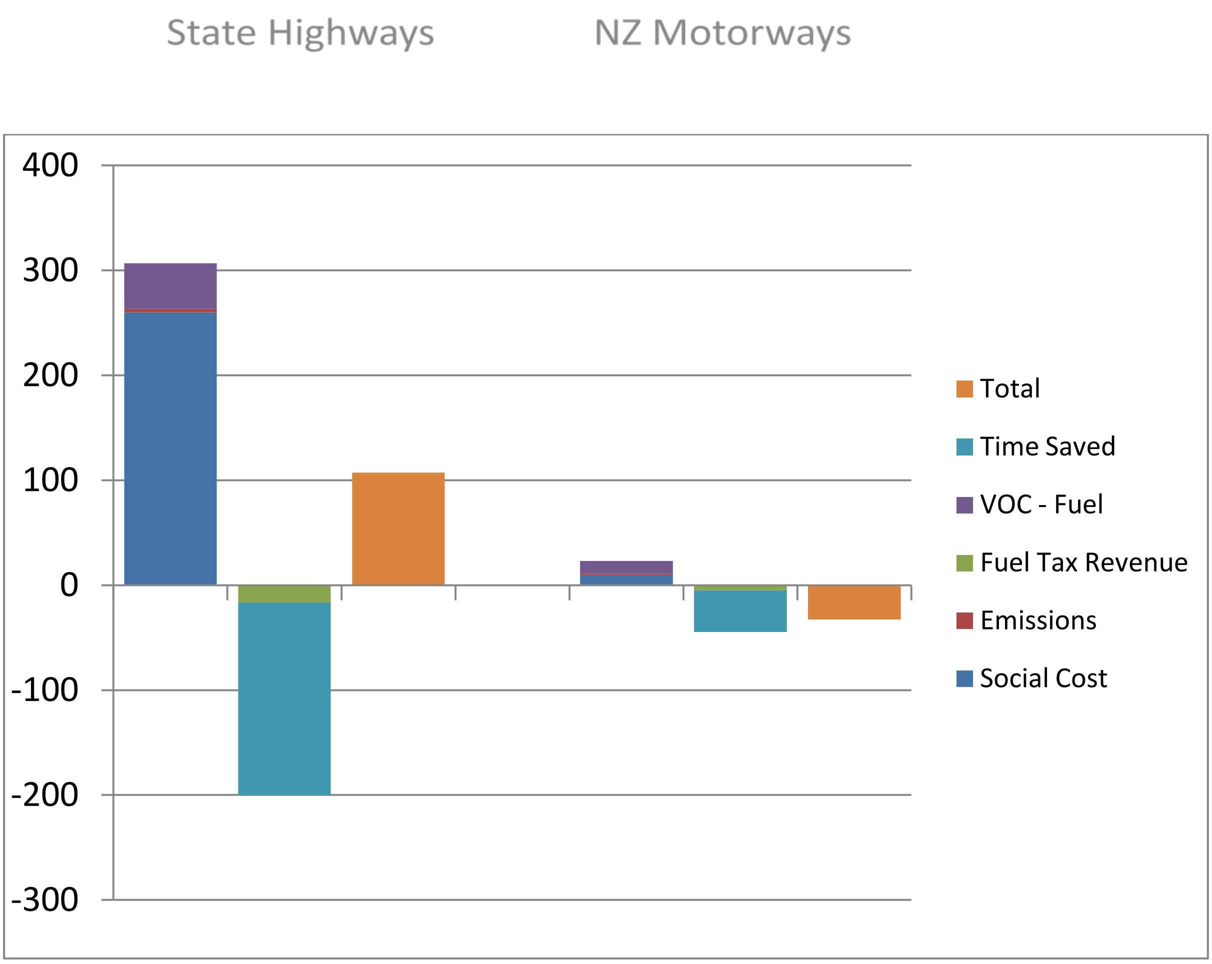

Figure 9: *Total economic costs broken down by positive and negative cost components for increasing speed limits on all 100km/h state highways or motorways alone (in 2011 NZD in millions).*

We acknowledge that a multitude of factors exist, which are not included in our current model, that would have tangible effects on the economic cost of changing speed limits. Much of the missing data was either not available, such as the cost of implementing a change in road signage, or was unobtainable due to the time constraints of the project. Limitations in available data that may have led to an underestimation in the social cost of accidents include being unable to adjust for the number of unreported accidents or incorporate PDO RTAs in to our figures. We assumed close to 100% of fatalities are reported, but as the severity of a crash decreases, so does reporting. While loss of income for the injured accident participants is included in the MoT's social cost calculations, potential losses of earnings for family members who may have to take time off work to act as carers, are not. Not being able to quantify this lost income may also underestimate the social cost of accidents.

Over a decade ago the MoT obtained data from insurance companies to incorporate the cost of vehicle repair in to the social cost of RTAs. Each year these values are inflated to current prices. However, following an accident, in addition to the cost of repairs (including deductable), private insurance premiums increase resulting in a substantial financial burden for the vehicle owner; a cost not included in our model. Our estimated rise in vehicle emissions with increasing speed is likely to be underestimated for the simple fact that the vehicle emissions prediction model only goes up to

100km/h and not 100.36km/h. Lastly, it is recognised by traffic authorities that increasing the speed limit in one zone can result in follow-on speeding in adjoining lower speed-zoned roads. This may result in a larger increase in accidents then presumed from the Elvik's adaptation of Nilsson's power model (5), underestimating both the social cost of accidents and vehicle emissions associated with our proposed speed changes.

Certain factors in our economic model may have led to an overestimation of the social cost of accidents and/or underestimation of the benefit of increasing the speed limit. Employment status of RTA participants are not recorded, which means that a potentially large portion of injured participants may not be eligible for ACC entitlement claims. After the first week of incapacity, ACC may pay out a lump sum compensation and independent allowance, which can be up to 80% of the earners wages (91). Whereas, if you are unemployed, Work and Income New Zealand pay a maximum weekly, non-taxable, disability benefit of $59.12 if your disability is likely to last at least 6 months (92). This may or may not be in addition to a maximum weekly un-employment/sickness benefit of$381.68 (93). The difference between disability benefits afforded by both organisations represents a significant overestimation of ACC entitlement benefits included in our model (see Section 4.1). However, we do not view this particular overestimation as concerning because it makes our results more conservative and our conclusion, that increasing the speed limit on 100km/h motorways is economically viable, more likely to be legitimate. The economic benefit due to time saved is also likely to be a conservative estimate. This is because increased speeds lead to a dispersion of traffic, resulting in a reduction in congestion (79). NZTA publish a value per hour associated with reduced congestion, but anticipating the exact reduction in congestion that we might expect from a 10km/h increase in speed limit was beyond our statistical expertise and we were unable to attain an appropriate model to replicate from our systematic review of the literature.

We recognize that one of our assumptions, that the New Zealand vehicle fleet is comparable to the composite American vehicle used to determine speed-dependent fuel consumption (75), may have resulted in *either* an under- or over-estimation of fuel related costs. The New Zealand vehicle fleet is on average 4-5 years younger and has smaller and more fuel efficient engines than the 8 vehicles used in the study (94). It has also been noted by a leading New Zealand petrol expert that while new vehicles are manufactured with optimal fuel efficiencies at higher speeds, the increasing popularity of sport utility vehicles-notoriously inefficient due to their poor aerodynamics and large engines, is decreasing the expected improvement in average fuel efficiency for the fleet (77). All of these factors have the potential to alter the true value of the VOCs and subsequently, the loss in fuel tax revenue, when changing speeds.

Overall, although there are tangible factors that were unavailable to us or that we were unable to include in our calculations, they are fairly evenly distributed across both the cost and benefit sides of the analysis. In addition, we are confident that crucial cost components have not been erroneously excluded from our economic model, and therefore believe our estimations to be valid despite the aforementioned limitations.

Section 5: CONCLUSION

Based on the results of our economic model, we found that it would be fiscally responsible, resulting in a net savings of 22 million NZD per annum (Table 8.a), to increase the speed limit to 110km/hour on New Zealand motorways. However, applying a like increase on all New Zealand State Highways resulted in a net deficit of 107 million NZD per annum (Table 8.b), primarily due to a significant increase in RTAs. Our advocating for a speed limit increase on motorways comes with a few caveats. We would strongly recommend that: 1) speed surveillance and enforcement of speed limits increase on motorways to reduce the upward trend of speeding; 2) it is implemented as a variable speed increase, which means increasing the speed limit for passenger cars and light commercial vehicles but keeping it at 100km/h for trucks and all vehicles during adverse conditions. After conducting a cost-benefit analysis of speed limit changes on Australian rural (divided) freeways Cameron (3) concluded that a variable speed limit change from 100 to 120km/h would keep social costs below current levels when considering increases in crashes and time saved. This implies that effecting a variable speed limit change on New Zealand motorways would improve upon the net benefit to society by reducing the number of RTAs.

Our study's conclusions are in agreement with the published literature on the societal cost of speeding (3,82,95). The validity of our findings is also supported by the process in which we derived the data. We conducted a comprehensive review of the literature and the NZTA 2010 speed survey results to determine accurate speeds currently travelled at on 100km/h State Highways, and what mean speed we could expect upon change of the speed limit; a level of detail not adopted by all speed studies. We employed widely used, internationally recognised power models for predicting increases in RTAs with increasing speeds (5). The use of these models allowed us to be confident that the numbers used to derive our social cost of accidents calculations are correct. The economic model we devised is comprehensive and also compares favourably to the published literature (3,96). In effect, we were as thorough as possible while working within the limits of the assumptions made and the data available for this study.

While we maintain that our model and therefore conclusions are reproducible, we accept that our efforts have been constrained by certain limitations, resulting in a final product that could be improved upon. Firstly, this research, in its entirety, had to be conducted inside of 4 weeks. Time limitations prevented us from conducting a sensitivity analysis in which we could have incorporated different assumptions and modelling more than one set of estimates. This would have been valuable and added more weight to our conclusions. The time limitations also restricted the amount of data we could acquire. For example, it did not allow for the 20 business day response time for requests made to the Ministry of Social Development (for disability benefit data). In Addition, our budget for conducting this study was exactly $0, which meant that if a document required purchasing, it was not incorporated in to our research. Lastly the statistical demands of our economic model far exceeded our proficiency in this area. This means that had we access to a statistician we may have been able to reduce our list of applied assumptions, which theoretically would have resulted in more precise and accurate cost estimates. Given additional time and resources there are data and further studies we would recommend acquiring and conducting, respectively to improve the accuracy of our model. If this research were to be replicated by an external body, we would suggest that these limitations be addressed.

The potential hazard of increased RTAs associated with our suggested change may be reduced by replicating our study using only motorways on which a speed limit of 110km/h would be appropriate given the design speed of the road. We recognise that while we have attempted to be conservative in our estimates (biased towards an increased cost to society and therefore against increasing the speed limit), valuable information may be derived from reproducing our results at the boundaries of standard error. Follow-on speeding from increased speed zones to lower limit areas is a known phenomenon. Future studies are necessary to determine the effects, and therefore economic impact, of increased speeding in the lower zones. Lastly, prior to a widespread implementation of a speed limit increase, we suggest a trial variable increase be implemented in a smaller region, such as on the Canterbury motorway, the results of which could be analysed to determine if the actual effects are in line with our theoretical estimates.

We caution that our findings need to be considered with an appreciation of the assumptions we have made and the limitations discussed. This financial gain also needs to be weighed against an increase in air pollution and an increase in human mortality and morbidity. Regardless of the value of the net savings, we, like Richter *et al*., (23 p.46) question the *"...flawed ethical paradigm in which intangibly defined gains from time saved results in tolerating losses of human life."*

This ethical issue becomes more pertinent when it is considered that certain groups of society already disadvantaged, such as young Maori, the elderly and people of lower SES, will be disproportionately affected. Additionally, many of the costs associated with increased speeds are borne largely by people other than the driver and fellow-occupants of the vehicle. For instance, air pollution will have a greater effect on those living close to open roads. On the other hand, the financial gain of 22 million NZD per annum from increasing the speed limit on motorways could potentially have a significant positive impact elsewhere, saving far more lives than the increase may cost. For example, 20 million NZD would cover the running costs of an urban emergency department (such as Wellington) for 6 months, treating over 25,000 patients during that time (97). In conclusion, while we recognise the potential ethical considerations of implementing measures that may increase mortality and morbidity we recommend that a variable increase in speed limits on suitable motorways be entertained by the Ministry of Transport.

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Section 7: APPENDIX MATERIAL

SECTION 1

Appendix 1: Assumptions

1. The international data and models are applicable to New Zealand
2. That using the average annual value for free speed and motor vehicle accidents and casualties from the most recently available five year period (2006-2010 as 2011 data is yet to be formalised for some accident categories) is appropriate for the purpose of this analysis. This was chosen as it incorporates a large enough data set to minimise the effect of any outliers but is still within a recent time period such that there will have been minimal changes to vehicles and roads.
3. The road design and features have not changed significantly over the previous 5 years and will not change in the future.
4. Weather conditions have been consistent over the previous 5 years and will not change in the future
5. Steady speeds are travelled at all times
6. When driving, there is no braking for curves
7. With a change in speed limit from 100-110km/hour, the change in mean speed will rise by 4km/hour
8. Congestion before the change in speed limit will be comparable to congestion after the change.
9. People within different population demographics will not respond differently to the change in speed limit.
10. That the roads have level gradients,
11. That steady inflation rates can be applied across all variables
12. Our final values are GST exclusive
13. That the proportion of petrol vs diesel cars on 100km highways are equivalent to that in all of New Zealand
14. Cars that run on LPG and electric are so few that they do not need to be factored into our fuel or emissions analysis.
15. That the definitions of fatal, serious and slight injury accidents and casualties used by the different data sources are consistent. As discussed by IRTAD (98), the definition of the severity of an injury varies from country to country, however, as we are only forming an estimate, the New Zealand definition is consistent enough with international definitions for our purposes.

SECTION 2

Appendix 2:

Search Engines:

1. TRID (Transport Research International Documentation)
2. Google Scholar
3. Scopus

Search Strings:

1. “speed limit change”
2. “speed limit”
3. “speed limit effectiveness”
4. “change in speed limit”

SECTION 3

Appendix 3:

Literature review on the effect of speed on road safety and the effect of an increase in speed on road safety

Search engines

Google Scholar search strings:
1. power model "meta analysis" vehicle crash "speed Limit"
2. "natural experiment" vehicle speed crash injury death

TRID (Transport Research International Documentation) search strings:
1. Speed and limit and crash and death

Grey literature search

OpenGrey search strings:
1. “Speed limit”
2. “Speed accident”

WHO
1. Speed
2. Road traffic accident

New Zealand Ministry of Transport
1. speed
2. death

International Transport Forum OECD

1. speed and injury and crash and death

NZTA
1. " Speed"

Appendix 4:

Elvik's 2009 Power estimates for rural roads and freeways		
Accident or injury severity	**Best estimate of exponent**	**95% confidence interval**
Crashes*		
Fatal crashes	4.1	(2.9, 5.3)
Serious injury	2.6	(-2.7, 7.9)
Slight injury	1.1	(0.0, 2.2)
Property damage only	1.5	(0.1, 2.9)
Casualties		
Fatalities	4.6	(4.0- 5.2)
Seriously injured	3.5	(0.5-5.5)
Slightly injured	1.4	(0.5-2.3)

Figure (number). Elvik's 2009 Power estimates for rural roads and freeways (5)

*Crashes are classified based on the worst injury that occurs in the crash.

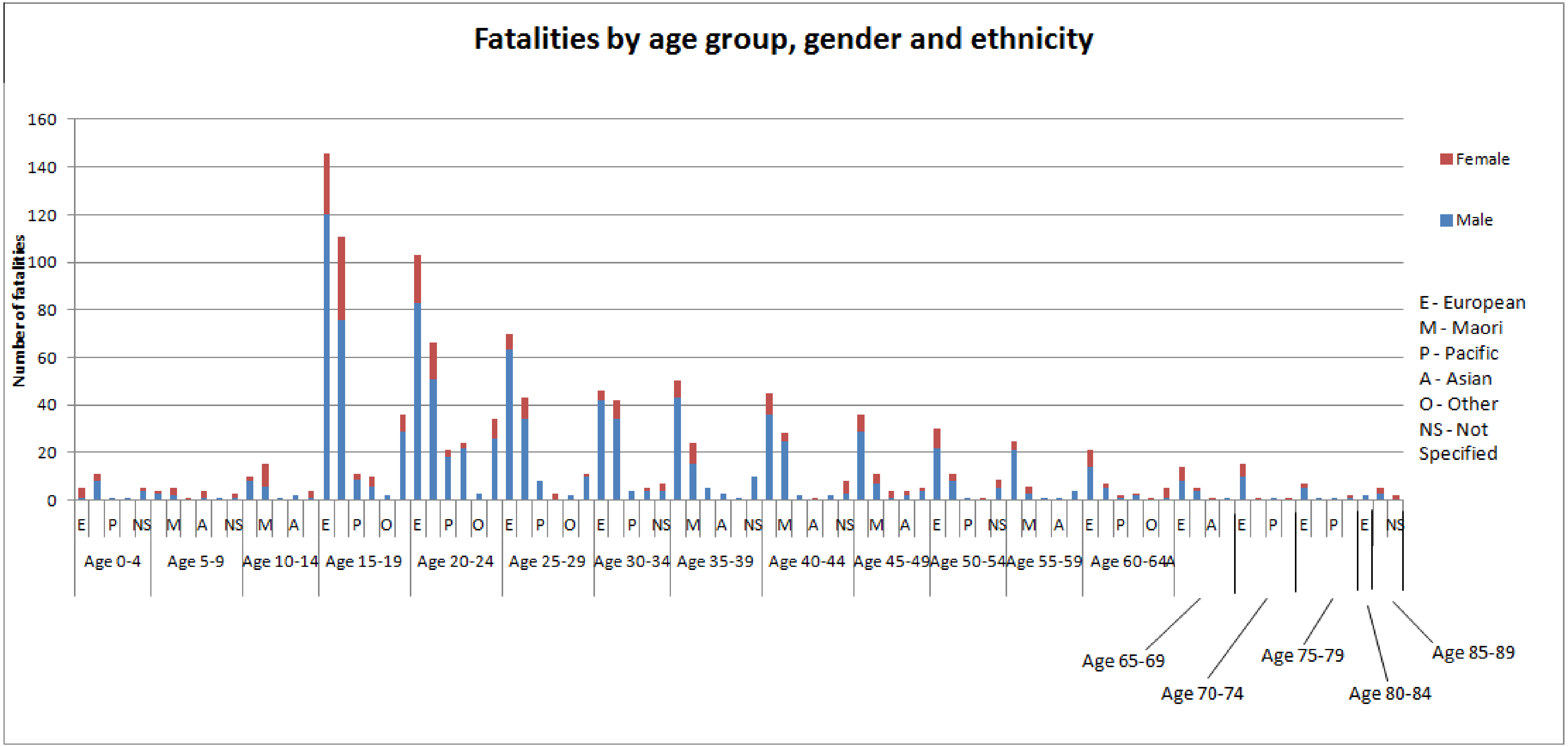
Appendix 5:

The premise of Nilsson's power model is the physics law is based on the following probabilities:

(a) The probability of a personal injury accident in the road system reported by the police is proportional to the square of the speed, which is a shortened formula for the kinetic energy.

(b)The probability of a fatal accident resulting from a personal injury accident is also proportional to the square of the speed, which means that the number of fatal accidents is proportional to the fourth power of the speed (v^4) (Reviewed in (1)).

Appendix 6:



Graph X Speed related crash Fatalities for the period 2002-2010 by age group, gender and ethnicity. Crashes were classified by police as speeding or going too fast for the conditions. Not age standardised. Drawn from data obtained from the MoT (34)

SECTION 4

Appendix 7 – Search engines, search strings and websites used to conduct a systematic review of the literature

Search Engines:

1. Transport Research International Documentation (TRID)
2. Google Scholar
3. Google
4. Ebsco
5. Proquest

Search Strings:

1. “speed limit” and road
2. “speed limit” and road and “economic benefits”
3. “speed limit” and road and “economic benefits” and “time saved”
4. “road toll” and “economic”
5. England and “speed limit change” and economics
6. “road accidents” and economics
7. “road accidents” and “health care”
8. “road accidents” and medical
9. “traffic accidents” and economics
10. “traffic accidents” and “health care”
11. “traffic accidents” and medical
12. "speed" and "health care"
13. "speed" and "cost"
14. "road traffic accident & "health cost"
15. "road traffic injury" & "health cost"
16. "motor vehicle accident" & "health cost"

Websites:

1. New Zealand Ministry of Transport - http://www.transport.govt.nz/
2. New Zealand Transport Agency - http://www.nzta.govt.nz/
3. Accident & Compensation Corporation - http://www.acc.co.nz/
4. New Zealand Ministry of Health - http://www.health.govt.nz/
5. The Association of British Drivers - http://www.abd.org.uk/

Appendix 8– Table: Share of average cost per accident (all cause) by cost component (53)

Social Cost Components	Rural Crashes			Urban Crashes		
	Fatalities	Serious Injuries	Minor Injuries	Fatalities	Serious Injuries	Minor Injuries
Loss of life/ permanent disability	98.95%	93.34%	69.83%	99.04%	93.61%	71.64%
Loss of output/ temporary disability	0.02%	0.35%	1.18%	0.01%	0.34%	1.22%
Medical -						
Hospital/Medical	0.19%	2.19%	0.58%	0.16%	2.20%	0.59%
Emergency/ Pre-hospital	0.09%	0.33%	2.98%	0.09%	0.31%	3.06%
Follow on	0.05%	1.08%	0.49%	0.03%	1.08%	0.50%
Legal and court	0.43%	1.06%	2.76%	0.45%	1.16%	3.08%
Property damage	0.26%	1.65%	22.17%	0.21%	1.30%	19.92%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Appendix 9 – Exchange rate calculations for international comparisons of RTA health costs

Study Currency → NZD	Date of exchange rate used	Exchange rate (sourced from: http://www.x-rates.com)
Swedish Krona → NZD	01/06/1995	0.20644 NZD
Euro → NZD	01/06/2007	1.80791 NZD
USD → NZD	01/06/2004 01/06/2005 01/06/2007	1.59033 NZD 1.4298 NZD 1.34517 NZD
Australian dollar → NZD	01/06/2007	1.11824 NZD

Year of Cost to be Inflated	Inflated 2011 NZD Value (per dollar) (http://www.rbnz.govt.nz/statistics/0135595.html - CPI, and Q2-Q2 utilised)
1995	1.45
2004	1.24
2005	1.20
2007	1.13

Appendix 10 - Table: Average social cost per crash by injury type for all causes in 2011 prices (adapted from* (53)*).

Year	Fatalities	Serious Injuries	Minor Injuries
	All Cause	All Cause	All Cause
2001	$4,384,000	$ 807,000	$ 90,000
2002	$4,384,000	$ 807,000	$ 90,000
2003	$4,385,000	$ 746,000	$ 91,000
2004	$4,480,000	$ 784,000	$ 93,000
2005	$4,462,000	$ 783,000	$ 94,000
2006	$4,419,000	$ 785,000	$ 92,000
2007	$4,316,000	$ 793,000	$ 89,000
2008	$4,331,000	$ 790,000	$ 85,000
2009	$4,322,000	$ 749,000	$ 80,000
2010	$4,322,000	$ 749,000	$ 80,000
2011	$4,322,000	$ 749,000	$ 81,064

Note: Year-to-year variations are due to

(1) variations in the average number of injuries per crash (for each crash type) over time; and

(2) *variations in the level of under-reporting (for serious and minor crashes only) over time*

Appendix 11 – Projected increase in social cost by injury type on all 100km/h state highways

5-year projected increase in number of accidents by injury type / 5 years = yearly increase
Average social cost by injury type x projected yearly increase in number of accidents by injury type

Fatal (177/5=35.4)
$4,283,080 x 35.4 = $151,621,032

Serious (553/5=110.6)
$778,889 x 110.6 = $86,145,123

Minor (855/5=171)
$81,508 x 171 = $13,937,868

***Total projected increase in social cost** = Fatal + Serious + Minor*
= $151,621,032 + $86,145,123 + $13,937,868
= $251,704,023

Appendix 12 – Projected increase in social cost by injury type on all 100km/h motorways

Average social cost by injury type x projected yearly increase in number of accidents by injury type

Fatal
$4,283,080 x 1.2 = $5,139,696

Serious
$778,889 x 3.5 = $2,726,112

Minor
$81,508 x 16.5 = $1,344,882

Total projected increase in social cost *= Fatal + Serious + Minor*
= $5,139,696 + $2,726,112 + $1,344,882
= $9,210,690

Appendix 13 – Projected increase in social cost, with inclusion of rehabilitation and disability benefits, on all 100km/h state highways

Acute medical costs already factored into MoT social cost (0.23%, 3.6% and 4.05% derived from Figure 11)

Fatal = $151,621,032 x 0.0033 = $500,349.41
Serious = $86,145,123 x 0.036 = $3,101,224.43
Minor = $13,937,868 x 0.0405 = $564,483.65
Serious + Minor = $3,665,708.08

[(Average cost of Rehabilitation + Average entitlement benefit by injury type)/Number of claims-Acute medical cost factored into MoT social cost] x projected increase in number of accidents by injury type* (67)*,p.97)]*

Fatal
($31,287,000 / 344) x 35.4 – $500,349.41 = $2,719,301.17

[(Average cost of Rehabilitation + Average entitlement benefit by injury type)/Number of claims – Acute medical cost factored in to MoT social cost] x projected increase in number of accidents by injury type (67)*,p.97)]*

** Includes - Serious, Medical only, Time off Work and Other recovery figures*

Serious + Minor
[($856,577,000 + 23,437,000 + 322,632,000 + 75,208,000) / (108 + 31,578 + 3,753 + 1,477)] x (110.6 + 171) – $3,665,708.08
= $6,081,926.72

Total increase due to rehabilitation and disability benefits = $2,719,301.17 + $6,081,926.72
= $8,801,227.89

Total increase in social cost due to increasing speed limits on all 100km/h state highways
= MoT injury RTAs + ACC related rehab/entitlement claims
= $251,704,023 + $8,801,227.89
= $260,505,250.90

Appendix 14 – Projected increase in social cost, with inclusion of rehabilitation and disability benefits, on all 100km/h motorways

Acute medical costs already factored in to social cost (0.23%, 3.6% and 4.05% derived from Figure 11)

Fatal = \$5,139,696 x 0.0033 = \$16,961.00
Serious = \$2,726,112 x 0.036 = \$98,140.03
Minor = \$1,344,882 x 0.0405 = \$54,467.72
Serious + Minor = \$152,607.75

[(Average cost of Rehabilitation + Average entitlement benefit by injury type)/Number of claims-Acute medical cost factored in to MoT social cost] x projected increase in number of accidents by injury type* (67)*,p.97)*

Fatal
(\$31,287,000 / 344) x 1.2 – \$16,961.00 = \$92,179.70

[(Average cost of Rehabilitation + Average entitlement benefit by injury type)/Number of claims – Acute medical cost factored in to MoT social cost] x projected increase in number of accidents by injury type (67)*,p.97)*

** Includes - Serious, Medical only, Time off Work and Other recovery figures*

Serious + Minor
[(\$856,577,000 + 23,437,000 + 322,632,000 + 75,208,000) / (108 + 31,578 + 3,753 + 1,477)] x (3.5 + 16.5) – \$152,607.75 = \$539,695.86

Total increase due to rehabilitation and disability benefits = \$92,179.70 + \$539,695.86
= \$631,875.56

Total increase in social cost due to increasing speed limits on all 100km/h motorways
= MoT injury RTAs + ACC related rehab/entitlement claims
= \$9,210,690 + \$631,875.56
= \$9,842,565.56

Appendix 15: Fuel consumed on roads of interest

$$\text{Fuel consumed} = \frac{\text{Vehicle Kilometres Travelled}}{\text{Fuel consumption distance unit}} \times \text{Speed associated fuel consumption}$$

State highways

$$96.36\text{km/h} = \frac{15{,}676{,}000{,}000}{100} \times 10.16 = 1{,}592{,}681{,}600 \text{ Litres}$$

$$100.00\text{km/h} = \frac{15{,}676{,}000{,}000}{100} \times 10.32 = 1{,}617{,}763{,}200 \text{ Litres}$$

Difference = 25,081,600 Litres

NZ motorways

$$96.36\text{km/h} = \frac{4{,}419{,}628{,}812}{100} \times 10.16 = 449{,}034{,}287.3$$

$$100.00\text{km/h} = \frac{4{,}419{,}628{,}812}{100} \times 10.32 = 456{,}105{,}693.4$$

Difference = 7,071,406.1 Litres

Appendix 16: Total fuel costs on roads of interest

Fuel cost = (litres of fuel consumed x % of fleet petrol) x Price of petrol
+ (litres of fuel consumed x % of fleet diesel) x Price of diesel
= Total fuel costs

State highways

(25,081,600 Litres x 0.915) x 1.77/L petrol
+ (25,081,600 Litres x 0.085) x 1.28/L diesel
= $43,349,783.36

NZ motorways

(7,071,406.1 Litres x 0.915) x 1.77/L petrol
+ (7,071,406.1 Litres x 0.085) x 1.28/L diesel
= $12,221,864.73

Appendix 17: Maintenance & repair cost for distances travelled on roads of interest

All State Highways

15,676,000,000 km x $0.11 = $1,724,360,000

NZ Motorways

4,419,628,812 km x $0.11 = $486,159,169.32

Appendix 18: Revenue from fuel tax associated with speeds of interest

Tax revenue = (litres of fuel consumed x % of fleet petrol) x Taxable revenue from petrol
+ (litres of fuel consumed x % of fleet diesel) x Taxable revenue from diesel
= Taxable revenue from fuel consumed

State highways

(25,081,600 Litres x 0.915) x $0.6983
+ (25,081,600 Litres x 0.085) x $0.25
= $16,558,734.37

NZ motorways

(7,071,406.1 Litres x 0.915) x $0.6983
+ (7,071,406.1 Litres x 0.085) x $0.25
= $5,119,305.55

Appendix 19: Calculation of the economic cost of vehicle emissions

	Difference in Vehicle Emissions from VEPM (tonnes)		Economic Cost of Emissions ($NZ, 2003)		Adjustment of cost for Inflation ($NZ)	
Vehicle Emissions	Motorways	All State Highways	Motorways	All State Highways	Motorways	All State Highways
CO	839.73	2,978.44	1,897.79	6,731.27	2,491.25	8,836.21
CO2	19,357.97	68,660.88	481,239.13	1,705,417.88	527,144.47	1,869,730.92
NO	88.39	313.52	173,792.42	616,443.02	201,893.10	809,211.48
PM	10.61	37.62	165,092.66	585,370.96	216,718.94	786,422.85
				Total Economic Cost ($NZ)	948,247.76	3,456,201.46

*Adjustment for inflation from Reserve Bank of New Zealand (2012)(99)

Appendix 20: Calculation

***$/hr Inflation Calculation** (72)*

- $/hr is a value given to time savings made while travelling.

- $/hr for motorways for all time periods (2002) = 16.27
- $/hr for rural strategic for all time periods (2002) = 23.25
- Inflation rate per year = 1.33*

- $/hr motorways (Inflated) = 21.64
- $/hr rural strategic (Inflated) = 30.92

Time Saved Calculation

$$t = \frac{d\ (km)}{v\ (km.hr^{-1})}$$

- VKT is the vehicle kilometres travelled for all state highways for the year 2010. VKT On all 100km/h state highways in 2010 was 15,676,000,000km (71); whereas the corresponding VKT on New Zealand motorways alone was 4,419,628,812km (12). This means the VKT on Rural Strategic roads was 11,256,371,190km (VKT on All 100km/h state highways – VKT on motorways).
- Velocity change of 4km.hr^{-1} originates from reports that find there is a real change of 4km.hr^{-1} for every 10km.hr^{-1} increase in speed limit (see section 2).

Motorways

$$t = \frac{VKT * 365}{v\ (original)} - \frac{VKT * 365}{v\ (new)}$$

$$= \frac{4,419,628,812km}{96.36km.hr^{-1}} - \frac{4,419,628,812km}{100.36km.hr^{-1}}$$

= 1,828,051.15hr per year

Rural Strategic

$$t = \frac{VKT * 365}{v\ (original)} - \frac{VKT * 365}{v\ (new)}$$

$$= \frac{11{,}256{,}371{,}190km}{96.36km/hr} - \frac{11{,}256{,}371{,}190km}{100.36km/hr}$$

= 4,655,871.155hr per year

Economic Benefit Calculation

Motorways

$ saved = hr saved per year*$/hr (2010)
= 1,828,051.15*21.64
= $39,559,026.89 per year

Rural Strategic
$ saved = hr saved per year*$/hr (2010)
= 4,655,871.155*30.92
= $143,959,536.1 per year

All State Highways
$ saved = Motorways Savings + Rural Strategic Savings
= $39,559,026.89 + $143,959,536.1
= $183,518,563.1 saved per year