Time and fuel effects of different travel speeds

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An important note for the reader

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Abbreviations and acronyms

ANOVA	analysis of variance
CI	confidence interval
ECMT	European Conference of Ministers of Transport
EPA	US Environmental Protection Agency
ETSC	European Transport Safety Council
km/h	kilometres per hour
LPG	liquefied petroleum gas
MoT	Ministry of Transport (New Zealand)
mph	miles per hour
nd	no date (of publication)
OBDII	onboard diagnostic ports
OECD	Organisation of Economic Co-operation and Development
SD	standard deviation
SPSS	Statistical Package for the Social Sciences
Transport Agency	New Zealand Transport Agency

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Executive summary

Background

In 2010, the then Minister for Transport (Hon Steven Joyce), assisted by the Associate Minister of Transport (Hon Nathan Guy), launched the *Safer Journeys* strategy, which identified the vision of a New Zealand road system increasingly free of death and serious injury. In 2014, 295 people were killed and 2,709 people had hospital stays as a result of road traffic injury. The social cost of crashes on New Zealand's roads in 2013 was $3.12 billion. Regardless of what causes a crash, speed determines the impact of the crash and the severity of the injury.

The relationship between speed and travel time is an important part of the conversation on speed because decisions to speed may be based on the desire to save time. For example, a survey of New Zealand drivers found one-third agreed when they speed it is because they want to get where they are going sooner. The theoretical relationship between mean travel speed and travel time is straightforward. The effect of a reduced maximum speed limit on mean speed, travel time and fuel consumption in real driving conditions is less clear. The New Zealand road network differs from those in many other countries, for example in the number of motorways, tortuous sections and hills. Drivers travel at the highest speeds in open road situations, but speed choice is also important in urban environments where there are frequent intersections and hazards. Half of the deaths and serious injuries from road crashes occur in towns and usually at intersections.

Data collection method

This project investigated the effect of setting different maximum speed limits on mean speed, actual fuel consumption and travel time for six different New Zealand routes in real driving conditions. The six selected routes included three short urban routes and three long routes chosen to be representative of metro driving or open road driving across a variety of road classifications. The short urban routes, one in Auckland (12km) and two in Wellington (10km and 6km respectively) were driven at 40km/h and 50km/h for between 102 and 120 times. The long routes, Auckland to Tauranga (211km), Hastings to Levin (197km) and Christchurch to Kaikoura (178km), were driven at 80km/h, 90km/h and 100km/h between 40 and 42 times. Trips were only included in the final dataset where the drivers stayed below the trip maximum speed limit plus a 2km/h margin of error for 95% of the driving time excluding idle periods.

One driver was employed for each route. All routes were driven in different vehicles of the same model, 2013 Toyota Corollas, with data loggers that connected to their vehicles.

Findings

1 **Mean speed** decreased when the maximum speed limit was decreased, but by a smaller proportion.

Decreasing the maximum speed on the long routes by 20% from 100km/h to 80km/h decreased mean speed by between 8% and 12%. The same percentage decrease in maximum speed on the short routes (20%, from 50km/h to 40km/h) decreased the mean speed by 9% on Wellington short route one, 7% on Wellington short route two, and 14% in Auckland. Drivers' speed is not just dictated by the maximum limit in real-world driving. This difference in the size of the decrease in maximum and mean speeds is likely to be explained by factors such as traffic, road conditions and intersections that prevented the drivers travelling at the maximum trip speed.

2 **Travel time:** Decreasing maximum speed had a strong effect on travel time. Travel time increased by a smaller proportion than the decrease in maximum speed.

Results across all of the routes tested in this study consistently demonstrated that decreasing maximum trip speed increased travel time. However, the extent of the increase in travel time varied. On the long routes drivers spent much of their driving time at cruising speeds close to the maximum speed, but travel time still increased by a smaller proportion than the reduction in the trip maximum speed. The potential effects of other factors (traffic and weather) on speed and travel time were explored but most of the travel time variation was explained by the change in maximum speed. On the short routes and two of the three long routes, idle time and travel time were strongly correlated. However, there was no significant difference in the amount of idle time when comparing the tested speeds.

Taken together, the results show that trip maximum speed limits have a strong effect on travel time; however, increase in travel time is not equally proportional to the decrease in travel speed. Other factors, such as traffic volumes and number of controlled intersections, affect travel time in urban routes to a greater extent than long distance trips. The evidence for a strong and consistent relationship between travel time and maximum trip speed on long routes in real driving conditions provides useful information for understanding the effect that speed limit modifications may have on drivers' fuel consumption and travel time.

3 **Fuel consumption** was closely related to maximum speed, with higher maximum speeds leading to higher fuel consumption on all but one route. Lower maximum speed decreased fuel consumption by a smaller proportion than the decrease in mean speed on two of the short routes. However, the decrease in fuel consumption was larger than the decrease in mean speed on the long routes.

Fuel consumption and maximum speed were highly correlated with on all three of the long routes. Maximum speed was a significant predictor of increased fuel consumption on all three long routes. Higher ratings for the effect of weather predicted increased fuel consumption on two of the three long routes and idle time predicted higher fuel consumption on one route. The findings suggest the effect of factors such as weather and traffic may be more substantial if they were recorded with more sensitivity. However, it is clear that adopting the higher speeds had a strong and consistent effect on fuel consumption.

On the short routes, there was less consistency. Five percent and 3% decreases were identified on the Wellington short routes. Pulling over to allow following traffic to pass at the lower speed could have increased fuel consumption, closing the gap between the lower speed and the higher speed. As with travel time, factors other than maximum speed had a greater effect on the short routes than on the long routes. Traffic density, traffic light stops and idle time were important variables in understanding fuel consumption. This is consistent with evidence in the literature that 'stop-and-go' driving, where the driver is frequently decelerating at delay points and subsequently accelerating, can result in higher fuel consumption.

Higher trip maximum speed predicted increased fuel consumption on the two Wellington short routes but not the Auckland short route. The Auckland short route in particular was dominated by factors causing the driver to come to a complete stop such as traffic lights and pulling over for other drivers. Increased idle time predicted higher fuel consumption on all three short routes. Though it was an important factor in predicting fuel consumption, there was no significant difference in the idle time recorded between the different maximum speeds.

4 **Variation within and between routes:** The routes had different characteristics and drivers encountered different challenges, leading to variation in results across routes.

There was more variation recorded in fuel consumption and travel time on the short routes than the long routes. On the short routes, idle time and traffic ratings were significant predictors of fuel consumption, highlighting the influence of factors other than trip maximum speed. The direction of travel was also an important variable. That these factors were significant emphasised the effect that small variations in the driver's experience on each trip had on fuel consumption and travel time. Short delays, such as those caused by a traffic light or another driver parking, could have relatively large effects on the measurements for those trips.

Differences across routes may be attributable to factors which were not controlled by the method adopted for this project. While the vehicles were of the same model, driver technique can play a role in the amount of fuel consumed and travel time. As the drivers were different for each route, differences in the figures for fuel consumption and travel time savings between routes could be a result of differences between the drivers. Driving style can account for large variance in fuel consumption.

There was also variation in the type of terrain covered by each of the routes. All three long routes had sections through the outskirts of major cities and sections where the nature of the road limited speed.

5 **Safety:** Speed is an important factor in all crashes in both urban and open road environment**s.**

Any discussion of different travel speeds and their time and fuel costs must acknowledge the well-established relationship between travel speed and safety. The relationship has two important aspects: the effect of speed on the risk of crashing and the effect of increased speed on the severity of a crash should one occur. Increasing speed increases both the risk of crashing and the severity of crashes should they occur. The relationship between speed and safety is important in both urban environments and open road environments.

Conclusion

The results of this study demonstrate that decreasing maximum travel speed results in decreases in mean speed but by a smaller proportion than may be expected. Decreasing maximum speed increases travel time but by a smaller proportion. Fuel consumption decreased on five of the six tested routes as the maximum speed was reduced. The proportion by which fuel consumption decreased was less than the proportionate decreases in mean speed on two of the three short, urban routes but was greater than the proportionate decreases in mean speed on all three long routes.

This information will inform the conversation on the costs and benefits of different speed limits. It is, however, important to note that any conversation about the costs and benefits of different speeds on travel time and fuel consumption takes place in the context of the well understood safety consequences of increased speed. Speed plays a part in every crash. Speed determines the impact of the crash and the severity of the injury.

This project provided evidence that for six different New Zealand routes in real driving conditions the benefits of reducing fuel consumption and the costs of additional travel time as a result of decreasing maximum speed were less than expected based on theoretical prediction of travel time.

Abstract

This project investigated the effect of different maximum trip speeds for six New Zealand routes. The study recorded actual mean speeds, time taken and fuel used. Speeds of 40km/h and 50km/h were tested on three short routes and speeds of 80km/h, 90km/h and 100km/h were tested on three long routes.

On the short routes, decreasing maximum speed decreased mean speed by 7% to 14% and increased travel time by 8% to 15%. Trips at 40km/h used 3% to 5% less fuel on the two Wellington routes but the difference in fuel used was not significant on the Auckland route. On the long routes, reducing trip maximum speed to 90km/h and 80 km/h reduced mean speed and increased travel time across all routes. Reducing maximum speed from 100km/h to 80km/h reduced mean speed by 8% to 12%, increased travel time by 9% to 13% and decreased fuel consumption by 14% to 15%.

Both fuel consumption and travel time were strongly correlated with trip maximum speed on the longer routes. Maximum speed was a significant predictor of fuel consumption and travel time on the short routes but traffic and idle time also had significant effects. This project has provided evidence of the effect on fuel consumption and travel time of decreasing maximum speed.

1 Introduction

1.1 Background

Each year the Ministry of Transport conducts a survey monitoring the free speed of unimpeded vehicles in both 100km/h and 50km/h speed limit areas. Although the mean free speed of New Zealand drivers in both areas has decreased over the decade between 2001 and 2013, there has been little change in recent years. Despite extensive investment in strategies to reduce speeding, the 85th percentile mean free speed[1] of New Zealand drivers on the open road in 2013 was higher than the posted speed limit in 100km/h areas. One in four drivers was travelling over the speed limit (table 1.1).

Table 1.1 Mean and 85th percentile free speed of unimpeded New Zealand drivers on the open road (speed limit 100km/h) and percentage of drivers travelling over 100km/h

	2006	2007	2008	2009	2010	2011	2012	2013	2014
Mean speed (km/h)	96.4	96.3	96.6	96.3	96.2	96.5	95.6	95.7	95.3
85th percentile (km/h)	103	103	103	103	103	103	102	102	101
Percent travelling over 100km/h	32%	29%	30%	29%	29%	31%	25%	25%	22%

Source: MoT (2014a)

New Zealand is no different from other countries in this regard. A number of international studies show that speeding is a concern in many countries. For example, in 2013 in the United Kingdom 47% of cars in free-flow conditions were exceeding the 70m/h speed limit on motorways and 39% on dual carriageways (Department for Transport 2013).

1.1.1 Effect of speed on safety

In 2010, the then Minister for Transport (Hon Steven Joyce), assisted by the Associate Minister of Transport (Hon Nathan Guy), launched the *Safer Journeys* strategy, which identified the vision of a New Zealand road system increasingly free of death and serious injury. Managing speed to safe levels is crucial to reducing deaths and serious injuries because the results of all crashes are strongly influenced by impact speed. Any discussion of the costs and benefits of different travel speeds must acknowledge the well-established relationship between travel speed and safety. The relationship has two important aspects: the effect of speed on the risk of crashing and the effect of increased speed on the severity of a crash should one occur.

Increasing speed at impact in any crash exponentially increases the amount of energy released, making speed an important factor in determining the severity of any crash. The effect of the relationship between speed and kinetic energy is demonstrated in New Zealand statistics showing that the more serious the crash, the more likely it is that driving too fast for the conditions was a contributing factor (MoT 2014a).

Estimates for the extent of the increased risk vary. A study in Adelaide found that in a 60km/h speed limit area in an urban environment, the risk of involvement in a casualty crash doubled with each 5km/h increase in travelling speed above 60km/h (Kloeden et al 1997). The power model describes the

[1] Free speeds are measured when vehicles are unimpeded by the presence of other vehicles (that is, there is some distance between a vehicle travelling at a free speed and the vehicle in front of it) or by environmental features such as traffic lights, intersections, hills, corners or road works (MoT 2015).

relationship between speed and road safety. While most recent analysis has shown that the degree of the increase in risk resulting from increasing speed varies with initial speed and road type, the model shows that the higher the speed, the greater the number of crashes and the greater the injury severity (Elvik 2009). Based on Nilsson's power model, a 1% reduction in average open road speed from 100km/h to 99km/h is associated with a 4.0% reduction in fatal crashes and a 2.6% reduction in crashes with a serious injury. On urban roads, a 2% reduction in average speed from 50km/h to 49km/h is associated with a 5.1% reduction in fatal crashes and a 3.0% reduction in crashes with a serious injury (SWOV 2012).

It is important to note that safety risk is related to both absolute speed and variation between the speed of vehicles and the mean speed of traffic around them.

The safety risk creates a cost to society that is important to consider alongside other costs (for example fuel consumption) and benefits (for example saving in travel time) of different travel speeds. Any analysis of the economic costs of speeding is incomplete without considering the costs of increased risk of injury or fatality resulting from speed. The economic consequence of injuries and fatalities is expressed as a social cost by MoT (2014b) including:

- loss of life and life quality
- loss of output due to temporary incapacitation
- medical costs
- legal costs
- vehicle damage costs.

The report estimates that the social cost per fatality is $3.98 million, $419,300 per serious injury and $22,400 per minor injury. The relationship between safety and speed at the individual and system levels is the subject of much research.

To examine speed limits, Cameron (2003) calculated optimum speeds for road systems based on the net costs and benefits of different mean speeds on different types of road in Tasmania, including the cost of safety risk. The author concluded that all scenarios where speed limits were increased for some vehicle types and circumstances to produce travel time saving benefits were accompanied by increased road trauma. Optimum speeds were approximately consistent with existing speed limits with some variation based on road and vehicle type.

The current study informs the discussion by providing information about the effects of speed on travel time and fuel consumption.

1.1.2 Effect of speed choice on travel time

The theoretical relationship between speed and travel time is that travel time equals distance divided by average speed (ACC and LTSA 2000). Travelling at a higher speed therefore has the potential to decrease journey times.

Table 1.2 provides some examples of the theoretical impact of decreased average speeds on travel time. The table demonstrates that decreasing a higher original speed results in a lower increase in travel time as a proportion of the original speed.

Table 1.2 Theoretical extra travel time on a journey of 10km when average speed is changed 10km/h

Measurement	Values for different speeds							
Original mean speed (km/h)	40	50	60	70	80	90	100	100
Reduced speed (km/h)	30	40	50	60	70	80	90	80
Travel time increase (minutes : seconds)	5:00	3:00	2:00	1:26	1:04	0:50	0:40	1:30
Travel time increase (%)	33%	25%	20%	17%	14%	13%	11%	25%

Adapted from Archer et al (2008)

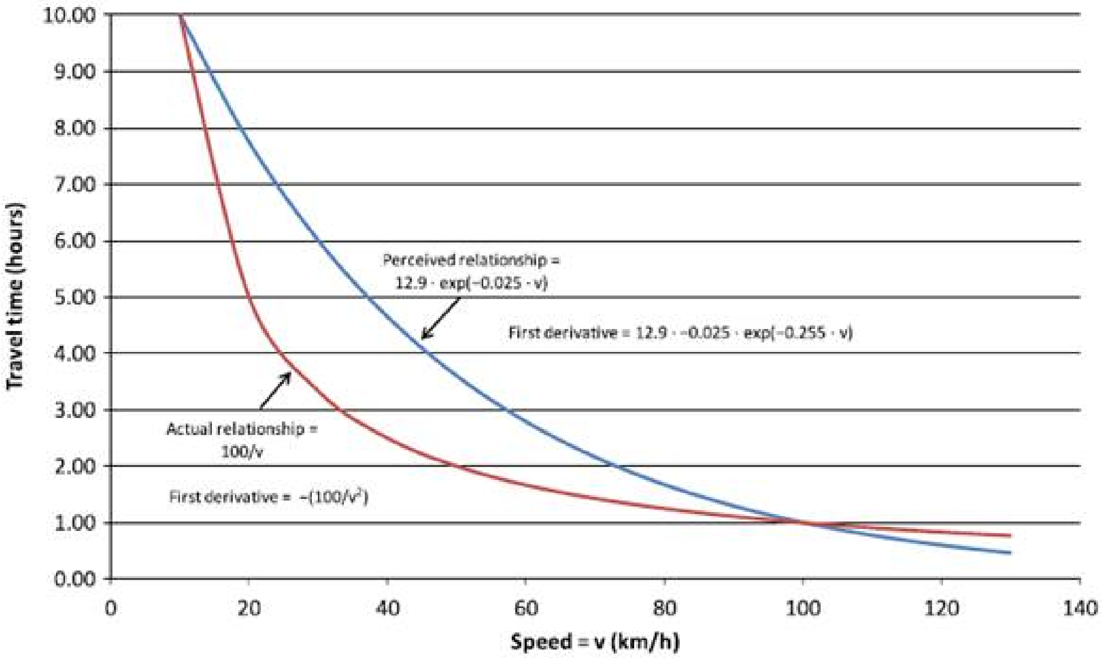
The application of the theoretical relationship to real driving conditions is more complex, however, as travel speed is affected by factors such as traffic control at intersections, congestion, weather and road conditions, speed of traffic flow, and delays due to road work, breakdowns and crashes.

1.1.3 Estimating travel time savings

The relationship between speed and travel time is an important part of the conversation on speed because decisions to speed may be based solely or in part on the desire to save time. For example, a survey conducted of the New Zealand drivers found that one-third agreed that when they speed it is because they want to get where they are going sooner (Rowland and McLeod 2015).

Studies in the United Kingdom and Sweden have shown that people consistently make poor estimates of the amount of time that will be saved by increasing travel speed. The travel time savings by small speed increases at higher travel speeds is overestimated, while the travel time savings by small speed increases at lower travel speeds is underestimated (Svenson 2009; Fuller et al 2009). Elvik (2010) summarised the relationship between actual and perceived speeds and travel times as shown in figure 1.1.

Figure 1.1 Actual and perceived relationship between speed and travel time for a trip of 100km



Source: Elvik (2010) based on Svenson (2009) and Fuller et al (2009)

In a 2013 survey of New Zealand drivers, Malatest International found similar results (Rowland and McLeod 2015). Surveyed drivers were presented with two scenarios. In the first, where a driver increased their mean speed from 50km/h to 60km/h, more than two-thirds of respondents underestimated the amount of time saved. In the second, where a driver increased their mean speed from 95km/h to 110km/h, more than one-half of respondents overestimated the time saved.

1.1.4 Factors affecting travel speed

The effect of delays from traffic controls and congestion and other unexpected factors adds to the difficulty of making accurate estimates of time savings. Travel time, particularly on urban routes, can be affected by changes in capacity (such as incidents, weather, breakdowns, debris on the route, work zones), traffic control devices and changes in demand (such as special events, days of the week and random events) (Brennand 2011).

People may assume that faster speeds result in shorter journey times, but in urban environments where journeys are often interrupted by delay points, increased speed may result in longer waiting times at delay points rather than reaching the destination faster (Frith 2012; Archer et al 2008). The resultant 'stop-and-go' driving, where the driver is frequently decelerating at delay points and subsequently accelerating, can result in higher fuel consumption (LeBlanc et al 2010).

Archer et al (2008) conducted a review of the literature to investigate the hypothesis that reduction in average travel speed brought about by reducing urban speed limits would only have a small impact on travel time. They concluded that existing research tended to support that hypothesis, due to the impact of other factors such as congestion, weather and intersections on travel time. The extent that each of these factors impacts on travel speed can vary with road design, which is a cause of large amounts of variance in the speeds of individual drivers even when congestion is low (Archer et al 2008). There is no information available to identify a generalisable rule quantifying the extent of the effect of each factor.

On rural routes, drivers' free-speed and travel time are more likely to be limited by road geometry (for example, number and radius of curves). On curving roads, drivers are required to slow their vehicles to negotiate curves safely resulting in lower mean speeds than on straight roads with the same speed limit. The current study has attempted to provide information about the relationship between these factors, travel speed, travel time and fuel consumption on New Zealand roads where the impacts of the factors listed above may differ from those experienced internationally.

1.1.5 Actual time savings

Increasing speed on longer, open road trips may produce noticeable time savings (OECD 2006). However, in urban and metropolitan areas, speed changes have a relatively minor impact on average travel times at an individual level (Archer et al 2008).

A study of the effect of maximum speed on travel time in real driving conditions in an urban environment in Toulouse, France, demonstrated the effect of increased speed on travel time. Vehicles completed a 7.6km route containing 28 traffic lights at either fast (respecting the speed limit of 50km/h) or slow (not travelling faster than 30km/h) speeds. The average travel speed of the fast vehicles was 19.1km/h, while that of the slow vehicles was 15.9km/h. The study concluded that a 40% reduction of the maximum speed led to only a 20% increase in travel time, from 24 minutes for the fast vehicles to around 29 minutes for the slow vehicles. The greater number of times the faster vehicle was required to stop at traffic lights closed the gap in travel time between the higher and lower speed trips (ZELT 2004, as cited in OECD 2006).

1.1.6 Effect of speed choice on fuel consumption

Although speed choice is a significant factor influencing fuel consumption, other factors ranging from vehicle design, topography, road geometry, gradient and surfacing, to driver skill to environmental and driving conditions can also influence fuel consumption.

Most energy (82%) produced by the fuel vehicles consume is lost as heat in the engine. The remainder is converted to mechanical energy that is evenly split between overcoming rolling friction from tyres on the road surface and drag from air resistance (Frith and Cenek 2012). The effect of environmental conditions such as headwinds or rain can vary with vehicle design. The Environmental Protection Agency in the United States estimated that such conditions as wind, low tyre pressure, rough roads, hills, snow or ice, carrying cargo and variance in fuel quality can collectively reduce fuel economy by 10% (EPA nd).

1.1.7 Effect of driver behaviour on fuel consumption

The driver's influence on fuel consumption is through choice of speed, 'smoothness' (eg minimising the quantity and degree of braking and accelerating events) or driving conditions such as the number of stops and duration of idling. Frith and Cenek (2012) concluded that for light vehicles the relative importance of the driver's influence on fuel efficiency varies with driving conditions, but generally speed is more important than smoothness in highway driving while the opposite is true in urban driving.

It is worth noting that an aggressive driving style (eg rapid accelerations and hard braking) can increase fuel consumption by up to 30% (OECD 2006). Gonder et al (2012) modelled driver styles and found that fuel consumption could be reduced substantially. They tested their model with two drivers driving two different routes, one urban and one on the highway, 15 times each. The drivers alternated between aggressive driving, normal driving and energy conscious driving. On the city route, they found a 30% spread between the minimum consumption of the energy conscious driver style and the maximum consumption of the aggressive driver style. The spread was 20% on the highway route. The authors conclude that adopting efficient driving behaviours can result in fuel savings of 20% for aggressively driven trips and 5% to 10% for moderately driven trips.

In an American study (LeBlanc 2010), drivers recruited from the public were asked to drive one of 16 identical instrumented test vehicles for five to six weeks. The resulting data set included data from over 342,914km of driving using a total of 33,788 litres of fuel and included driving in a variety of conditions and road types. In these identical vehicles, driver fuel consumption averaged 9.9km per litre of fuel. The fuel efficiency of 80% of drivers fell within a range from 13% under to 16% over the average fuel efficiency, showing substantial differences in consumption rates, which the authors attributed to differences in routes, travel times and driving behaviour.

Analysis of the results showed that most fuel (78%) was consumed when vehicle speed was almost constant covering 88% of the distance travelled. Twenty percent of fuel was consumed while the cars were accelerating, though acceleration covered only 6% of the distance travelled. The study noted that, while driving style affects fuel consumption, speed variations (due to traffic and traffic control devices) have a greater impact on fuel consumption than individual differences between drivers (LeBlanc et al 2010).

1.1.8 Optimum travel speeds for fuel consumption

Estimates of optimum speeds for fuel consumption vary from vehicle to vehicle depending on numerous factors such as vehicle size, weight, degree of wind resistance caused by vehicle design and engine size.

Natural Resources Canada has determined that for passenger vehicles built from 1997 to 2008, peak fuel efficiency is found in the range of 50 to 80km/h (National Resources Canada 2013). Other research efforts have found fuel efficiency peaks between 80 and 90km/h (Davis 1997; ETSC 2005).

Operating passenger vehicles above or below optimal travel speeds results in significant reductions in fuel efficiency and correspondingly increased fuel consumption. The OECD (2006) estimated that fuel consumption of vehicles travelling at 90km/h was 23% better than when the same vehicles were travelling at 110km/h. Similarly, the ETSC report estimated that fuel consumption of vehicles travelling at 90km/h was 30% better than the same vehicles when travelling at 120 km/h (ETSC 2005).

1.1.9 System wide fuel savings

Estimates of the fuel savings from decreasing speed at a network level can vary considerably. In New Zealand, it was estimated that increasing speed limits from 100km/h to 110km/h would increase fuel consumption by 10%, based on the fleet characteristics of the time (Waring 1996, as cited in ACC and LTSA 2000). The European Conference of Ministers of Transport (ECMT 1996) reported several other international examples:

1. In the Netherlands, improved enforcement of speed limits on motorways with 100km/h speed limits reduced average speeds from 111km/h to 104km/h, resulting in energy savings of 40 million litres of petrol, 40 million litres of diesel fuel and 15 million litres of LPG.
2. In Germany, it was estimated that reducing average driving speeds on rural road networks by a given amount (x%) would reduce fuel consumption by 0.8 times x%.
3. In France, compliance with the existing speed limits was estimated to result in a saving of 1.4% of fuel consumed by vehicles annually.
4. In the USA, it was calculated that increasing the steady driving speed by 27% from 55mph (89km/h) to 70mph (113km/h) would increase fuel consumption by only 17%.

Other studies have attempted to model the effect of speed increases on fuel consumption by modelling real driving conditions, where speed is affected by other factors such as driving patterns and congestion. For example, one study using the European ARTEMIS model estimated that lowering speed limits on motorways from 120km/h to 110km/h could reduce fuel consumption by 18% for gasoline cars, but accounting for the effects of traffic and other factors meant a real-world estimate of fuel savings would only be 2% to 3% (European Environment Agency 2011).

1.1.10 Implications for this research

Differences in road geometry and design, transport planning and operation, congestion and environmental conditions between New Zealand roads and those in other countries may result in different relationships between travel speed choice, fuel consumption and travel time listed above.

By testing and quantifying these relationships on New Zealand roads, the current project aimed to improve our understanding of how speed choice influenced travel time and fuel consumption in New Zealand. The project generated New Zealand specific baseline speed and travel time values and aimed to provide a comparison between New Zealand and countries included in other studies. The findings will be used to inform decisions around the costs and benefits of different speed choices at both national and individual levels.

1.2 Objectives

The key objectives of this research were to:

- produce empirical evidence of the effect on actual travel times and fuel usage of set journeys across New Zealand networks when completed at different maximum speeds
- inform the public about travel speed, illustrating the costs and benefits in terms of travel time, fuel use and safety.

1.3 Methods

1.3.1 Steering group

The project was guided by input from a steering group. Members provided advice on the project from the development of the work plan to draft reporting. The agencies represented on the steering group were:

- The New Zealand Transport Agency (the Transport Agency)
- The Automobile Association of New Zealand
- Ministry of Transport
- New Zealand Police.

1.3.2 Route selection

Six routes were selected for the project: two short routes in Wellington and one in Auckland, and longer routes between Hastings and Levin, Auckland and Tauranga, and Christchurch and Kaikoura. The selection of routes was finalised in consultation with the steering group and considered:

- Route characteristics: A varied selection of routes were considered that were representative of a range of different road and journey characteristics including location, elevation, curvature, volume, intersection density, primary speed and road classification (applying the new One Network Road Classifications). The routes were selected to be of-interest to New Zealanders and to increase engagement with the findings among the community.
- Efficiency: Routes greater than 3.5 hours in length were not suitable for the project as drivers had to be able to complete a return trip in a single working day.
- Safety: Driver safety, the ability to pull over, have safe stopping areas and not risk extending the drivers' working days beyond safe levels was a critical factor.

Routes that began in major cities were preferred to reduce difficulties recruiting suitable drivers. The routes selected for the project had the following characteristics (table 1.3).

Table 1.3 Indications of characteristics of the selected routes

Route	Wellington 1 City – Lyall Bay	Wellington 2 City – Island Bay	Lynfield – Mount Wellington	Hastings – Levin	Auckland City – Tauranga via Hamilton	Christchurch – Kaikoura
Length (km)	9.6	6.2	12	197	211	178
Majority speed limit (km/h)	50	50	50	100	100	100
Approximate drive time (based on Google Maps)	20m	15m	25m	2h 42m	2h 46m	2h 17m
Degree of variance based on reported travel times	High	High	High	Low	Med	Low
Highly curved sections	Low	Low	Low	Med	Low	Med
Elevation change	Low	Low	Low	Low	Low	Med

Route	Wellington 1 City – Lyall Bay	Wellington 2 City – Island Bay	Lynfield – Mount Wellington	Hastings – Levin	Auckland City – Tauranga via Hamilton	Christchurch – Kaikoura
Traffic lights (count)	High (13)	High (12)	Med (8)	Low	Low	Low
Volume	Med	High	Med	Med	High	High
Proportion of route on state highways	Low	Low	Low	High	High	High
Primary classification	Arterial, connector, access	Arterial, connector, access	Arterial, connector, access	National strategic	National/ regional strategic	National strategic

The **Lyall Bay to Wellington City** route ensured coverage of small trips on connector and arterial roads, allowing for analysis of travel time differences at lower speed limits across high and low volumes of traffic. The route included a one-way section, a 40km/h section and a segment through busy controlled intersections with traffic lights phased for 50km/h traffic. The section around the waterfront between Kilbirnie and Oriental bay is relatively free-flowing but quite curved.

The **Island Bay to Wellington City** route covered a typical commute, primarily on 50km/h roads with high intersection density and high traffic in peak travel times. The route included a short 40km/h zone through the Island Bay town centre. It has longer straight sections than the Lyall Bay to Wellington City route.

The **Lynfield to Mount Wellington** route was shorter and designed to be representative of a commute through suburban Auckland. It avoided the motorway but still included some of the Auckland arterial roads, particularly Great South Road. It was the longest of the three short routes.

The **Hastings to Levin** route is important for freight and for people travelling across the North Island. It has a combination of sections with and without passing-lanes, is often subject to a high volume of traffic and has some tortuous sections. As with the Tauranga route, fatigue and traffic management were key considerations.

The **Auckland City – Tauranga via Hamilton** route is considered by the Transport Agency to be a strategic, high-volume North Island route that is familiar to many North Island drivers. The route has the greatest travel time of those selected so managing driver fatigue, particularly in the afternoon traffic, was a priority. The route finish was in East Tamaki, avoiding some of the more congested sections of the Auckland Motorway.

The **Christchurch to Kaikoura** route is a strategic section of state highway with heavy traffic but is also used for holiday trips, and includes some elevation and tortuous sections. One of the unique issues with the stretch of road is the possible impact of traffic surges resulting from Cook Strait ferry offloading. There is a relatively short section of 80km/h limited road close to Christchurch.

Drivers were assigned a schedule for each route with driving speeds arranged in random order to minimise the effect of time of day on the data collected. They drove at the same times of day for each day worked, approximately within normal working hours on weekdays (8am to 6pm). As the study considered driving in real world conditions, some variation due to traffic was expected in the results.

1.3.3 Recruitment of drivers

A single driver was hired through employment agencies for each of the six selected routes. The same driver drove each of the two Wellington short routes. A single driver was used on each route to minimise the effect of driver technique on comparison of results within each route. Drivers were required to have at least seven years of driving experience but not to be professionally trained drivers. Professional drivers were not used as their additional skill and experience may have made their driving less representative of a typical New Zealand driver. Drivers were also required to have a 'clean' driving record (for example, no speeding tickets, no offences), to hold full licences and to be aged over 25 years of age for insurance purposes. The recruitment process included:

- Driver screening: Drivers were screened by the Transport Agency for driving offences and infringements.
- Driver interview: The interview included discussion of driving experience and any factors that could affect the safety of the candidate's driving such as working late night shifts, problems with fatigue, health conditions that may affect driving or any other factor that may raise concern (for example, sleep apnoea, smoking, alcoholism).
- Driving assessment: Drivers were required to pass a practical driving assessment completed with a professional driving instructor through the New Zealand Automobile Association.

The drivers selected were:

- all male
- aged between 27 and 63 years of age
- experienced drivers with no history of traffic infringements or unsafe driving.

1.3.4 Number of trips

Table 1.4 shows the total number of trips completed with usable data on each route showing the speed and direction of travel. The table excludes trips that were removed from the dataset during data cleaning for containing too much driving time (>5% of all moving time) at 2km/h or more above the speed limit. If trips exceeded this limit, they were considered not to have been completed with the maximum speed in place.

Table 1.4 Total number of completed trips with usable data at each of the tested speeds

Trip speed	40km/h	50km/h	80kmh	90km/h	100km/h	Total
Wellington short one	55	50				105
Wellington short two	59	61				120
Auckland short	51	51				102
Hastings to Levin			15	15	10	40
Christchurch to Kaikoura			11	15	16	42
Auckland to Tauranga			14	11	15	40

1.3.5 Hardware used in data collection

Each route used a different vehicle but of the same model: a rented 2013 Toyota Corolla provided by the study. The vehicle was selected because it is consistently amongst the highest selling vehicles in New Zealand. The 2013 model's specifications include:

- high safety rating
- 1.8 litre engine

- CVT automatic transmission with seven stepped ratios
- 103kW at 6,400rpm
- 173Nm maximum torque
- estimated fuel economy 7.1 litres/100km.

The vehicle data loggers are devices that connect to the onboard diagnostic (OBDII) ports of the vehicles and record vehicle data directly from the vehicle and from a GPS connection. OBDII ports report the status of vehicle systems for use in monitoring or diagnosing problems. The resulting data was saved in logs containing data (for example, GPS position, speed, fuel level) recorded at one-second intervals for the duration of each trip. The data loggers required no manual input from drivers during trips.

Drivers used GPS units in the initial stages of their driving to ensure they were able to accurately learn the route. Video cameras were used on one trip to collect photos to produce a time lapse video of each of the routes.

At the conclusion of each trip on each route, drivers recorded any unplanned stops, detours, or other events that might have affected their fuel consumption and travel time for that trip. They also provided a subjective rating for the effect of traffic and weather on the trip, from one (no effect) to five (great effect). These ratings were included in the driving datasets for analysis.

Vehicles were refuelled at the beginning of each driving day. All trips were driven during working hours (between 8am and 6pm).

1.4 Analysis

1.4.1 Data cleaning

The records for each trip were scanned by the researchers to ensure they followed the same route, were driven at the expected speed and did not contain any unusual data. This process is outlined below:

- Speed checking: Any trips where the driver's speed exceeded the assigned trip maximum speed limit by 2km/h or more for more than 5% of the time the vehicle was moving were deemed ineligible for inclusion in the dataset.
- Stop checking: Analysis of each trip identified all complete stops (for example, those made for driver breaks). It was important to include stops in the trip data as real-world driving includes complete stops at times. However, trips at lower speeds included stops to let other drivers who wanted to travel above the trip maximum speed past. If all traffic was travelling to the same maximum speed, these stops would not occur.
- The effect of these stops on fuel consumption and travel time was therefore removed from the final data. At slower trip speeds (80km/h and 90km/h on long routes and 40km/h on short routes) drivers pulled over when it was safe to do so to let following cars pass. On some drives, this led to drivers pulling over more than 15 times. A random sample of 20 of these stops at each speed on each route was selected and used to calculate an average stop 'cost'. These costs were multiplied by the number of stops on each trip and removed from the overall travel time and fuel consumption calculations.
- Idle, wrong turn and other removal: Drivers often had short idle periods at the beginning of trips, during breaks and at the end of trips. The effect of these idles on travel time and fuel consumption was removed.

1.4.2 Approach to statistical analysis

Each of the routes was analysed separately. The datasets used for analysis contained:

- fuel consumption (litres)
- travel time from trip start to end
- percentage of time when the vehicle was not stationary that it was over the trip maximum speed limit and the trip maximum speed limit +2km/h
- distance covered by the trip
- idle time – time when the vehicle was stationary
- weather (rating on the effect weather had on the trip from the driver's point of view, from one – no effect to five – strong effect)
- traffic (rating from one to five as for weather)
- direction of travel
- date and time of trip beginning
- mean speed calculated from distance and travel time.

In addition, for 83 of the trips on Wellington short route one drivers rated the effect of the phased lights on Customhouse Quay using the same one to five rating scale used for weather and traffic. Traffic lights were identified as a factor by the driver after the first two days of data collection so were included from that point on. All trips on Wellington short route two included a rating for the effect of the traffic lights.

The three short routes, two in Wellington and one in Auckland, were analysed using the following approach:

- Independent t-test comparing the fuel and travel time of the two directions of travel at each of the two tested speeds (40km/h and 50km/h). Where a significant difference was identified, the two directions were treated as two separate routes. This was the case for both short routes.
- Descriptive statistics examining the shape of the distributions, identifying outliers, testing normality and variance.
- Independent t-tests comparing fuel and travel time for each speed, where assumptions were met. Where assumptions were not met, the Mann-Whitney U test was used as an alternative to confirm the results.
- Multiple regression to examine the effect of other variables (weather, traffic, direction of travel) alongside maximum speed limit.

For the long route data a similar process was followed, except a one way analysis of variance (ANOVA) was used instead of an independent samples t-test as there were three tested maximum speed limits (80km/h, 90km/h and 100km/h).

Data analysis was completed using SPSS. Where the assumptions of any of the tests used were violated, it is described in footnotes. The significance level used for all tests is $p < 0.05$.

1.5 Limitations

Care should be taken in generalising the findings beyond the drivers and routes included in this project. Drivers were not professional and were not necessarily equally capable. All drivers passed AA assessments of their driving, so all were capable and able to drive safely. However the drivers' level of skill has an impact on both the travel time and fuel consumption on their routes. This effect has not been quantified in the comparisons of changes in travel time and fuel consumption across the tested routes. This limitation does not apply to comparison within each route using a single driver.

While the vehicles were the same make and model, there may have been some mechanical variation between vehicles that affected their travel time or fuel consumption. This effect has not been quantified and so should be noted when comparing findings between routes.

Drivers quantified the effect of traffic on each trip on their route by providing subjective ratings. Some drivers found it difficult to make those ratings so the analysis also took idle time into account as a substitute for traffic rating when comparing trips as heavy traffic had the effect of increasing the number and duration of complete stops.

On some routes, significant differences were identified between the two directions of travel on a single route. Comparing the two directions of travel as different distributions greatly reduced the sample size available for testing. This is noted in the results for each individual route.

2 Results

Figure 2.1 presents the actual results for mean speeds at the different maximum speeds on each route. The central column lists the statistically significant changes in the recorded measures from decreasing maximum speed.

Figure 2.1 Change in mean speeds, travel time increases and fuel consumption savings from decreasing speed on each of the tested routes. Note that only statistically significant differences are included in the figure

Starting speed: Max.	Starting speed: Mean	Route and changes	New speed: Max.	New speed: Mean
50km/h	30km/h	**Wellington short one – 10km** **Max. speed decrease:** –10km/h – 20% **Mean speed decrease:** – 9% **Fuel consumption:** –0.026 litres – 5% **Travel time:** + 1:54 minutes +9%	40km/h	27km/h
50km/h	26km/h	**Wellington short two – 6km** **Max. speed decrease:** –10km/h – 20% **Mean speed decrease:** – 7% **Fuel consumption:** –0.015 litres – 3% **Travel time:** + 1:08 minutes +8%	40km/h	24km/h
50km/h	33km/h	**Auckland short – 12km** **Max. speed decrease:** –10km/h – 20% **Mean speed decrease:** –14% **Fuel consumption:** No change **Travel time:** + 3:13 minutes +15%	40km/h	29km/h
100km/h	79km/h	**Hastings to Levin – 197km** **Max. speed decrease:** –10km/h – 10% **Mean speed decrease:** – 4% **Fuel consumption:** –0.568 litres –5% **Travel time:** + 6 minutes +4%	90km/h	76km/h
100km/h	79km/h	**Max. speed decrease:** –20km/h – 20% **Mean speed decrease:** –11% **Fuel consumption:** –1.578 litres –15% **Travel time:** + 18 minutes +12%	80km/h	71km/h
100km/h	75km/h	**Christchurch to Kaikoura– 178km** **Max. speed decrease:** –10km/h – 10% **Mean speed decrease:** – 3% **Fuel consumption:** – 0.661 litres – 7% **Travel time:** + 4 minutes +3%	90km/h	73km/h
100km/h	75km/h	**Max. speed decrease:** –20km/h – 20% **Mean speed decrease:** – 8% **Fuel consumption:** –1.406 litres –14% **Travel time:** + 12 minutes + 9%	80km/h	69km/h
100km/h	75km/h	**Auckland to Tauranga– 211km** **Max. speed decrease:** –10km/h – 10% **Mean speed decrease:** – 5% **Fuel consumption:** –0.899 litres – 7% **Travel time:** + 8 minutes +5%	90km/h	72km/h
100km/h	75km/h	**Max. speed decrease:** –20km/h – 20% **Mean speed decrease:** – 12% **Fuel consumption:** – 1.812 litres – 14% **Travel time:** + 23 minutes +13%	80km/h	66km/h

Table 2.1 shows the increase in travel time when maximum speed limit was decreased 20% from 50km/h to 40km/h on the three short routes. Increases ranged from 7.6% to 14.9%.

Table 2.1 Travel times recorded with 40km/h and 50km/h maximum speeds across the three short routes

Route	Distance (km)	Maximum speed (km/h)	Mean speed (km/h)	Mean idle time (minutes)	Travel time (minutes)	Increase from 50km/h (minutes)	Increase from 50km/h (%)
Wellington short one	10.21	50	29.62	3.40	20.78	–	–
		40	27.11	3.15	22.68	1.90	9.1%
Wellington short two	6.2	50	25.64	3.22	14.82	–	–
		40	23.97	3.40	15.95	1.13	7.6%
Auckland short	11.8	50	33.03	2.98	21.65	–	–
		40	28.50	2.82	24.87	3.22	14.9%

Note: Travel time does not perfectly match maximum speed and distance due to slight variation in trip distances recorded for each individual trip.

Table 2.2 shows the travel times and mean speeds recorded on the longer routes at the three tested maximum speeds, with comparison of the two lower speeds (80km/h and 90km/h) to 100km/h. Increases in travel time from reducing speed from 100km/h to 90km/h ranged from 2.6% to 4.9%. Increases in travel time from reducing speed from 100km/h to 80km/h ranged from 8.6% to 13.4%.

Table 2.2 Travel times recorded with 80km/h, 90km/h and 100km/h maximum speeds across the three long routes

Route	Distance (km)	Maximum speed (km/h)	Mean speed (km/h)	Mean idle time (minutes)	Travel time (minutes)	Increase from 100km/h (minutes)	Increase from 100km/h (%)
Hastings to Levin	196.7	100	79.39	1.08	148.60	–	–
		90	76.40	1.25	154.62	6.02	4.1%
		80	70.73	0.50	166.83	18.23	12.3%
Christchurch to Kaikoura	178	100	74.84	3.27	142.83	–	–
		90	72.94	2.12	146.48	3.65	2.6%
		80	68.95	2.60	155.12	12.29	8.6%
Auckland to Tauranga	211.6	100	75.01	3.63	169.32	–	–
		90	71.67	3.00	177.57	8.25	4.9%
		80	66.19	3.12	191.98	22.66	13.4%

Note: Travel time does not perfectly match maximum speed and distance due to slight variation in trip distances recorded for each individual trip.

Table 2.3 shows the decreases in fuel consumption between the 50km/h and 40km/h speed limits on the short routes. The differences were 3.4% and 4.6% on the two Wellington short routes but there was no significant difference detected in Auckland. On the two Wellington short routes, the decreases in fuel consumption were proportionately lower than the increase in travel time.

Table 2.3 Difference in fuel consumption from decreasing speed across the short routes

Route	Distance (km)	Maximum speed (km/h)	Mean speed (km/h)	Mean idle time (minutes)	Decrease in mean speed compared to 50km/h max speed (%)	Fuel consumed (l)	Decrease from 50km/h (l)	Decrease from 50km/h (%)
Wellington short one	10.21	50	29.62	3.40	–	0.572	–	–
		40	27.11	3.15	8.5%	0.546	0.026	4.6%
Wellington short two	6.2	50	25.64	3.22	–	0.446	–	–
		40	23.97	3.40	6.5%	0.432	0.015	3.4%
Auckland short	11.8	50	33.03	2.98	–	0.794	–	–
		40	28.50	2.82	13.7%	0.793	Change not significant	

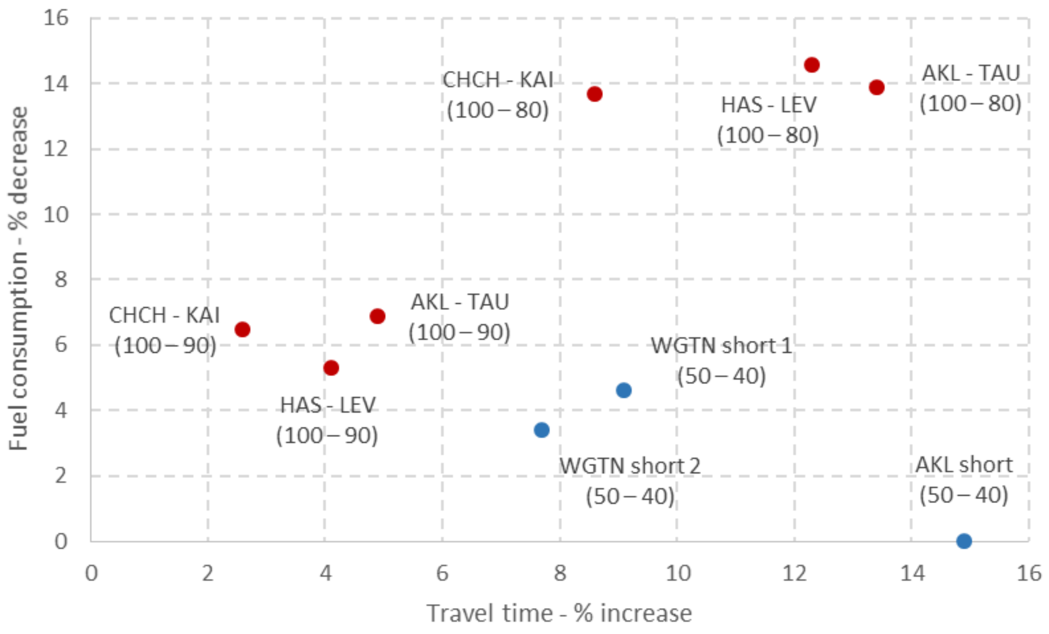
Table 2.4 shows the difference in fuel consumption between trips at 100km/h maximum speed and the two lower speeds tested (80km/h and 90km/h). Decreasing maximum speed to 90km/h reduced fuel consumption by between 5.3% and 6.9%. Decreasing maximum speed to 80km/h reduced fuel consumption by between 13.7% and 14.6%. On all long routes, the reduction in fuel consumption was proportionately greater than the increase in travel time.

Table 2.4 Difference in fuel consumption from decreasing speed across the long routes

Route	Distance (km)	Max speed (km/h)	Mean speed (km/h)	Mean idle time (minutes)	Decrease in mean speed compared to 100km/h max speed (%)	Fuel consumed (l)	Decrease from 100km/h (l)	Decrease from 100km/h (%)
Hastings to Levin	79.39	100	79.39	1.08	-	10.799	-	-
		90	76.40	1.25	3.8%	10.231	0.568	5.3%
		80	70.73	0.50	10.9%	9.221	1.578	14.6%
Christ-church to Kaikoura	178	100	74.84	3.27	-	10.241	-	-
		90	72.94	2.12	2.5%	9.579	0.662	6.5%
		80	68.95	2.60	7.9%	8.835	1.406	13.7%
Auckland to Tauranga	211.6	100	75.01	3.63	-	13.077	-	-
		90	71.67	3.00	4.5%	12.178	0.899	6.9%
		80	66.19	3.12	11.8%	11.265	1.812	13.9%

Charting decreases in fuel consumption alongside increases in travel time showed a clear relationship on the long routes, but not on the short routes (figure 2.2).

Figure 2.2 Percentage increase in travel time plotted against % decrease in fuel consumption for each route, with the speed change for each point bracketed



The following sections describe detailed results for each route. The summary preceding each route's section reports only significant results ($p < 0.05$).

2.1 Wellington short route one

Figure 2.3 Lyall Bay to Wellington City route

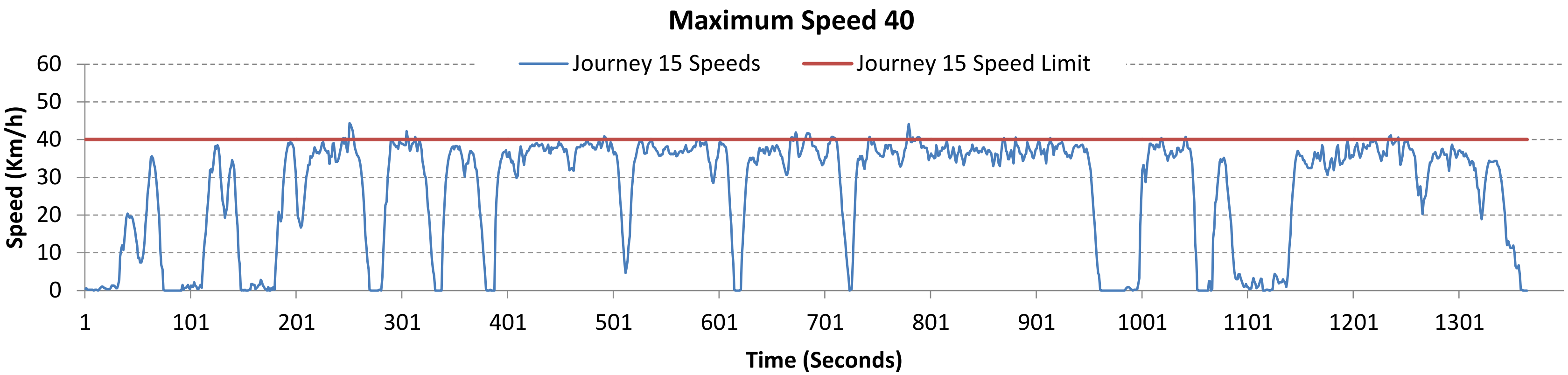
The **Lyall Bay to Wellington City** route ensured coverage of small trips on connector and arterial roads, allowing for analysis of time differences at lower speed limits across high and low volumes of traffic. The route included a one-way section, a 40km/h section and a segment through busy controlled intersections with traffic lights phased for 50km/h traffic. There were 13 traffic lights in total and the route included a tortuous section around the coast.

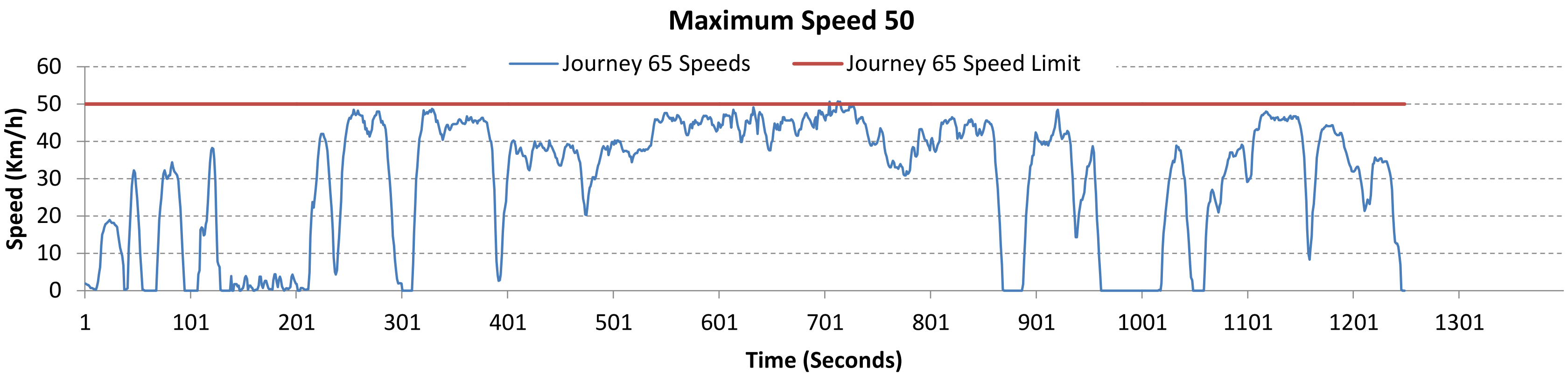
- The driver completed 105 trips, including 55 at a maximum speed of 40km/h (mean speed 27.11km/h (SD = 1.54)) and 50 at a maximum speed of 50km/h (mean speed 29.62km/h (SD = 1.87))
- Trips north into the city (Lyall Bay to Thorndon Quay) took longer and consumed significantly more fuel with a 40km/h maximum speed and used significantly more fuel with 50km/h maximum speed than trips in the opposite direction.
- Into the city:
  - Reducing the maximum speed from 50km/h to 40km/h reduced the mean speed by 9.0% from 29.47km/h (SD = 1.41) to 26.81km/h (SD = 1.70).
  - The mean idle time at 40km/h and 50km/h was 3:21 minutes (SD = 1:12) and 3:30 minutes (SD = 0:51) respectively. The differences in the idle time were not significant.
  - Travelling at a 40km/h maximum speed took 2:08 minutes (CI±0:42) longer than trips at a 50km/h maximum speed – a 10.2% increase.
  - The difference in fuel consumption was not significant.
- Out of the city
  - Reducing the maximum speed from 50km/h to 40km/h reduced the mean speed by 8.4% from 29.85km/h (SD = 2.38) to 27.34km/h (SD = 1.38).
  - The mean idle time at 40km/h and 50km/h was 3:00 minutes (SD = 1:01) and 3:16 minutes (SD = 1:20) respectively. The differences in the idle time were not significant.
  - Travelling at a 40km/h maximum speed took 01:51 minutes (CI±0:46) longer to arrive at their destination – a 9% increase.
  - Travelling at a 40km/h maximum speed used an average of 0.030 litres (CI±0.023) less fuel – a 5.4% decrease.
- Overall:
  - Reducing the maximum speed from 50km/h to 40km/h reduced the mean speed by 8.5% from 29.62km/h (SD = 1.87) to 27.11km/h (SD = 1.54).
  - Decreasing maximum speed by 20%, from 50km/h to 40km/h, increased travel time by 1:54 minutes (CI±0:31) (9.1%) and reduced fuel consumption by 0.026 litres (CI±0.016) (4.6%).
  - The mean idle time at 40km/h and 50km/h was 3:09 minutes (SD = 1:06) and 3:24 minutes (SD = 1:04) respectively. The differences in the idle time were not significant.
- Both travel time and fuel consumption were closely correlated with idle time. Overall, the measured variables explained 95% of the variation in travel time and 80% of the variation in fuel consumption.
- Travelling at the higher maximum speed predicted shorter travel time. Increases in the driver's ratings of the effect of traffic, the traffic lights on a main section of road (Customhouse Quay), idle time and travelling into the city predicted longer travel time.

- Travelling at the higher maximum speed and increased idle time, more traffic light stops and travelling into the city predicted higher fuel consumption.

Figure 2.4 shows driver speed over time on two trips with travel times close to the mean for the out of the city direction on Wellington short route one.

Figure 2.4 Two plots of driver speed over time for two randomly selected trips on Wellington short route one





2.1.1 Change in mean speed

The mean travel speeds for each of the tested maximum speeds are shown in table 2.5.

Table 2.5 Recorded mean speeds (km/h) between trips at different maximum speeds overall and in each trip direction (n = 105)

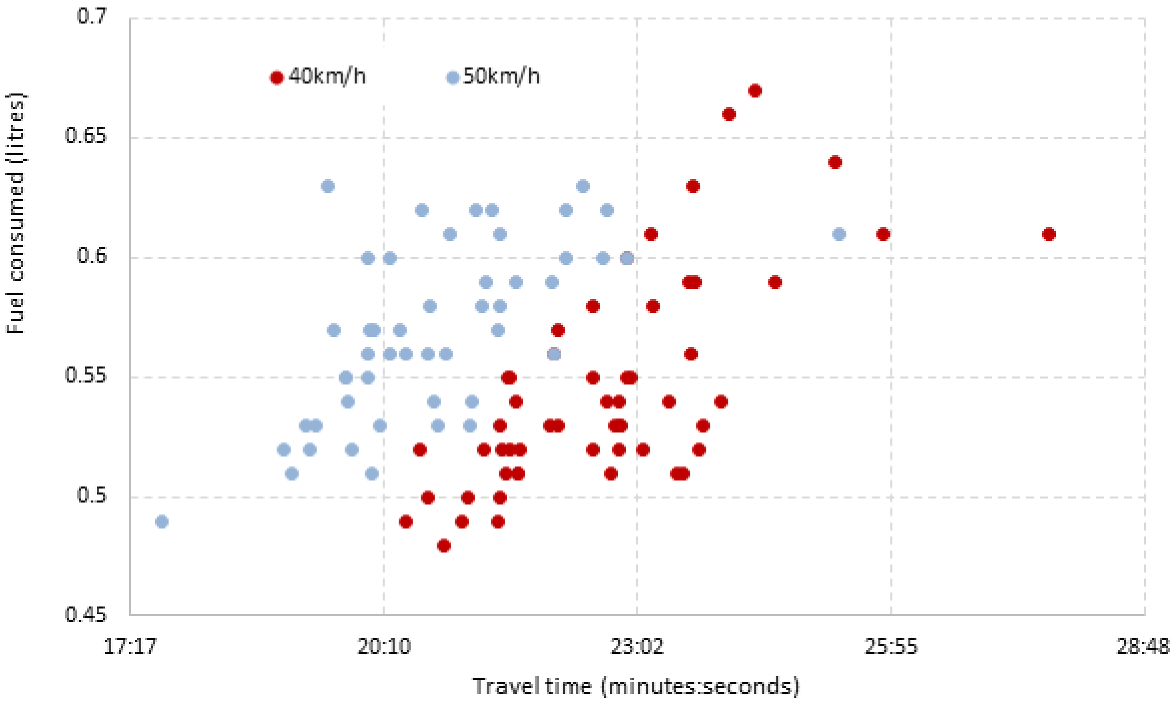
Direction of travel	40km/h maximum speed	50km/h maximum speed	Mean difference between speeds (95% CI)
Overall	**27.11 (SD = 1.54, n = 55)**	**29.62 (SD = 1.87, n = 50)**	**2.51 (1.86 – 3.18)***
Into the city	26.81 (SD = 1.70, n = 24)	29.47 (SD = 1.41, n = 29)	2.66 (1.80 -3.52)*
Out of the city	27.34 (SD = 1.38, n = 31)	29.85 (SD = 2.38, n = 21)	2.51 (1.33 – 3.68)*

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk.

2.1.2 Combining fuel consumption and travel time

The relationship between fuel consumption, travel time and maximum speed is illustrated by figure 2.5. For Wellington short route one, trips that took longer used more fuel. Trips of the same duration used more fuel with a maximum speed of 50km/h compared with 40km/h.

Figure 2.5 Travel time plotted against fuel consumption for all trips on Wellington short route one (n = 105)



2.1.3 Travel time by direction of travel

Direction of travel, into or out of the city, had a significant effect on travel time (table 2.6). For trips with a 40km/h maximum speed, travelling into the city took significantly longer than returning from the city but the difference in trip direction was not significant for trips with a 50km/h maximum speed. The difference may be explained by a small section in the route where the directions follow different one-way roads.

Table 2.6 Effect of direction of travel on travel time at 40km/h and 50km/h maximum speeds on Wellington short route one (n = 105)

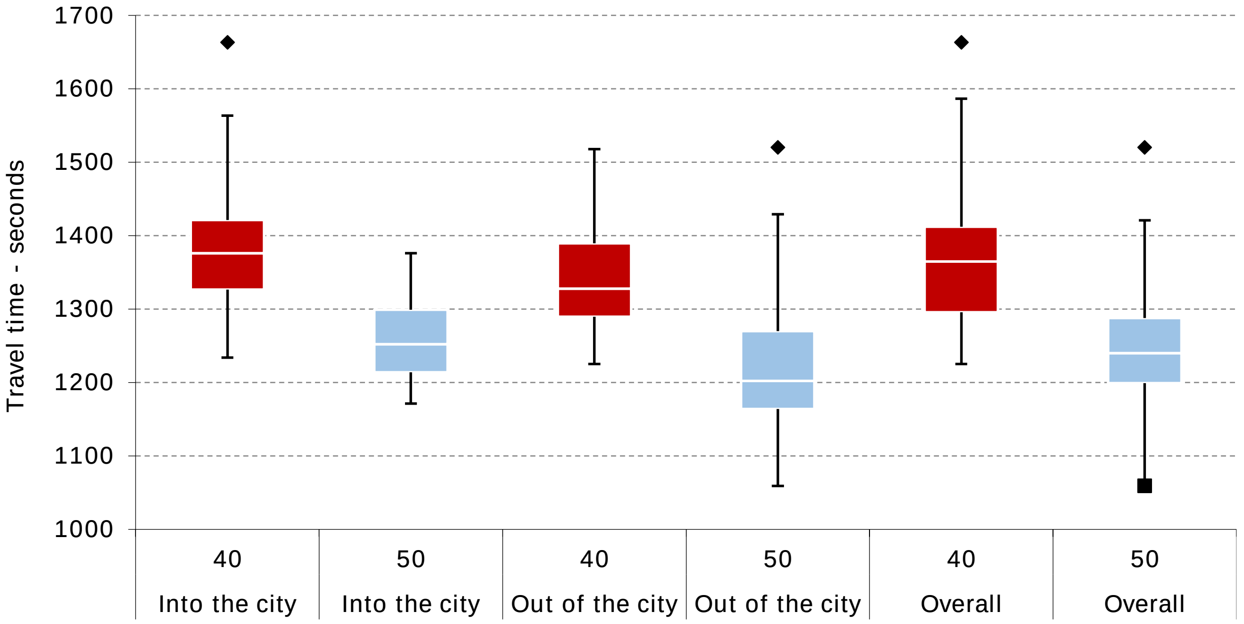
Maximum trip speed	Into the city	Out of the city	Mean difference in direction of travel (95% CI)
40km/h	23:08 (SD = 01:31, n = 24)	22:19 (SD = 01:09, n = 31)	00:48 (00:05 – 01:31)*
50km/h	21:00 (SD = 00:59, n = 29)	20:29 (SD = 01:36, n = 21)	00:31 (-00:13 – 01:20)

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk.

2.1.4 Effect of changing maximum speed on travel time

Figure 2.6 shows the distribution of travel time for the trips into and out of the city, alongside the combined results, for each of the tested maximum speeds.

Figure 2.6 Box plots for travel time at the tested maximum speeds on Wellington short route one into and out of the city, and overall (n = 105). Diamonds mark upper outliers and squares mark lower outliers



The differences in travel time between the two tested maximum speeds were significant when comparing trips into and out of the city, and overall ($p < 0.001$) (table 2.7). On average, driving at a maximum speed of 40 km/h resulted in a trip that was 1:54 minutes slower than when travelling at a maximum of 50km/h.

Table 2.7 Differences in travel time between trips at different maximum speeds overall and in each trip direction (n = 105)

Maximum trip speed	40km/h	50km/h	Mean difference between speeds (95% CI)
Overall	**22:41 (SD = 1:23, n = 55)**	**20:47 (SD = 1:18, n = 50)**	**01:54 (01:23 - 02:25)***
Into the city	23:08 (SD = 01:31, n = 24)	21:00 (SD = 00:59, n = 29)	02:08 (01:26 - 02:50)*
Out of the city	22:19 (SD = 01:09, n = 31)	20:29 (SD = 01:36, n = 21)	01:51 (01:05 - 02:37)*

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk. The assumption of normality was violated for travel time at 40km/h so significance of the difference was confirmed with a Mann-Whitney U test ($p < 0.001$).

2.1.5 Idle time

There were no significant differences identified in idle time between trips at the two maximum speeds in either direction or overall (table 2.8). Idle time was strongly correlated with total travel time (R_p = 0.70).

Table 2.8 Differences in idle time between trips at different maximum speeds overall and in each trip direction (n = 105)

Maximum trip speed	40km/h	50km/h	Mean difference between speeds (95% CI)
Overall	**03:09 (SD = 1:06, n = 55)**	**03:24 (SD = 1:04, n = 50)**	**- 00:15 (- 00:41 - 00:10)**
Into the city	03:21 (SD = 01:12, n = 24)	03:30 (SD = 00:51, n = 29)	-00:09 (-00:43 - 00:25)
Out of the city	03:00 (SD = 01:01, n = 31)	03:16 (SD = 01:20, n = 21)	-00:16 (-00:56 - 00:23)

2.1.6 Predicting travel time

A multiple regression was run to predict travel time on Wellington short route one based on:

- maximum speed
- traffic rating
- idle time
- Customhouse Quay traffic light ratings
- direction of travel.

The effect of the Customhouse Quay lights was only recorded for 83 of the 105 trips as those particular lights were only identified as an important factor after data collection began. Weather rating was not included in the analysis as the driver recorded a rating of 1 (no effect) for each trip.

The other variables significantly predicted travel time ($F(5,77) = 285.74$, $p < 0.001$) and explained 95% of the variation in travel time across trips (adj. $R^2 = 0.946$). All variables added significantly to the prediction. An increase in maximum speed predicted a lower travel time. Increases in traffic rating, Customhouse Quay light stops and idle time predicted higher travel time. Travelling into the city also predicted higher travel time (table 2.9).

Table 2.9 Multiple regression results for travel time showing significant ($p < 0.05$) predictors (n = 83)

Variable	B	SE_B	β
Trip maximum speed	-13.665	0.556	-0.690
Direction of travel	20.288	5.370	0.103
Traffic	32.589	5.150	0.206
Customhouse Quay	12.525	3.075	0.115
Idle time	0.921	0.049	0.607

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

Including the remaining 22 trips and excluded the Customhouse Quay traffic light stops variable also produced a significant model ($F(5,99) = 260.499$, $p < 0.001$, adj. $R^2 = 0.926$).

2.1.7 Fuel consumption by direction of travel

Direction of travel, into or out of the city, had a significant effect on fuel consumption on Wellington short route one. At a 50km/h maximum speed, travelling into the city consumed significantly more fuel than returning from the city but the difference in trip direction was not significant for trips made with a 40km/h maximum speed (table 2.10).

Table 2.10 Effect of direction of travel on fuel consumption (litres) at 40km/h and 50km/h (n = 105)

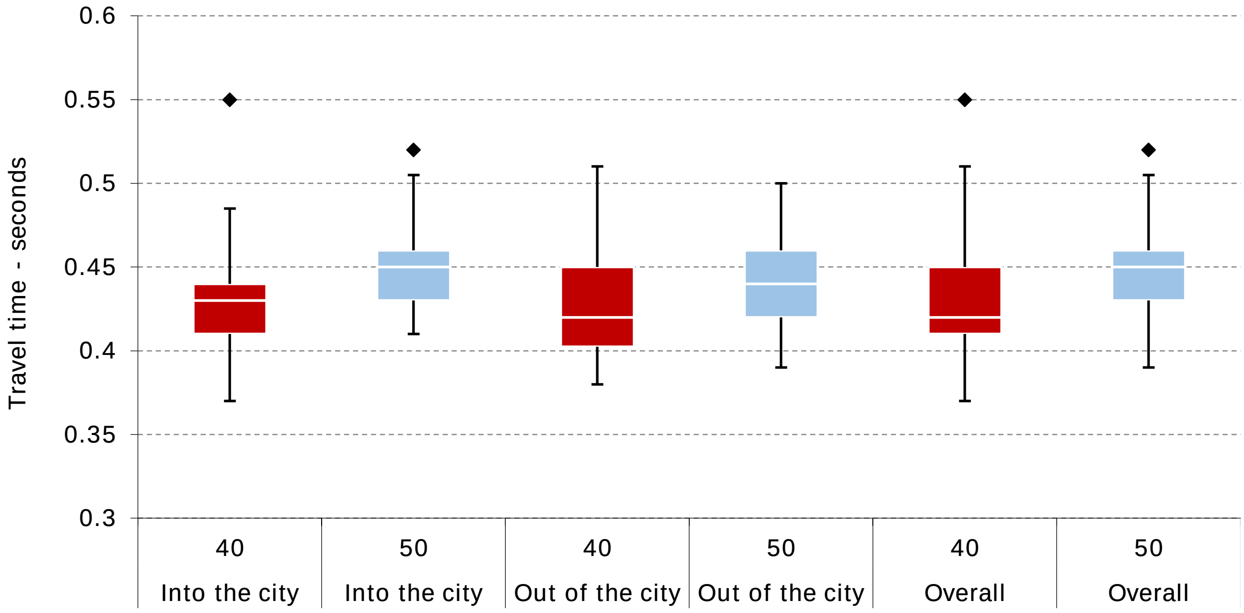
Trip maximum speed	Into the city	Out of the city	Mean difference in direction of travel (95% CI)
40km/h	0.572 (SD = 0.043, n = 24)	0.525 (SD = 0.033, n = 31)	0.047 (0.027 – 0.068)
50km/h	0.584 (SD = 0.024, n = 29)	0.555 (SD = 0.050, n = 21)	0.029 (0.008 – 0.050)*

Note: Differences significant (t-test, $p < 0.05$) are marked with an asterisk.

2.1.8 Effect of changing maximum speed on fuel consumption

Figure 2.7 shows the distribution of fuel consumption for the trips into and out of the city, alongside the combined results, for each of the tested travel speeds.

Figure 2.7 Box plots for fuel consumption at the tested speeds on Wellington short route one into and out of the city, and overall (n = 105). Diamonds mark upper outliers and squares mark lower outliers



The differences in fuel consumption between the two tested maximum speeds were significant when comparing trips into and out of the city, and overall ($p < 0.001$) (table 2.11).

Table 2.11 Differences in fuel consumption (litres) between trips at different maximum speeds on Wellington short route one overall and in each trip direction (n = 105)

Trip maximum speed	40km/h	50km/h	Mean difference between speeds (95% CI)
Overall	**0.546 (SD = 0.044, n = 55)**	**0.572 (SD = 0.039, n = 50)**	**- 0.026 (- 0.042 to - 0.010)***
Into the city	0.572 (SD = 0.043, n 24)	0.584 (SD = 0.024, n = 29)	-0.012 (-0.031 to 0.007)
Out of the city	0.525 (SD = 0.033, n = 31)	0.555 (SD = 0.050, n = 21)	-0.030 (-0.053 to -0.007)*

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk. The assumption of normality was violated for travel time at 40km/h so significance of the difference was confirmed with a Mann-Whitney U test ($p < 0.001$).

2.1.9 Predicting fuel consumption

A multiple regression was run to predict fuel consumption on Wellington short route one based on:

- maximum speed
- traffic rating
- Customhouse Quay traffic light ratings
- direction of travel
- idle time.

The effect of the Customhouse Quay lights was only recorded for 83 of the 105 trips. Weather rating was not included in the analysis as it was recorded as having no effect on all trips. These variables significantly predicted fuel consumption ($F(5,77) = 64.761$, $p < 0.001$) and explained 80% of the variation in fuel consumption across trips (adj. $R^2 = 0.795$).

All variables except traffic rating added significantly to the prediction, with an increase in maximum speed, idle time, the effect of the traffic lights on Customhouse Quay and travelling into the city increasing fuel consumption (table 2.12).

Table 2.12 Multiple regression results for travel time showing significant ($p < 0.05$) predictors (n = 83)

Variable	B	SE_B	β
Trip maximum speed	.002	.000	.234
Direction of travel	.036	.004	.531
Customhouse Quay	.006	.002	.152
Idle time	.000	.000	.384

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

Including the remaining 22 trips and excluding the Customhouse Quay traffic rating variable also produced a significant model but with lower accuracy ($F(4,99) = 16.333$, $p < 0.001$, adj. $R^2 = 0.371$).

2.2 Wellington short route two

Figure 2.8 Island Bay to Wellington City route

The Island Bay to Wellington City route covered a typical commute, primarily on 50km/h roads with high intersection density and high traffic in peak travel times. The route included a short 40km/h zone through the Island Bay town centre. It has longer straight sections than the Lyall Bay to Wellington City.

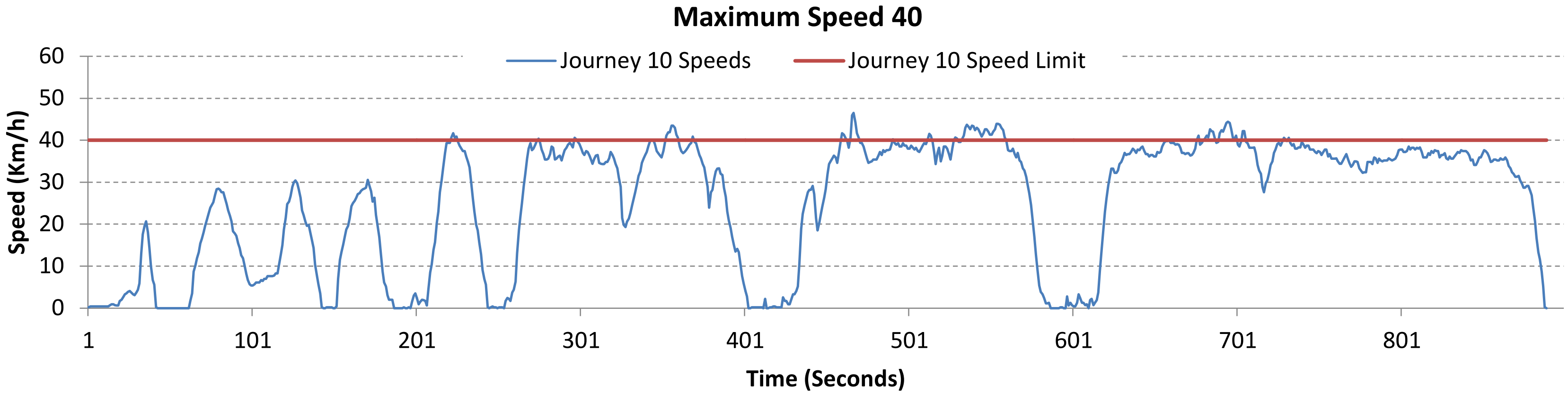
- The driver completed 120 trips, including 59 at a maximum speed of 40km/h (mean speed 23.97km/h (SD = 3.28)) and 61 at a maximum speed of 50km/h (mean speed 25.64km/h (SD = 2.53)).
- There was no significant difference in the amount of fuel used on trips into and out of the city at either maximum speed.
- Trips out of the city took significantly longer than trips into the city at 40km/h but not at 50km/h.
- Into the city:
  - The differences in mean speed, travel time and fuel consumption were not significant.

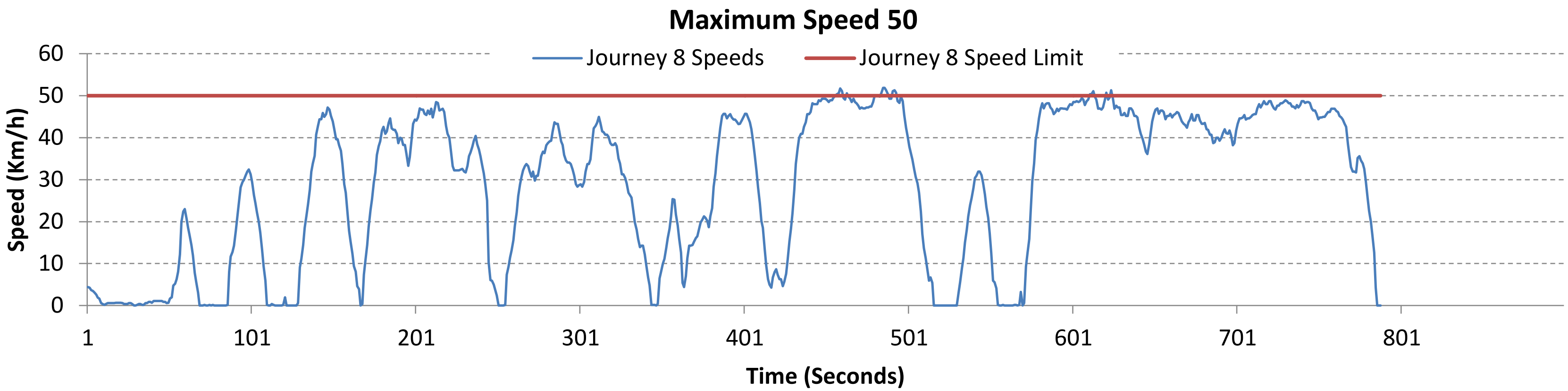
  - The mean idle time at 40km/h and 50km/h was 3:01 minutes (SD = 1:36) and 3:05 minutes (SD = 0:56) respectively. The differences in the idle time were not significant.

- Out of the city:
  - Reducing the maximum speed from 50km/h to 40km/h reduced the mean speed by 7.8% from 25.37km/h (SD = 2.52) to 23.37km/h (SD = 2.92).
  - The mean idle time at 40km/h and 50km/h was 3:45 minutes (SD = 1.39) and 3:23 minutes (SD = 1.27) respectively. The differences in the idle time were not significant.
  - Travelling at a 40km/h maximum speed took 01:19 minutes (CI±1:01) longer to arrive at their destination – an 8.8% increase.
  - There was no significant difference in fuel consumption.
- Overall:
  - Reducing the maximum speed by 20% from 50km/h to 40km/h reduced the mean speed by 6.6% from 25.64km/h (SD = 2.53) to 23.97km/h (SD = 3.28).
  - The mean idle time at 40km/h and 50km/h was 3:24 minutes (SD = 1:39) and 3:13 minutes (SD = 1:13) respectively. The differences in the idle time were not significant.
  - Decreasing maximum speed by 20%, from 50km/h to 40km/h increased travel time by 1:08 minutes (CI±0:44) (7.7%) and reduced fuel consumption by 0.015 litres (CI±0.012) (3.4%).
- Both travel time and fuel consumption were closely correlated with idle time. Overall, the measured variables explained 92% of the variation in travel time and 74% of the variation in fuel consumption.
- Travelling at the higher maximum speed predicted shorter travel time. Increases in the driver's ratings of the effect of traffic, idle time and travelling into the city predicted longer travel time.
- Travelling at the higher maximum speed, increased idle time and driver ratings for the effect of traffic and travelling into the city predicted higher fuel consumption.

Figure 2.9 shows driver speed over time on two trips with travel times close to the mean for the city to Island Bay direction on the Wellington short route.

Figure 2.9 Two plots of driver speed over time for two randomly selected trips on Wellington short route two from Island Bay to Wellington City





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2.2.1 Change in mean speed

The mean travel speeds for each of the tested maximum speeds are shown in table 2.13.

Table 2.13 Recorded mean speeds (km/h) between trips at different maximum speeds overall and in each trip direction (n = 120)

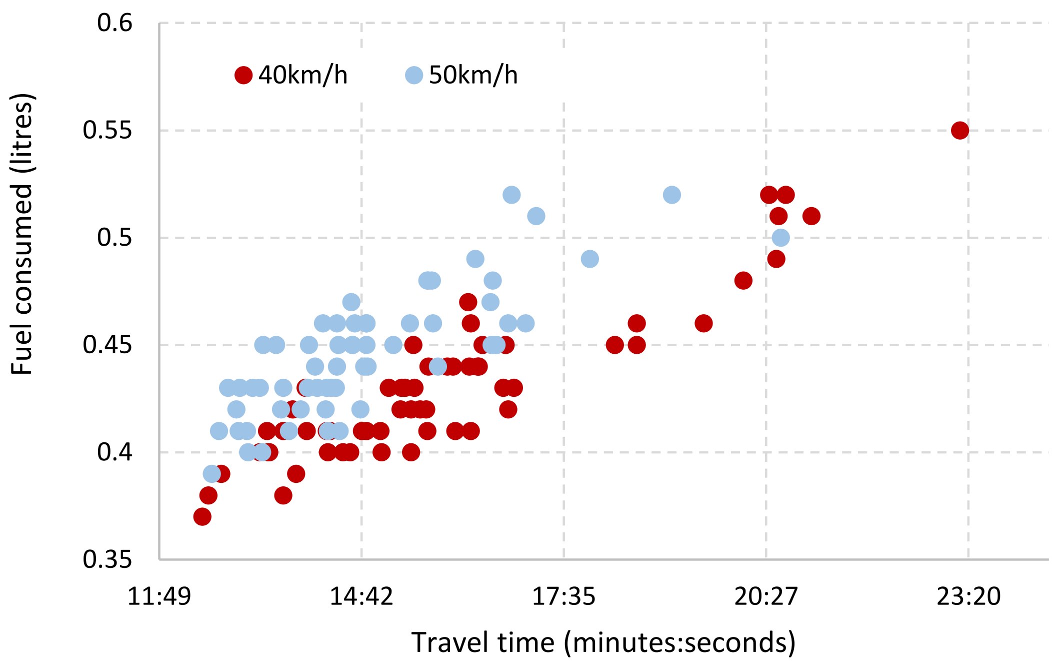
Direction of travel	40km/h maximum speed	50km/h maximum speed	Mean difference between speeds (95% CI)
Overall	**23.97 (SD = 3.28, n = 59)**	**25.64 (SD = 2.53, n = 61)**	**1.68 (0.62 – 2.73)***
Into the city	24.58 (SD = 3.56, n = 29)	25.91 (SD = 2.55, n = 31)	1.33 (0.26 -2.92)
Out of the city	23.37 (SD = 2.92, n = 30)	25.37 (SD = 2.52, n = 30)	1.99 (0.58 – 3.40)*

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk.

2.2.2 Combining fuel consumption and travel time

The relationship between fuel consumption, travel time and maximum speed is illustrated by figure 2.10. For Wellington short route two, trips that took longer used more fuel. Trips of the same duration used more fuel with a maximum speed of 50km/h than at 40km/h.

Figure 2.10 Travel time plotted against fuel consumption for all trips on Wellington short route two (n = 120)



2.2.3 Travel time by direction of travel

Direction of travel, into or out of the city, had a significant effect on travel time (table 2.14). For trips with a 40km/h maximum speed, travelling into the city took significantly longer than returning from the city but the difference in trip direction was not significant for trips with a 50km/h maximum speed. The difference may be explained by a small section in the route where the directions follow different one-way roads. The mean idle time for each direction was not significantly different.

Table 2.14 Effect of direction of travel on travel time at 40km/h and 50km/h maximum speeds on Wellington short route two (n = 120)

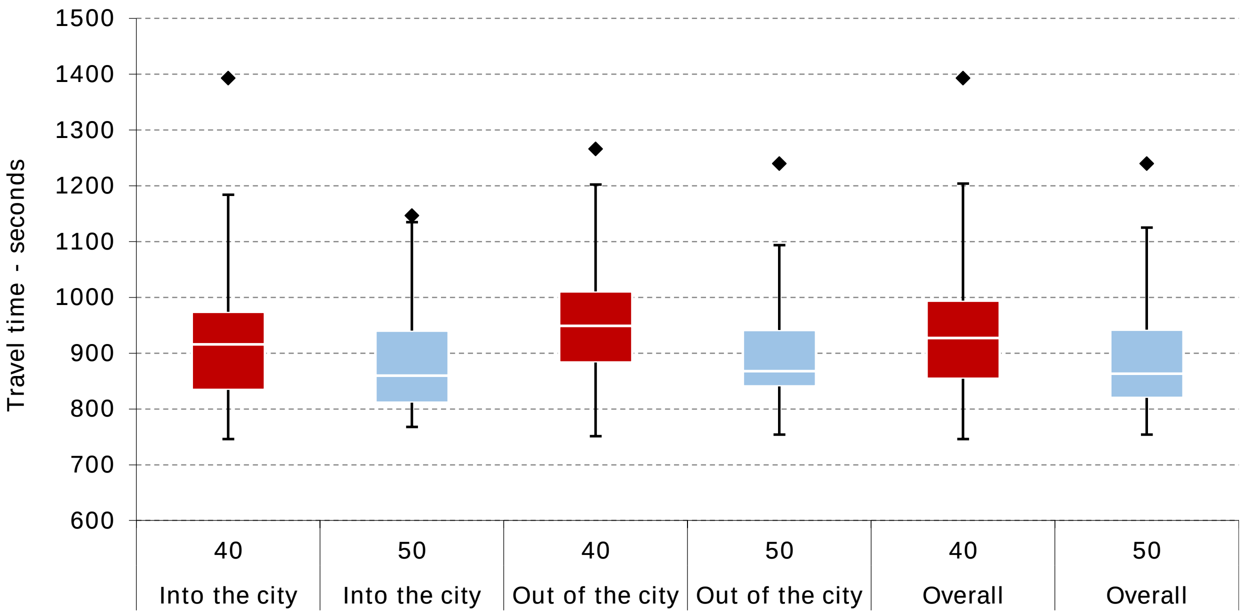
Maximum trip speed	Into the city	Out of the city	Mean difference in direction of travel (95% CI)
40km/h	15:39 (SD = 02:37, n = 29)	16:14 (SD = 02:11, n = 30)	00:35 (00:40 – 01:50)*
50km/h	14:43 (SD = 01:34, n = 31)	14:55 (SD = 01:41, n = 30)	00:12 (-00:38 – 01:02)

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk.

2.2.4 Effect of changing maximum speed on travel time

Figure 2.11 shows the distribution of travel time for the trips into and out of the city, alongside the combined results, for each of the tested maximum speeds.

Figure 2.11 Box plots for travel time at the tested maximum speeds on the Wellington short route into and out of the city, and overall (n = 120). Diamonds mark upper outliers and squares mark lower outliers



The differences in travel time between the two tested maximum speeds were significant when comparing trips out of the city and overall ($p < 0.05$) (table 2.15). On average, driving at a maximum speed of 40 km/h resulted in a trip that was 1:08 minutes slower than when travelling at a maximum of 50 km/h.

Table 2.15 Differences in travel time between trips at different maximum speeds overall and in each trip direction (n = 120)

Maximum trip speed	40km/h	50km/h	Mean difference between speeds (95% CI)
Overall	**15:57 (SD = 02:24, n = 59)**	**14:49 (SD = 01:39, n = 61)**	**01:08 (00:24 - 01:52)***
Into the city	15:39 (SD = 02:37, n = 29)	14:43 (SD = 01:34, n = 31)	00:56 (-00:09 - 02:02)
Out of the city	16:14 (SD = 02:11, n = 30)	14:55 (SD = 01:41, n = 30)	01:19 (00:18 - 02:20)*

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk.

2.2.5 Idle time

There were no significant differences in idle time detected across trips at the two tested speeds in either direction or overall (table 2.16). Idle time was strongly correlated with trip travel time (R_p = 0.91).

Table 2.16 Differences in idle time between trips at different maximum speeds overall and in each trip direction (n = 120)

Maximum trip speed	40km/h	50km/h	Mean difference between speeds (95% CI)
Overall	**03:24 (SD = 1:39, n = 59)**	**03:13 (SD = 1:13, n = 61)**	**00:10 (- 00:22 - 00:41)**
Into the city	03:01 (SD = 01:36, n = 29)	03:05 (SD = 00:56, n = 31)	-00:04 (-00:44 - 00:36)
Out of the city	03:45 (SD = 01:39, n = 30)	03:23 (SD = 01:27, n = 30)	00:22 (-00:26 - 01:10)

2.2.6 Predicting travel time

A multiple regression was run to predict travel time on Wellington short route two based on:

- maximum speed
- traffic rating
- idle time
- traffic light stops
- direction of travel.

Weather rating was not included in the analysis as the driver recorded a rating of 1 (no effect) for each trip. The other variables significantly predicted travel time (F(5,114) = 275.135, p < 0.001) and explained 92% of the variation in travel time across trips (adj. R^2 = 0.920).

All variables except traffic light stops added significantly to the prediction. An increase in maximum speed predicted lower travel time. Higher traffic rating and idle time predicted higher travel time. Travelling into the city predicted higher travel times (table 2.17).

Table 2.17 Multiple regression results for travel time showing significant (p < 0.05) predictors (n = 120)

Variable	B	SE_B	β
Trip maximum speed	-7.338	0.690	-.291
Direction of travel	14.268	6.652	0.57
Traffic rating	39.500	5.354	0.249
Idle time	1.054	0.055	0.723

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

2.2.7 Fuel consumption by direction of travel

Direction of travel, into or out of the city, did not have a significant effect on fuel consumption on Wellington short route two (table 2.18). Idle time was strongly correlated (R_p = 0.73) with fuel consumption.

Table 2.18 Effect of direction of travel on fuel consumption (litres) at 40km/h and 50km/h (n = 120)

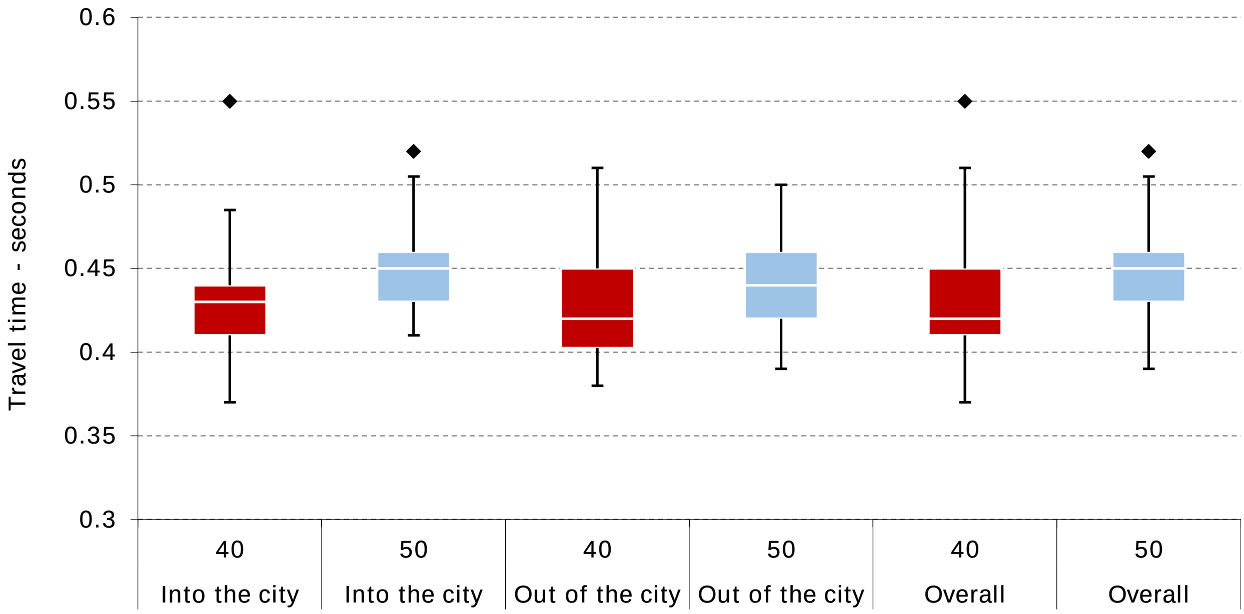
Trip maximum speed	Into the city	Out of the city	Mean difference in direction of travel (95% CI)
40km/h	0.436 (SD = 0.032, n = 29)	0.428 (SD = 0.032, n = 30)	-0.008 (0.028 – 0.011)
50km/h	0.452 (SD = 0.030, n = 31)	0.440 (SD = 0.028, n = 30)	-0.012 (-0.027 – 0.003)

Note: Differences significant (t-test, $p < 0.05$) are marked with an asterisk.

2.2.8 Effect of changing maximum speed on fuel consumption

Figure 2.12 shows the distribution of fuel consumption for the trips into and out of the city, alongside the combined results, for each of the tested travel speeds.

Figure 2.12 Box plots for fuel consumption at the tested speeds on Wellington short route two into and out of the city, and overall (n = 120). Diamonds mark upper outliers and squares mark lower outliers



The differences in fuel consumption between the two tested maximum speeds were significant when comparing trips overall ($p < 0.05$) (table 2.19).

Table 2.19 Differences in fuel consumption (litres) between trips at different maximum speeds on the Wellington short route overall and in each trip direction (n = 105)

Trip maximum speed	40km/h	50km/h	Mean difference between speeds (95% CI)
Overall	0.432 (SD = 0.037, n = 59)	0.446 (SD = 0.018, n = 61)	-0.015 (-0.027 to -0.003)*
Into the city	0.436 (SD = 0.032, n = 29)	0.452 (SD = 0.030, n = 31)	-0.016 (-0.035 to 0.002)
Out of the city	0.428 (SD = 0.032, n = 30)	0.440 (SD = 0.028, n = 30)	-0.013 (-0.028 to -0.003)

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk.

2.2.9 Predicting fuel consumption

A multiple regression was run to predict fuel consumption on Wellington short route two based on:

- maximum speed
- traffic rating
- number of traffic light stops
- direction of travel
- idle time.

Weather rating was not included in the analysis as it was recorded as having no effect on all trips. All remaining variables significantly predicted fuel consumption ($F(5,114) = 69.980$, $p < 0.001$) and explained 74% of the variation in fuel consumption across trips (adj. $R^2 = 0.741$).

All variables except the number of traffic light stops added significantly to the model. Increase in traffic rating, travelling into the city and idle time predicted higher fuel consumption (table 2.20).

Table 2.20 Multiple regression results for travel time showing significant ($p < 0.05$) predictors ($n = 120$)

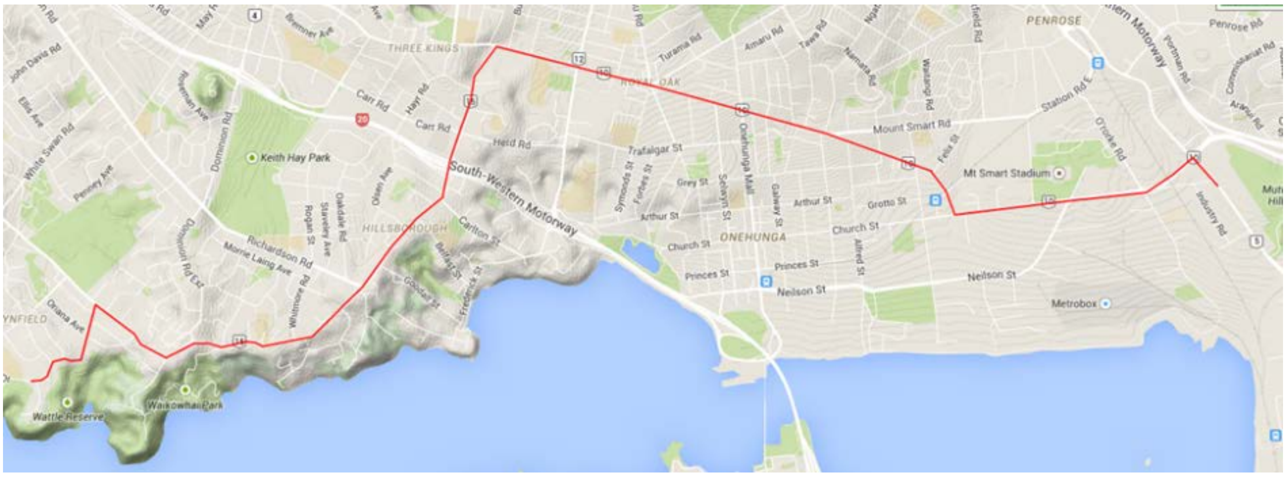
Variable	B	SE_B	β
Maximum speed limit	**0.001**	**0.000**	**0.173**
Direction of travel	0.019	0.003	0.274
Traffic rating	0.013	0.003	0.310
Idle time	0.000	0.000	0.585

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

2.3 Auckland short route

The **Lynfield to Mount Wellington** route was shorter and designed to be representative of a commute through suburban Auckland. It avoided the motorway but still included some of the Auckland arterial roads, particularly Great South Road. It was the longest of the three short routes.

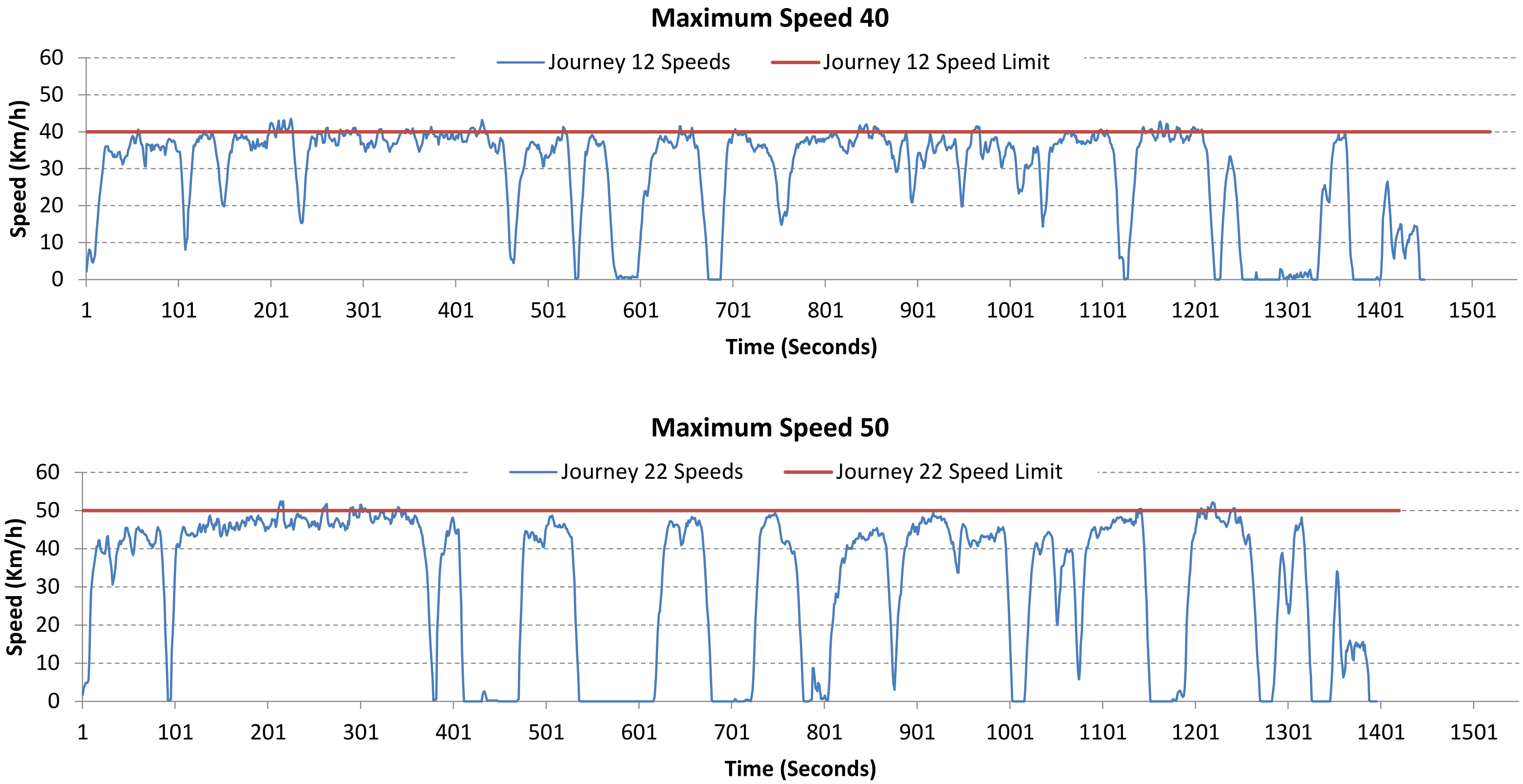
Figure 2.13 Lynfield to Mount Wellington route



- The driver completed 102 trips, including 51 at a maximum speed of 40km/h (mean speed 28.50km/h (SD = 1.57)) and 51 at a maximum speed of 50km/h (mean speed 33.03km/h (SD = 3.63)).
- Trips into the city (Lynfield to Mount Wellington) took significantly longer than trips out of the city at maximum speeds of 40km/h and 50km/h. They also used more fuel.
- Into the city:
  - Reducing the maximum speed by 20% from 50km/h to 40km/h reduced the mean speed by 9.8% from 30.82km/h (SD = 3.52) to 27.79km/h (SD = 1.56).
  - The mean idle time at 40km/h and 50km/h was 3:16 minutes (SD = 1:15) and 4:09 minutes (SD = 2:27) respectively. The differences in the idle time were not significant.
  - Travelling at a 40km/h maximum speed took 2:13 minutes (CI±1:17) longer than trips at a 50km/h maximum speed – a 9.5% increase.
  - There was no significant difference in fuel consumption.
- Out of the city
  - Reducing the maximum speed by 20% from 50km/h to 40km/h reduced the mean speed by 16.5% from 35.16km/h (SD = 2.21) to 29.37km/h (SD = 1.08).
  - The mean idle time at 40km/h and 50km/h was 2:16 minutes (SD = 0:52) and 1:52 minutes (SD = 0:59) respectively. The differences in the idle time were not significant.
  - Travelling at a 40km/h maximum speed took 4:00 (CI±0:43) minutes longer than trips at a 50km/h maximum speed – a 20% increase.
  - There was no significant difference in fuel consumption.
- Overall:
  - Decreasing maximum speed by 20%, from 50km/h to 40km/h, decreased mean speed by 13.7% from 33.03km/h (SD = 3.63) to 28.50km/h (SD = 1.57).
  - The mean idle time at 40km/h and 50km/h was 2:49 minutes (SD = 1:12) and 2:59 minutes (SD = 2:10) respectively. The differences in the idle time were not significant but travel time was highly correlated with idle time.
  - Decreasing maximum speed by 20%, from 50km/h to 40km/h, increased travel time by 3:13 minutes (CI±0:52) (14.9%).
  - There was no significant difference in fuel consumption.
  - Overall, the measured variables explained 96% of the variation in travel time and 67% of the variation in fuel consumption.
  - Travelling at the higher maximum speed predicted shorter travel time. Increases in the driver's ratings of the effect of traffic, idle time and travelling into the city predicted longer travel time.
  - Travelling into the city and increased idle time predicted higher fuel consumption.

The two figures below show driver speed over time on single trips with travel times close to the mean for the journey into the city on the Auckland short route.

Figure 2.14 Two plots of driver speed over time for two randomly selected trips on the Auckland short route



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2.3.1 Change in mean speed

The mean travel speeds for each of the tested maximum speeds are shown in table 2.21.

Table 2.21 Recorded mean speeds between trips at different maximum speeds overall and in each trip direction (n = 102)

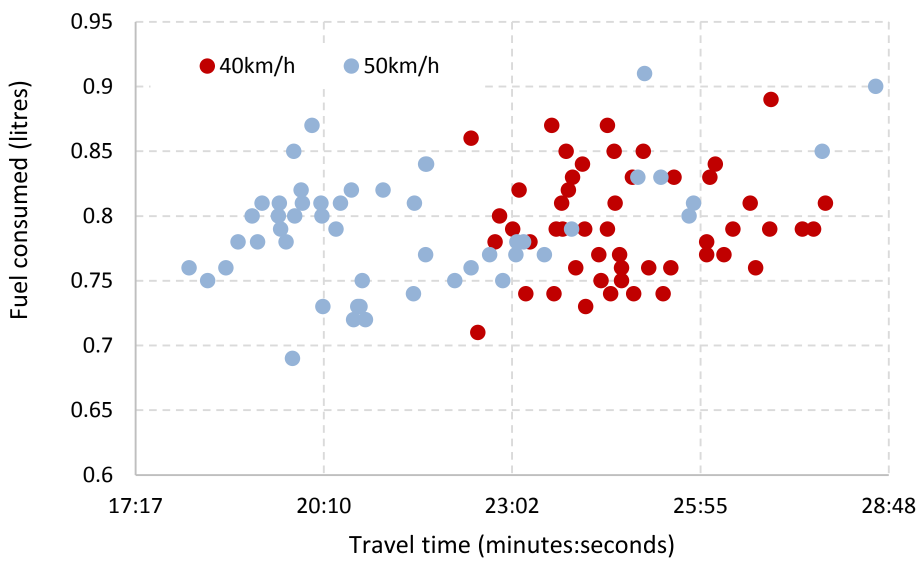
Direction of travel	40km/h maximum speed	50km/h maximum speed	Mean difference between speeds (95% CI)
Overall	**28.50 (SD = 1.57, n = 51)**	**33.03 (SD = 3.63, n = 51)**	**4.53 (3.43 – 5.63)***
Into the city	27.79 (SD = 1.56, n = 28)	30.82 (SD = 3.52, n = 25)	3.02 (1.55 – 4.49)*
Out of the city	29.37 (SD = 1.08, n = 23)	35.16 (SD = 2.21, n = 26)	5.80 (4.81 – 6.79)*

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk. The assumption of normality was violated for travel time at 50km/h overall so significance of the difference was confirmed with a Mann-Whitney U test ($p < 0.001$).

2.3.2 Combining fuel consumption and travel time

The relationship between fuel consumption, travel time and maximum speed on the Auckland short route is illustrated by figure 2.15. Trips that took longer used more fuel, but trips of the same duration used more fuel at 50km/h than at 40km/h.

Figure 2.15 Travel time plotted against fuel consumption for all trips on the Auckland short route (n = 102)



2.3.3 Travel time by direction of travel

Direction of travel, into or out of the city, had a significant effect on travel time for the Auckland short route (table 2.22). At a 40km/h maximum speed, travelling into the city took significantly longer than returning from the city and this was also significant for trips at a 50km/h maximum speed. The mean idle time for each direction was not significantly different.

Table 2.22 Effect of direction of travel on travel time at 40km/h and 50km/h maximum speeds (n = 102)

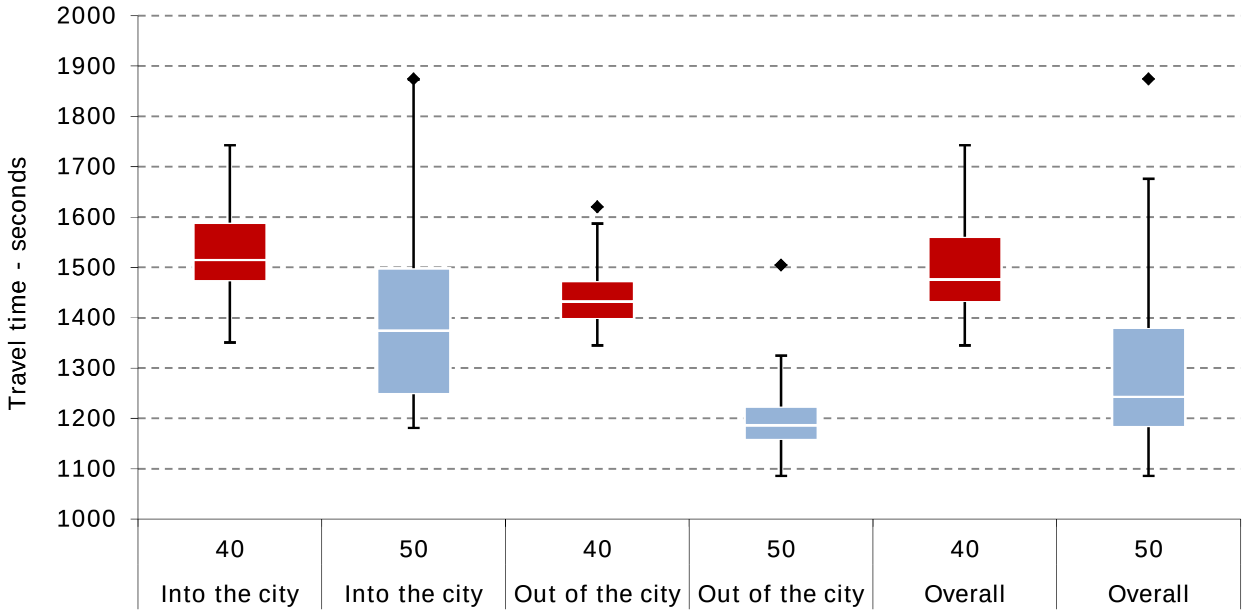
Trip maximum speeds	Into the city	Out of the city	Mean difference in direction of travel (95% CI)
40km/h	25:33 (SD = 01:27, n = 28)	24:03 (SD = 01:05, n = 23)	-01:30 (-02:15 to -00:46)*
50km/h	23:20 (SD = 02:51, n = 25)	20:03 (SD = 01:24, n = 26)	03:16 (04:34 – 02:00)*

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk.

2.3.4 Effect of changing speed on travel time

Figure 2.16 shows the distribution of travel time for the trips into and out of the city, alongside the combined results, for each of the tested maximum speeds.

Figure 2.16 Box plots for travel time at the tested maximum speeds into and out of the city, and overall (n = 102) for the Auckland short route. Diamonds mark upper outliers and squares mark lower outliers



The differences in travel time between the two maximum speeds was significant when comparing trips into and out of the city, and overall ($p < 0.01$) (table 2.23).

Table 2.23 Differences in travel time between trips at different maximum speeds overall and in each trip direction (n = 105)

Trip maximum speed	40km/h	50km/h	Mean difference between speeds (95% CI)
Overall	**24:52 (SD = 01:30, n = 51)**	**21:39 (SD = 02:46, n = 51)**	**03:13 (02:21 - 04:05)***
Into the city	25:33 (SD = 01:27, n = 28)	23:20 (SD = 02:51, n = 25)	02:13 (00:56 - 03:31)*
Out of the city	24:03 (SD = 01:05, n = 23)	20:02 (SD = 01:24, n = 26)	04:00 (03:16 - 04:43)*

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk. The assumption of normality was violated for travel time at 50km/h so significance of the difference was confirmed with a Mann-Whitney U test ($p < 0.001$).

2.3.5 Idle time

There were no significant differences detected in idle time between trips at the two different maximum speeds in both directions or overall (table 2.24). Travel time was highly correlated with idle time (R_p = -0.740, $p < 0.001$).

Table 2.24 Differences in idle time between trips at different maximum speeds overall and in each trip direction (n = 105)

Maximum trip speed	40km/h	50km/h	Mean difference between speeds (95% CI)
Overall	**02:49 (SD = 1:12, n = 51)**	**02:59 (SD = 2:10, n = 51)**	**- 00:10 (- 00:51 - 00:31)**
Into the city	03:16 (SD = 01:15, n = 28)	04:09 (SD = 02:27, n = 25)	-00:52 (-01:56 - 00:10)
Out of the city	02:16 (SD = 00:52, n = 23)	01:52 (SD = 00:59, n = 26)	00:24 (-00:08 - 00:56)

2.3.6 Predicting travel time

A multiple regression was run to predict travel time on the Auckland short route based on:

- maximum speed
- idle time
- traffic rating
- direction of travel.

Weather rating was not included in the analysis as it was recorded as having no effect on all trips. These variables generated a statistically significant model for predicting travel time ($F(4,97) = 555.728$, $p < 0.001$) and explained 96% of the variation in travel time across trips (adj. $R^2 = 0.956$).

All variables added significantly to the prediction. The higher maximum speed predicted lower travel time. Higher idle time and the driver's rating for traffic predicted higher travel time. Travelling into the city was predictive of higher travel times (table 2.25).

Table 2.25 Multiple regression results for travel time showing significant (p < 0.05) predictors (n = 102)

Variable	B	SE_B	β
Trip maximum speed	-20.594	0.686	-0.630
Direction of travel	36.113	7.813	0.110
Traffic	30.172	6.288	0.107
Idle time	1.076	0.040	0.684

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

2.3.7 Fuel consumption by direction of travel

Direction of travel, into or out of the city, had a significant effect on fuel consumption on the Auckland short route (table 2.26). At a 40km/h maximum speed, travelling into the city consumed significantly more fuel than returning from the city but the difference in trip direction was not significant for trips at 50km/h.

Table 2.26 Effect of direction of travel on fuel consumption (litres) at 40km/h and 50km/h (n = 105)

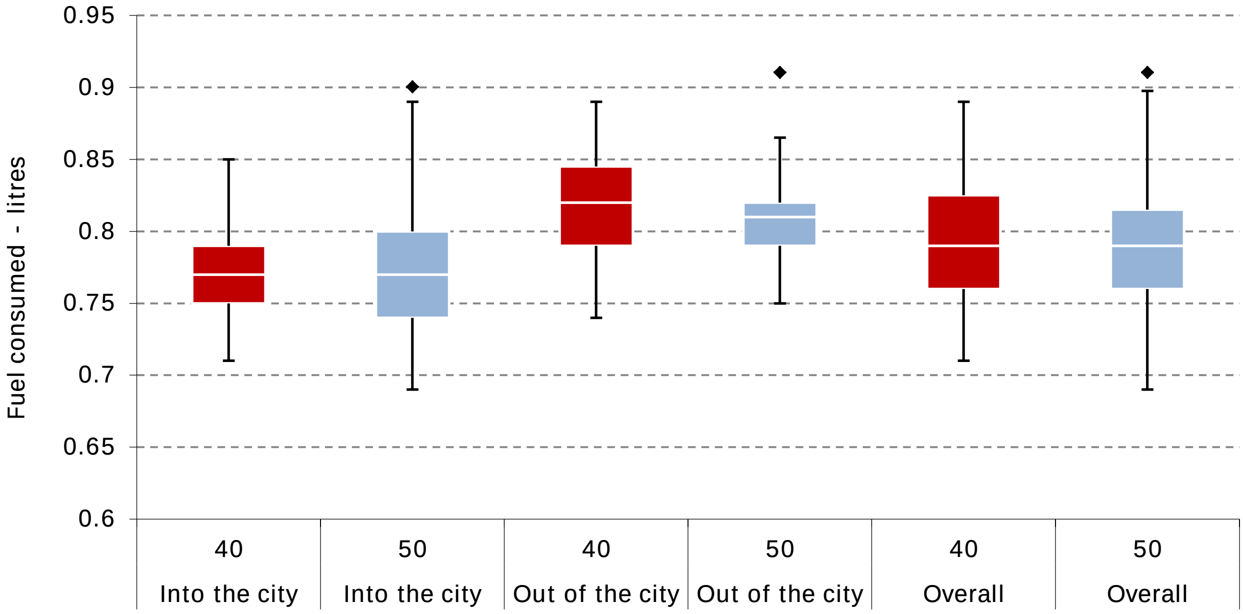
Trip maximum speed	Into the city	Out of the city	Mean difference in direction of travel (95% CI)
40km/h	0.772 (SD = 0.032, n = 28)	0.821 (SD = 0.036, n = 23)	0.049 (0.030 – 0.068)*
50km/h	0.777 (SD = 0.053, n = 25)	0.809 (SD = 0.035, n = 26)	0.032 (0.006 – 0.057)*

Note: Significant differences (t-test, $p < 0.05$) are marked with an asterisk.

2.3.8 Effect of changing maximum speed on fuel consumption

Figure 2.17 shows the distribution of fuel consumption for the trips into and out of the city, alongside the combined results, for each of the tested maximum speeds on the Auckland short route.

Figure 2.17 Box plots for fuel consumption at the tested maximum speeds into and out of the city, and overall (n = 102) for the Auckland short route. Diamonds mark upper outliers and squares mark lower outliers



The differences in fuel consumption between the two maximum speeds were not significant when comparing trips into and out of the city, and overall ($p > 0.05$) (table 2.27).

Table 2.27 Differences in fuel consumption (litres) between trips at different maximum speeds overall and in each trip direction (n = 102) for the Auckland short route

Trip maximum speed	40km/h	50km/h	Mean difference between speeds (95% CI)
Overall	**0.794 (SD = 0.041, n = 51)**	**0.793 (SD = 0.047, n = 51)**	**0.001 (- 0.016 to 0.019)**
Into the city	0.772 (SD = 0.032, n = 28)	0.777 (SD = 0.053, n = 25)	-0.005 (-0.029 to 0.019)
Out of the city	0.821 (SD = 0.036, n = 23)	0.809 (SD = 0.035, n = 26)	0.012 (-0.008 to 0.033)

Note: None of the differences were significant (t-test, $p > 0.05$).

2.3.9 Predicting fuel consumption

A multiple regression was run to predict fuel consumption for the Auckland short route based on:

- maximum speed
- traffic rating
- direction of travel
- weather rating
- idle time.

Weather rating was not included in the analysis as it was recorded as having no effect on all trips. These variables were significantly predictive of fuel consumption ($F(4,97) = 51.753$, $p < 0.001$) and explained 67% of the variation in fuel consumption across trips (adj. $R^2 = 0.668$).

Direction of travel and idle time added significantly to the prediction, with increases in idle time and travelling into the city increasing fuel consumption (table 2.28). Trip maximum speed was not a significant predictor of fuel consumption.

Table 2.28 Multiple regression results for travel time showing significant ($p < 0.05$) predictors ($n = 102$)

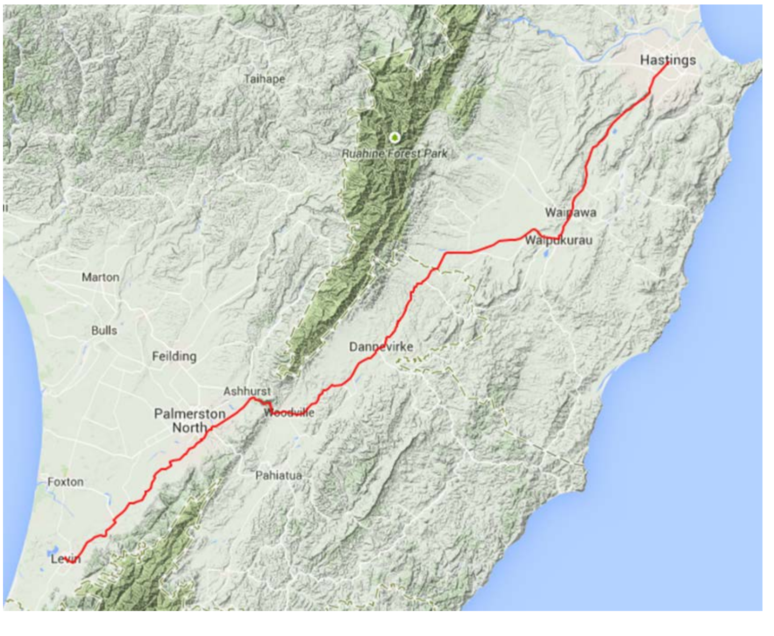
Variable	B	SE_B	β
Direction of travel	-0.071	.006	-.813
Idle time	0.000	0.000	0.738

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

2.4 Hastings to Levin

The **Hastings to Levin** route is important for freight and for people travelling across the North Island. It has a combination of sections with and without passing-lanes, is often subject to a high volume of traffic and has some tortuous sections. As with the Tauranga route, fatigue and traffic management were key considerations.

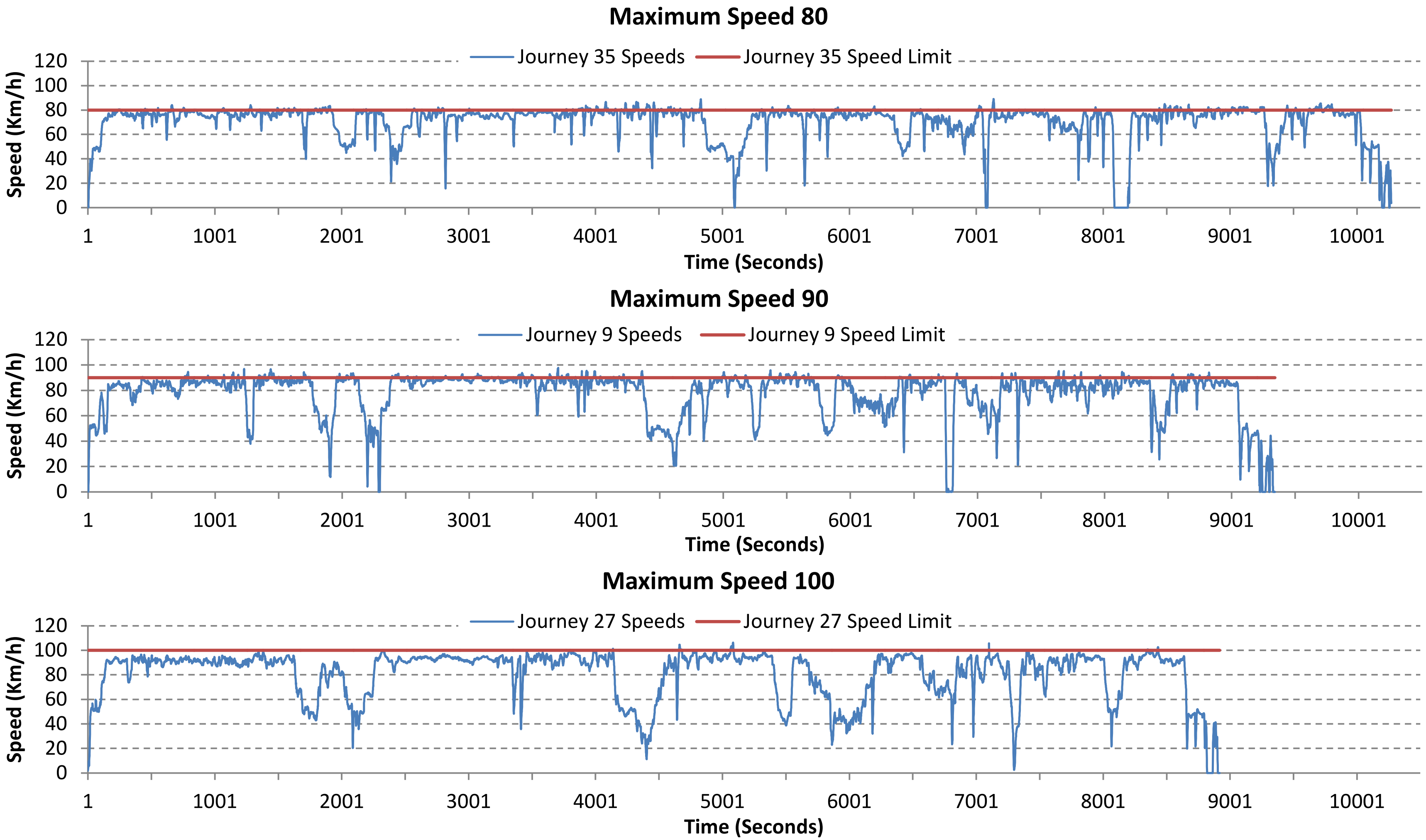
Figure 2.18 Hastings to Levin route



- The driver completed 40 usable trips, including 15 at a maximum speeds of 80km/h (mean 70.73km/h (SD = 0.72)), 15 at 90km/h (mean 76.40km/h (SD = 0.88)) and 10 at 100km/h (mean 79.39km/h (SD = 1.26)).
- Reducing the maximum speed by 20% from 100km/h to 80km/h reduced the mean speed by 10.9% from 79.39km/h (SD = 1.26) to 70.73km/h (SD = 0.72). Reducing the maximum speed from 100km/h to 90km/h reduced the mean speed by 3.8% from 79.39km/h (SD = 1.26) to 76.40km/h (SD = 0.88).
- The mean idle time at 80km/h, 90km/h and 100km/h was 0:30 seconds (SD = 0:53), 1:15 seconds (SD = 1:14) and 1:05 (SD = 1:26) seconds respectively. The differences in the idle time were not significant.
- Fuel consumption was consistent across both directions of travel but there was a small, significant difference in travel time at a maximum speed of 80km/h only.
  - Decreasing maximum speed by 20%, from 100km/h to 80km/h, increased travel time by 18:14 minutes (CI±1:58) (12.3%) and reduced fuel consumption by 1.578 (CI±0.445) litres (14.6%).
  - Decreasing maximum speed by 10% from 100km/h to 90km/h increased travel time by 6:02 minutes (CI±1:58) (4.1%) and reduced fuel consumption by 0.568 litres (CI±0.445) (5.3%).
- Both travel time and fuel consumption were highly correlated with trip maximum speed. Among the measured variables, maximum speed was the only significant predictor of travel time and fuel consumption. Travelling at higher maximum speeds predicted shorter travel time and explained 89% of the variation. Travelling at higher maximum speed predicted higher fuel consumption and explained 65% of the variation.

The three charts below show driver speed over time on single trips with travel times close to the mean for each of the tested speeds on the Hastings to Levin route.

Figure 2.19 Three plots of driver speed over time for two randomly selected trips on the Hastings to Levin short route



2.4.1 Change in mean speed

The mean travel speeds for each of the tested maximum speeds are shown in table 2.29.

Table 2.29 Recorded mean speeds between trips at different maximum speeds overall and in each trip direction (n = 40)

Trip maximum speed	Number of trips	Mean speed	Mean difference compared to mean speed at a maximum speed of 100km/h (95% CI)	Mean difference compared to mean speed at a maximum speed of 90km/h (95% CI)
80km/h	15	70.73 (SD = 0.72)	8.66* (7.73 – 9.59)	5.67* (4.84 - 6.51)
90km/h	15	76.40 (SD = 0.88)	2.99* (2.05 – 3.92)	–
100km/h	10	79.39 (SD = 1.26)	–	-2.99* (-3.92 to -2.05)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met ($p > 0.05$). Significant differences (one-way AONVA, $p < 0.05$) are marked with an asterisk.

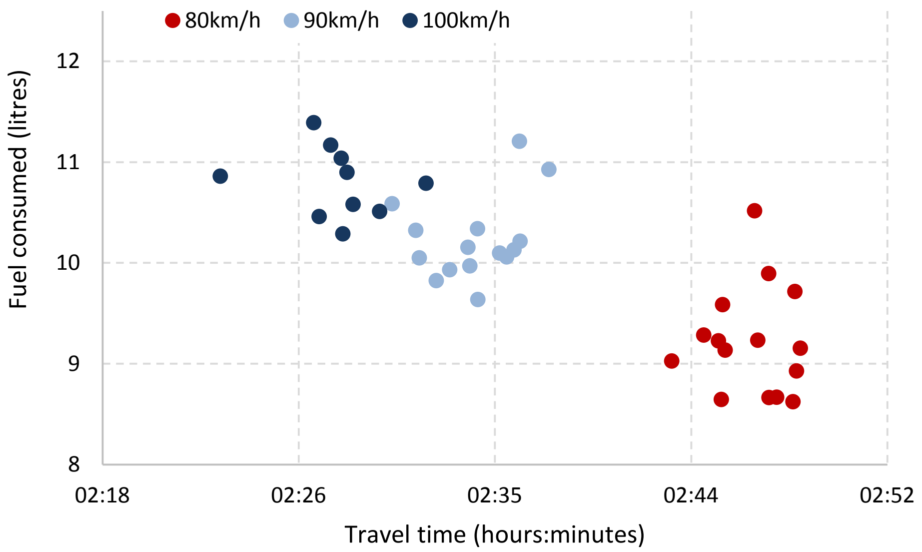
2.4.2 Direction of travel

Direction of travel had a significant effect on travel time only for trips completed at 80km/h ($t = -2.289$, $p = 0.04$). The mean difference was very small (00:01:49 (n = 15, 00:03:33 – 00:00:06)) so the overall results are presented in this section, covering both directions together.

2.4.3 Combining fuel consumption and travel time

There was a strong relationship between travel time and fuel consumption on trips between Hastings and Levin. The effect of increasing trip maximum speed is illustrated in figure 2.20.

Figure 2.20 Travel time and fuel consumption of trips between Hastings and Levin at different trip maximum speeds (n = 40)

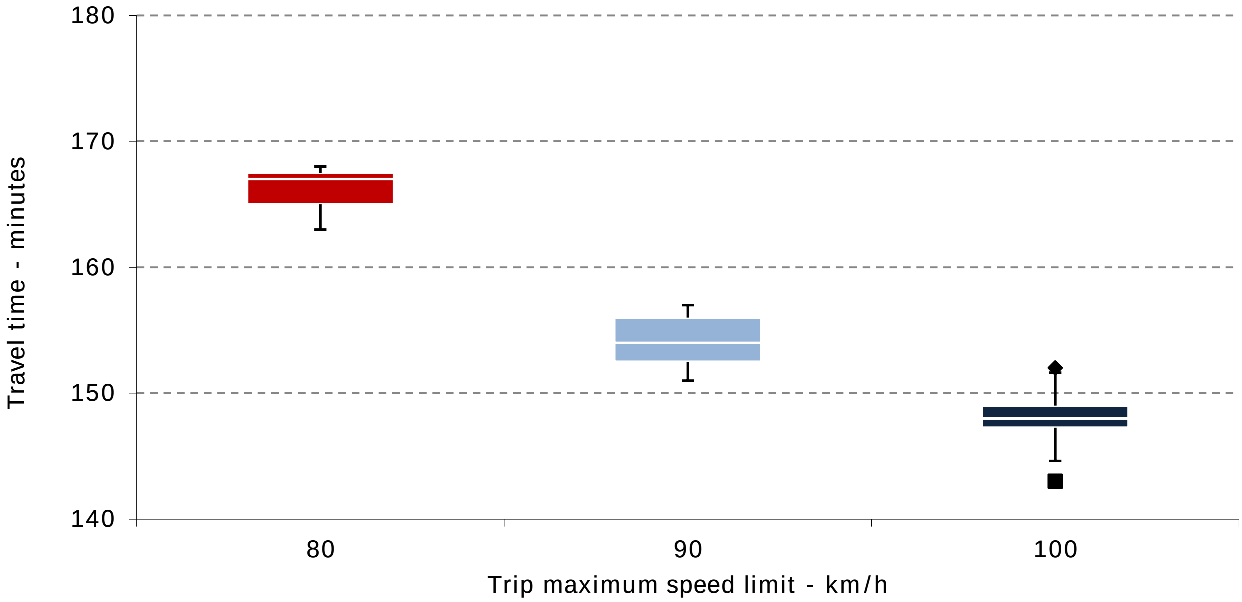


The difference between trips at 80km/h and trips at 100km/h was more marked than that between trips at 90km/h and 100km/h.

2.4.4 Effect of changing speed on travel time

Figure 2.21 shows the distribution of travel times for trips at the three tested maximum speeds on the Hastings to Levin route. Variation was highest at the 100km/h maximum speed.

Figure 2.21 Box plot of travel time for Hastings to Levin at the three tested maximum speeds (n = 40)



Results of one-way ANOVA of travel time at the three maximum speeds tested (80km/h, 90km/h and 100km/h) showed that the trip maximum speed had a significant effect on travel time ($F(2,37) = 284.389$, $p < 0.001$) (table 2.30). Trip maximum speed explained almost all (93%) of the variation in travel time ($\omega^2 = 0.93$).

Table 2.30 One- way ANOVA results of maximum trip speed's effect on mean travel time for the Hastings to Levin route (n = 40)

Trip maximum speed	Number of trips	Mean travel time	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	15	02:46:50 (SD = 00:01:44)	00:18:14*(00:16:16 - 00:20:13)	00:12:13* (00:10:27 - 00:13:58)
90km/h	15	02:34:37 (SD = 00:01:59)	00:06:02* (00:04:04 - 00:08:00)	–
100km/h	10	02:28:36 (SD = 00:02:18)	–	-00:06:02* (-00:04:04 to -00:08:00)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met ($p > 0.05$). Significant differences ($p < 0.05$) are marked with an asterisk.

The 10km/h decrease in trip maximum speed from 100km/h to 90km/h resulted in a 4% increase in travel time, much smaller than 8% increase from reducing speed from 90km/h to 80km/h. This may be because in some sections of the route, the driver was not able to drive 90km/h, even when driving to a 100km/h trip maximum speed.

2.4.5 Idle time

There was no significant difference detected in the mean idle time between trips at any of the three speeds tested (table 2.31).

Table 2.31 Differences in idle time between trips at different maximum speeds overall (n = 40)

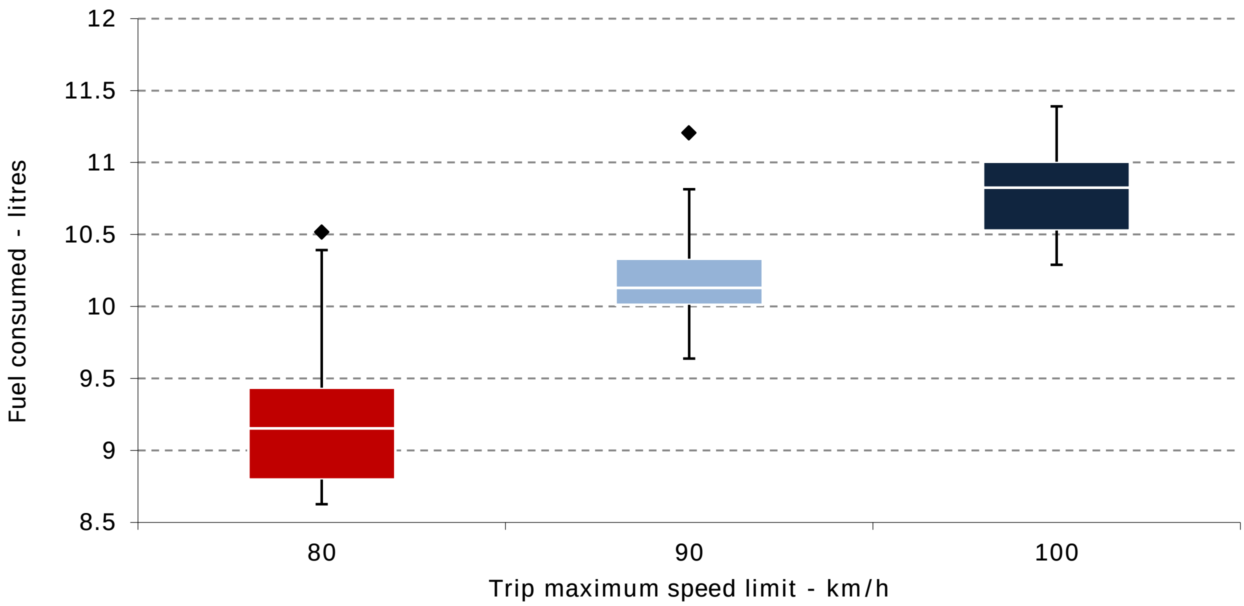
Trip maximum speed	Number of trips	Mean idle time	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	15	00:00:30 (SD = 00:00:53)	-00:00:35 (-00:01:33 - 00:00:22)	-00:00:46 (-00:01:34 - 00:00:02)
90km/h	15	00:01:15 (SD = 00:01:14)	00:00:11 (-00:00:56 - 00:01:17)	–
100km/h	10	00:01:05 (SD = 00:01:26)	–	-00:00:11 (00:00:56 to - 00:01:17)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met ($p > 0.05$). Significant differences ($p < 0.05$) are marked with an asterisk.

2.4.6 Effect of changing maximum speed on fuel consumption

The distribution of fuel consumption at each of the tested speeds is shown in figure 2.22.

Figure 2.22 Fuel consumed on Hastings to Levin trips by trip maximum speed (n = 40). Diamonds mark upper outliers and squares mark lower outliers



Results of a one-way ANOVA of fuel consumption at the three maximum speeds tested (80km/h, 90km/h and 100km/h) showed that the trip maximum speed had a significant effect on travel time ($F(2,37) = 40.861$, $p < 0.001$) (table 2.32). Trip maximum speed explained almost all (67%) of the variation in travel time ($\omega^2 = 0.67$).

Table 2.32 One- way ANOVA results showing maximum trip speed's effect on mean fuel consumption (litres) on Hastings to Levin trips (n = 40)

Trip maximum speed	Number of trips	Mean fuel consumption	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	15	9.221 (SD = 0.532)	-1.578*(-2.023 to -1.133)	-1.010*(-1.408 to -0.612)
90km/h	15	10.231 (SD = 0.410)	-0.568*(-1.013 to -0.123)	-
100km/h	10	10.799 (SD = 0.344)	-	-0.568*(-1.013 to -0.123)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met ($p > 0.05$). Significant differences ($p < 0.05$) are marked with an asterisk.

Decreasing maximum speed by 9% from 90km/h to 80km/h led to a 10% fuel saving, much greater than the 5% saving from decreasing from 100km/h to 90km/h.

2.4.7 Predicting travel time and fuel consumption

There was a strong correlation between maximum speed and both travel time (R_p = - 0.950, $p < 0.001$) and fuel consumption (R_p = 0.818, $p < 0.001$). Multiple regression was run to predict travel time and fuel consumption using the following variables:

- maximum speed limit
- direction of travel
- traffic rating
- weather rating
- idle time.

The model was significantly predictive of travel time ($F(5,34) = 66.451$, $p < 0.001$) and explained 89% of the variation in travel time across trips (adj. $R^2 = 0.894$). However, trip maximum speed was the only significant predictor, with the higher speed predictive of lower travel times (table 2.33).

Table 2.33 Multiple regression results for travel time showing significant ($p < 0.05$) predictors (n = 40)

Variable	B	SE_B	β
Maximum speed	-57.100	3.203	-0.966

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

The model for fuel consumption was significant ($F(5,34) = 15.752$, $p < 0.001$) and explained 65% of the variation in fuel consumption across trips (adj. $R^2 = 0.654$). As for travel time, trip maximum speed was the only significant predictor (table 2.34). Higher speeds predicted higher fuel consumption.

Table 2.34 Multiple regression results for fuel consumption significant ($p < 0.05$) predictors (n = 40)

Variable	B	SE_B	β
Maximum speed	0.80	0.010	0.816

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

The results suggest that the effect of maximum trip speed choice on both outcome variables far outweighed the effect of all other variables on the Hastings to Levin route.

2.5 Christchurch to Kaikoura

Figure 2.23 Christchurch to Kaikoura route

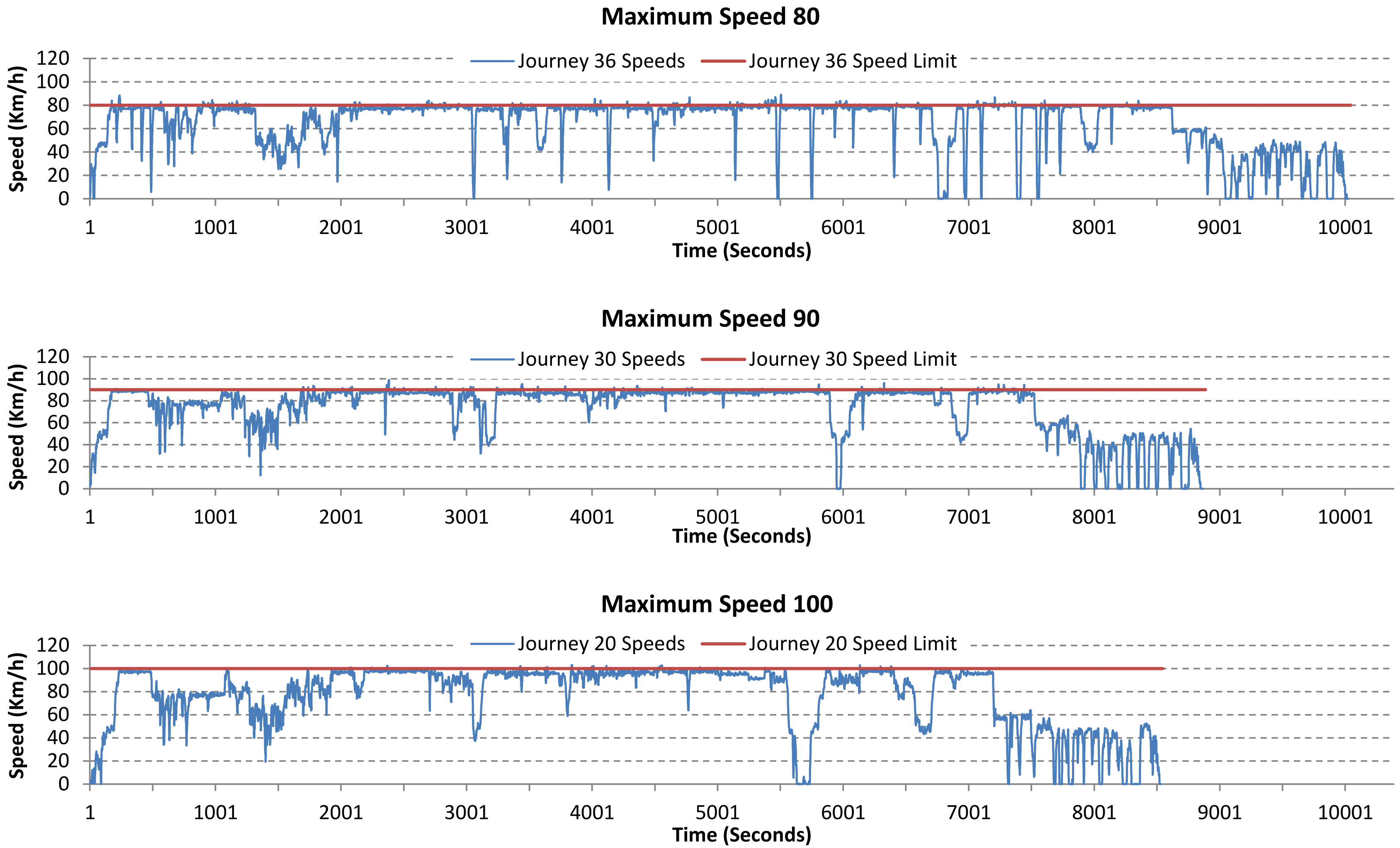
The **Christchurch to Kaikoura** route is a strategic section of state highway with heavy traffic but is also used for holiday trips, and includes some elevation and tortuous sections. One of the unique issues with the stretch of road is the possible impact of traffic surges resulting from Cook Strait ferry offloading. There is a relatively short section of 80km/h limited road close to Christchurch.

- The driver completed 42 usable trips across the three maximum speeds tested, including 11 at an 80km/h maximum speed (mean speed 68.95km/h (SD = 1.96)), 15 at 90km/h (mean speed 72.94km/h (SD = 1.96)) and 16 at 100km/h (mean speed 74.84km/h (1.62)).
- Reducing the maximum speed from 100km/h to 80km/h reduced the mean speed by 7.9% from 74.84km/h (SD = 1.62) to 68.95km/h (SD = 1.96). Reducing the maximum speed from 100km/h to 90km/h reduced the mean speed by 2.5% from 74.84km/h (SD = 1.62) to 72.94km/h (SD = 1.96).
- The mean idle time at 80km/h, 90km/h and 100km/h was 2:36 minutes (SD = 1:33), 2:07 minutes (SD = 1:38) and 3:16 minutes (SD = 1:45) respectively. The differences in the idle time were not significant.
- Decreasing trip maximum speed by 20%, from 100km/h to 80km/h, increased travel time by 12:17 minutes (CI±3:45) (8.6%) and reduced fuel consumption by 1.406 litres (CI±0.537) (13.7%).

- Decreasing maximum speed by 10% from 100km/h to 90km/h increased travel time by 3:40 minutes (CI±3:27)) (2.6%) and reduced fuel consumption by 0.661 litres (CI±0.298) (6.5%).
- Overall, the measured variables explained 87% of the variation in travel time and 67% of the variation in fuel consumption. Higher maximum speeds predicted shorter travel time. Increased driver ratings for weather and traffic, increased idle time and travelling from Christchurch to Kaikoura predicted longer travel time. Higher maximum speeds and higher weather ratings predicted increased fuel consumption.

The three charts below show driver speed over time on single trips with travel times close to the mean for each of the tested speeds on the Christchurch to Kaikoura route.

Figure 2.24 Three plots of driver speed over time for two randomly selected trips on the Christchurch to Kaikoura short route



2.5.1 Change in mean speed

The mean travel speeds for each of the tested maximum speeds are shown in table 2.35.

Table 2.35 Recorded mean speeds between trips at different maximum speeds overall and in each trip direction (n = 42)

Trip maximum speed	Number of trips	Mean speed	Mean difference compared to mean speed at a maximum speed of 100km/h (95% CI)	Mean difference compared to mean speed at a maximum speed of 90km/h (95% CI)
80km/h	11	68.95 (SD = 1.96)	5.88* (4.13 – 7.64)	3.99* (2.21 – 5.76)
90km/h	15	72.94 (SD = 1.96)	1.90* (0.29 – 3.51)	–
100km/h	16	74.84 (SD = 1.62)	–	-1.90* (-3.51 to -0.29)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met (p > 0.05). Significant differences (one-way ANOVA, p < 0.05) are marked with an asterisk.

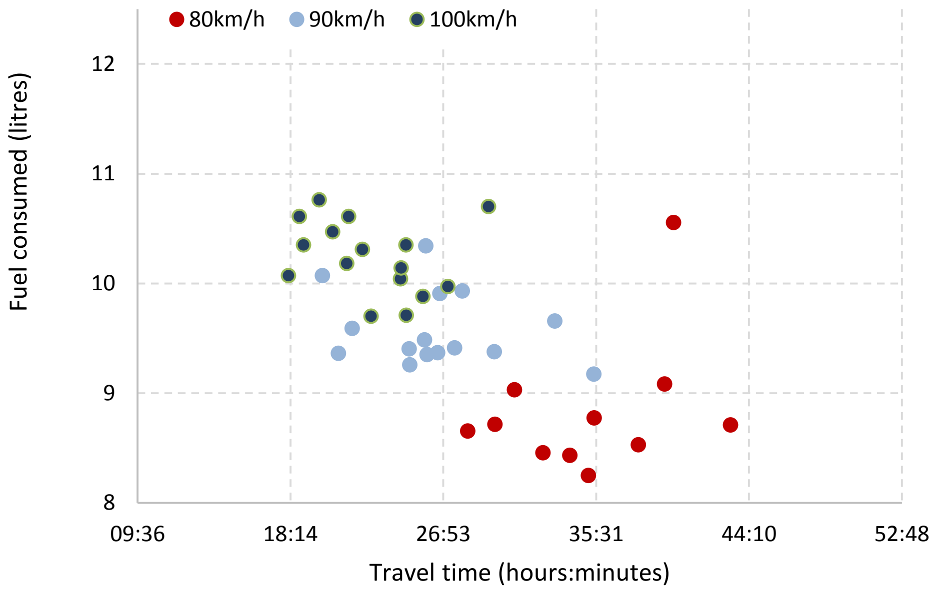
2.5.2 Direction of travel

Travel time was different between the two directions of travel for trips completed at a maximum speed of 90km/h (t = -2.483, p = 0.03). The mean difference was significant (-00:04:48, n = 15, -00:08:58 to -00:00:37); however, overall results are presented for clarity due to the small size of the difference.

2.5.3 Combining fuel consumption and travel time

There was a strong relationship between travel time and fuel consumption on trips between Christchurch and Kaikoura. The effect of increasing trip maximum speed is illustrated in (figure 2.24).

Figure 2.25 Travel time and fuel consumption of trips between Christchurch and Kaikoura at different trip maximum speeds (n = 42)

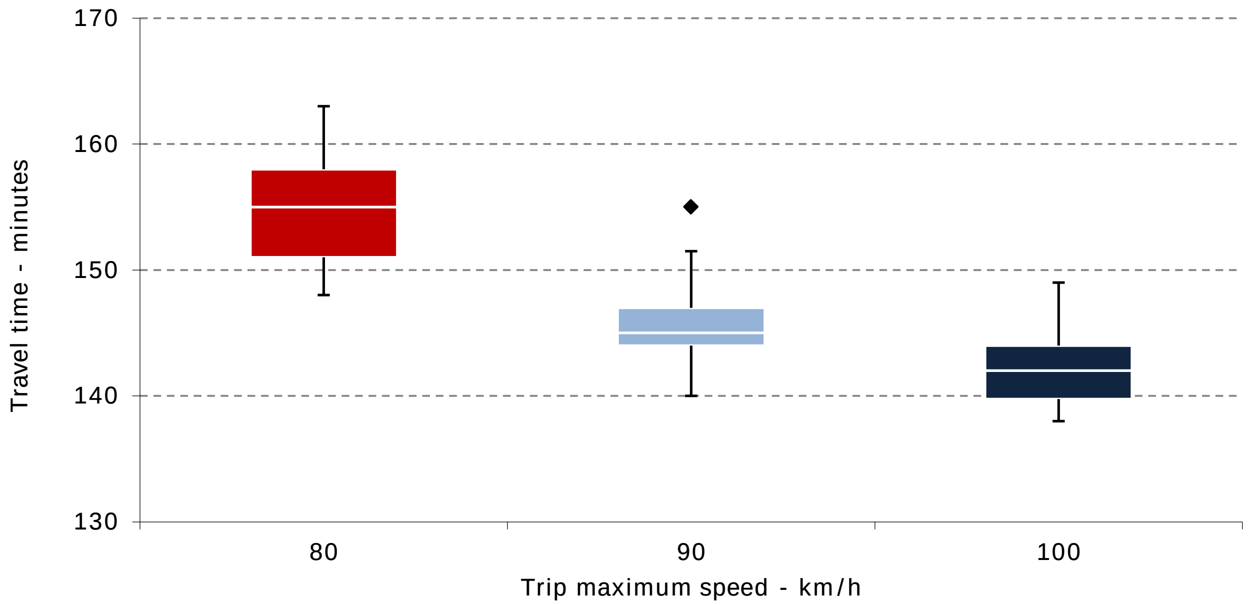


The difference between trips at 80km/h and trips at 100km/h was more marked than that between trips at 90km/h and 100km/h.

2.5.4 Effect of changing speed on travel time

Figure 2.26 shows the distribution of travel times for trips at the three tested maximum speeds on the Christchurch to Kaikoura route. Variation was highest at a maximum speed of 80km/h.

Figure 2.26 Box plot of travel time for Christchurch to Kaikoura at the three tested speeds (n = 42). Diamonds mark upper outliers and squares mark lower outliers



Results of a one-way ANOVA of travel time at the three maximum speeds tested (80km/h, 90km/h and 100km/h) showed that the trip maximum speed had a significant effect on travel time ($F(2,39) = 32.189$, $p < 0.001$) (table 2.36). Trip speed explained more than half (60%) of the variation in travel time ($\omega^2 = 0.60$).

Table 2.36 One- way ANOVA results maximum trip speed's effect on mean travel time (n = 40) for Christchurch to Kaikoura route

Trip maximum speed	Number of trips	Mean travel time	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	11	02:35:07 (SD = 00:01:24)	00:12:17* (00:08:32 - 00:16:03)	00:08:3* (00:04:49 - 00:12:26)
90km/h	15	02:26:29 (SD = 00:01:04)	00:03:40* (00:00:13 - 00:07:07)	-
100km/h	16	02:22:50 (SD = 00:03:13)	-	00:03:40* (00:00:13 - 00:07:07)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met ($p > 0.05$). Significant differences ($p < 0.05$) are marked with an asterisk.

The 10km/h decrease in maximum speed from 100km/h to 90km/h on the Christchurch to Kaikoura route resulted in a 3% increase in travel time, much smaller than the 8% increase from reducing maximum speed from 90km/h to 80km/h. This may be a result of the significant sections of the route where the driver's speed was limited by the terrain (Kaikoura mountain range).

2.5.5 Idle time

There were no significant differences in mean idle time between any of the three tested maximum speeds (table 2.37).

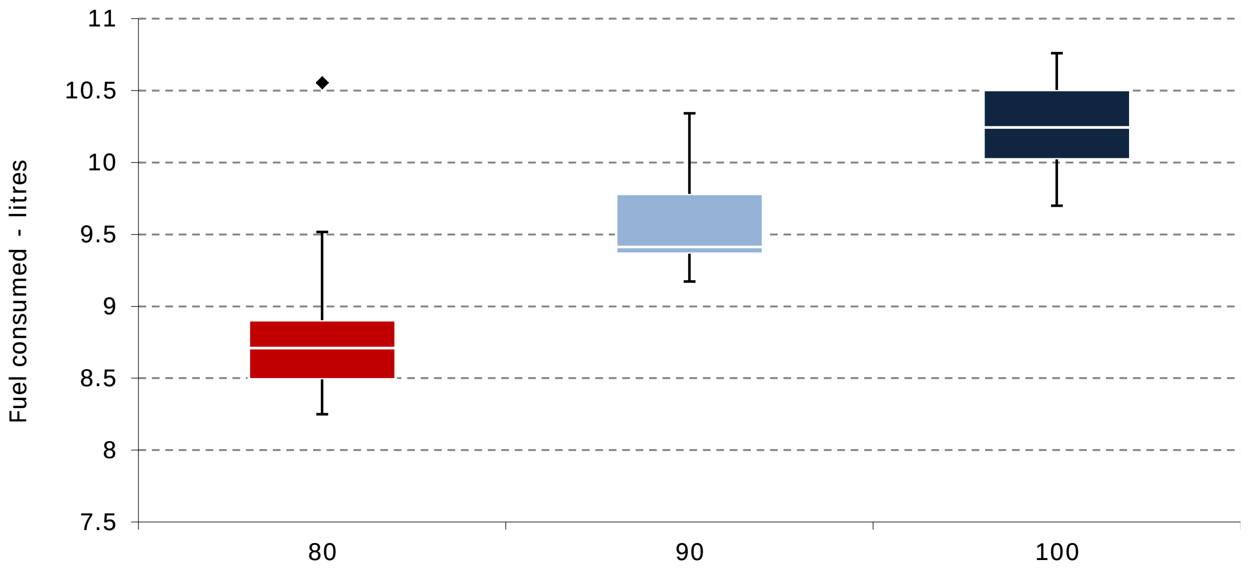
Table 2.37 Differences in idle time between trips at different maximum speeds overall (n = 40)

Trip maximum speed	Number of trips	Mean idle time	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	11	00:02:36 (SD = 00:01:33)	-00:00:41 (-00:02:02 - 00:00:40)	00:00:29 (-00:00:50 - 00:01:48)
90km/h	15	00:02:07 (SD = 00:01:38)	-00:01:10 (-00:02:24 - 00:00:05)	–
100km/h	16	00:03:16 (SD = 00:01:45)	–	00:01:10 (00:02:24 to - 00:00:05)

2.5.6 Effect of changing speed on fuel consumption

The distribution of fuel consumption at each of the tested speeds on the Christchurch to Kaikoura route is shown in figure 2.27. One trip at a maximum speed of 80km/h had higher fuel consumption due to a high level of traffic in the tortuous section of the journey.

Figure 2.27 Fuel consumed on Christchurch to Kaikoura trips by trip maximum speed (n = 42). Diamonds mark upper outliers and squares mark lower outliers



Results of one-way ANOVA of fuel consumption at the three speeds tested showed that the trip maximum speed had a significant effect on fuel consumption (Welch's $F(2,21.590) = 29.266$, $p < 0.001$) (table 2.38). Trip speed explained over half (57%) of the variation in fuel consumption (adj. $\omega^2 = 0.57$).

Table 2.38 One- way ANOVA results showing maximum speed's effect on mean fuel consumption (n = 42) on the Christchurch to Kaikoura route

Trip maximum speed	Number of trips	Mean fuel consumption	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	11	8.835 (SD = 0.622)	-1.406* (-1.943 to -0.868)	-0.744* (-1.284 to -0.205)
90km/h	15	9.579 (SD = 0.336)	-0.661* (-0.960 to -0.363)	–
100km/h	16	10.241 (SD = 0.336)	–	-0.661* (-0.960 to -0.363)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met ($p > 0.05$). Significant differences ($p < 0.05$) are marked with an asterisk. The assumption of normality was violated for fuel consumed at 80km/h so significance of the difference was confirmed with the Welch t-test ($p < 0.001$).

Decreasing maximum speed from 90km/h to 80km/h led to an 8% fuel saving, greater than the 6% saving from decreasing from 100km/h to 90km/h.

2.5.7 Predicting travel time and fuel consumption

There was a strong correlation between maximum speed and both travel time (R_p = -0.766, $p < 0.001$) and fuel consumption (R_p = 0.802, $p < 0.001$). Multiple regression was run to predict travel time and fuel consumption using the following variables:

- maximum speed limit
- direction of travel
- traffic rating
- weather rating
- idle time.

The model was significantly predictive of travel time ($F(5,36) = 54.461$, $p < 0.001$) and explained 87% of the variation in travel time across trips (adj. R^2 = 0.867). Higher trip maximum speed limits predicted lower travel time. Travelling from Kaikoura to Christchurch, higher traffic ratings, weather ratings and idle times predicted higher travel time (table 2.39).

Table 2.39 Multiple regression results for travel time showing significant ($p < 0.05$) predictors (n = 42)

Variable	B	SE_B	β
Maximum speed	-40.320	2.717	-0.861
Direction of travel	136.754	47.341	0.184
Traffic rating	86.512	39.440	0.129
Weather rating	147.557	47.904	0.179
Idle time	1.469	0.232	0.398

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

The model for fuel consumption was significant ($F(5,36) = 17.535$, $p < 0.001$) and explained 67% of the variation in fuel consumption across trips (adj. $R^2 = 0.668$). Higher trip maximum speeds and weather rating were the only significant predictors, with both predicting higher fuel consumption (table 2.40).

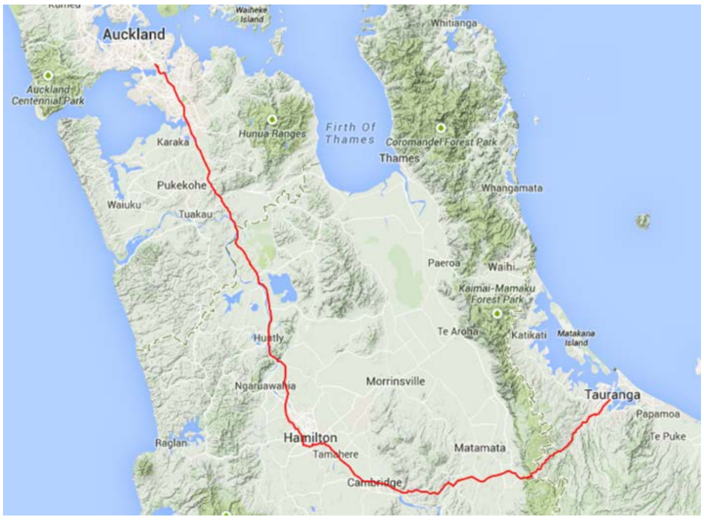
Table 2.40 Multiple regression results for fuel consumption significant ($p < 0.05$) predictors ($n = 42$)

Variable	B	SE_B	β
Maximum speed	0.071	0.008	0.809
Weather rating	0.343	0.141	0.223

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

2.6 Auckland to Tauranga

Figure 2.28 Auckland to Tauranga route



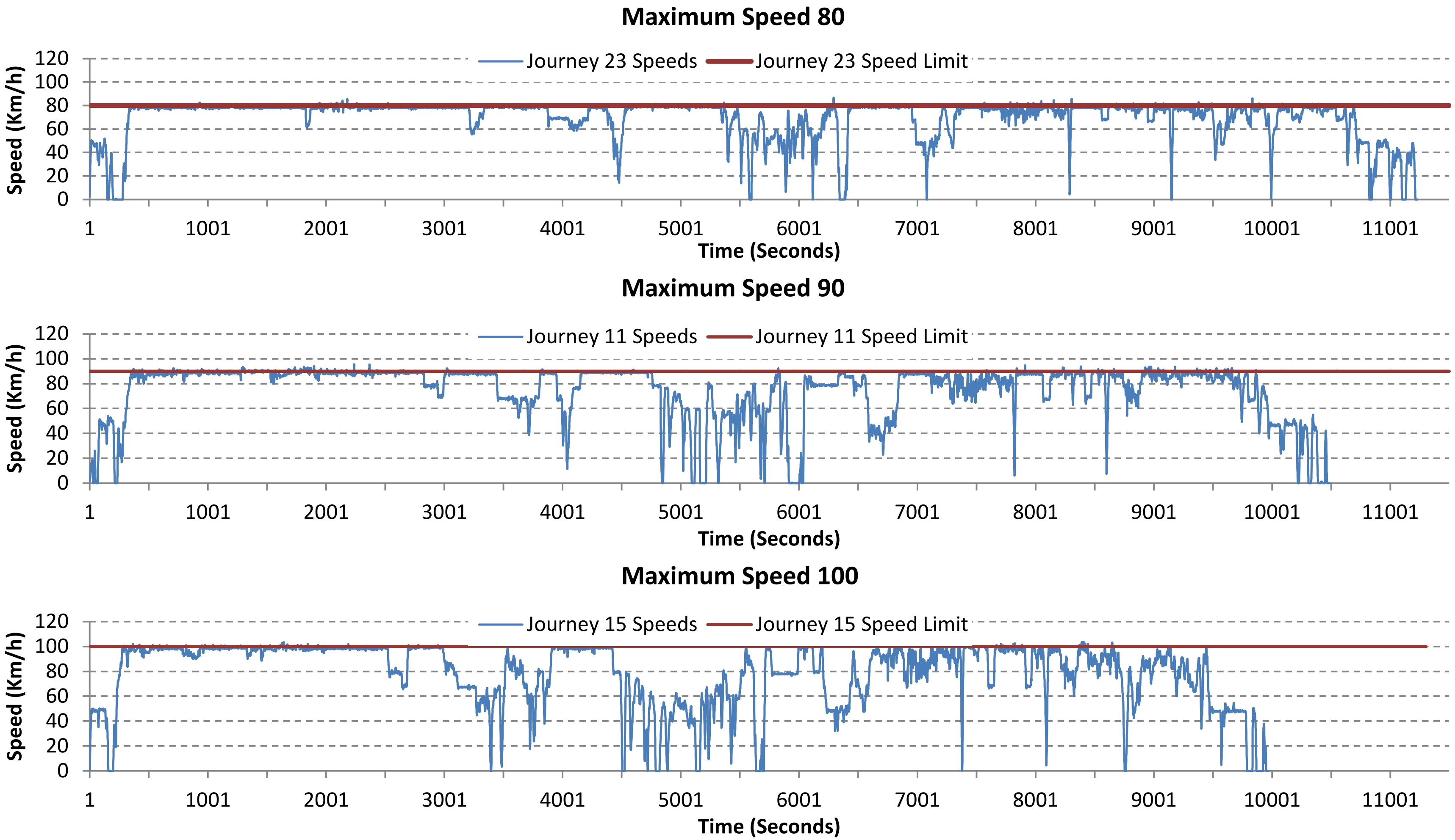
The **Auckland City – Tauranga via Hamilton** route is considered by the Transport Agency to be a strategic, high-volume North Island route familiar to many North Island drivers. The route has the greatest length and travel time of those selected so managing driver fatigue, particularly in the afternoon traffic, was a priority. The route finish was in East Tamaki, avoiding some of the more congested sections of the Auckland Motorway.

- The driver completed 40 usable trips, including 14 at 80km/h (mean 66.19km/h (SD = 2.19)), 11 at 90km/h (mean 71.67km/h (SD = 2.74)) and 15 at 100km/h (mean 75.01km/h (SD = 1.82)).
- Reducing the maximum speed from 100km/h to 80km/h reduced the mean speed by 11.8% from 75.01km/h (SD = 1.82) to 66.19km/h (SD = 2.19). Reducing the maximum speed from 100km/h to 90km/h reduced the mean speed by 4.5% from 75.01km/h (SD = 1.82) to 71.67km/h (SD = 2.74).
- Trips to Tauranga took significantly less time than trips to Auckland at all tested speeds though the difference in fuel consumption between the two directions was not significant.
- Trips to Tauranga:
  - Travelling at a maximum speed of 80km/h took 13:46 minutes (CI±2:45) longer than trips at a maximum speed of 90km/h (7.9%) and 22:14 minutes (CI±3:01) longer than trips at a maximum speed of 100km/h (13.5%).

- Trips to Auckland:
  - Travelling at a maximum speed of 80km/h took 11:54 minutes (CI±6:09) longer than trips at a maximum speed of 90km/h (6.4% increase) and 25:19 minutes (CI±4:50) longer than trips at a maximum speed of 100km/h (14.8% increase).
- Overall:
  - Decreasing maximum speed by 20%, from 100km/h to 80km/h, increased travel time by 22:40 minutes (CI±5:04) (13.4%) but decreased fuel consumption by 1.812 litres (CI±0.391) (13.9%).
  - Decreasing maximum speed by 10%, from 100km/h to 90km/h, increased travel time by 8:15 minutes (CI±5:25) (4.9%) but decreased fuel consumption by 0.899 litres (CI±0.418) (6.9%).
  - The mean idle time at 80km/h, 90km/h and 100km/h was 3:07 minutes (SD = 1:50), 3:00 minutes (SD = 1:59) and 3:38 minutes (SD = 1:18) respectively. The differences in the idle time were not significant.
  - Overall, the measured variables explained 94% of the variation in travel time and 84% of the variation in fuel consumption. Higher maximum speeds predicted shorter travel time. Increased driver ratings for traffic, increased idle time and travelling from Tauranga to Auckland predicted longer travel time. Higher maximum speeds, idle time and weather ratings predicted increased fuel consumption.

The three charts below show driver speed over time on single trips with travel times close to the mean for each of the tested speeds on the Auckland to Tauranga route.

Figure 2.29 Three plots of driver speed over time for two randomly selected trips on the Auckland to Tauranga short route



2.6.1 Change in mean speed

The mean travel speeds for each of the tested maximum speeds are shown in table 2.41.

Table 2.41 Recorded mean speeds between trips at different maximum speeds overall and in each trip direction (n = 40)

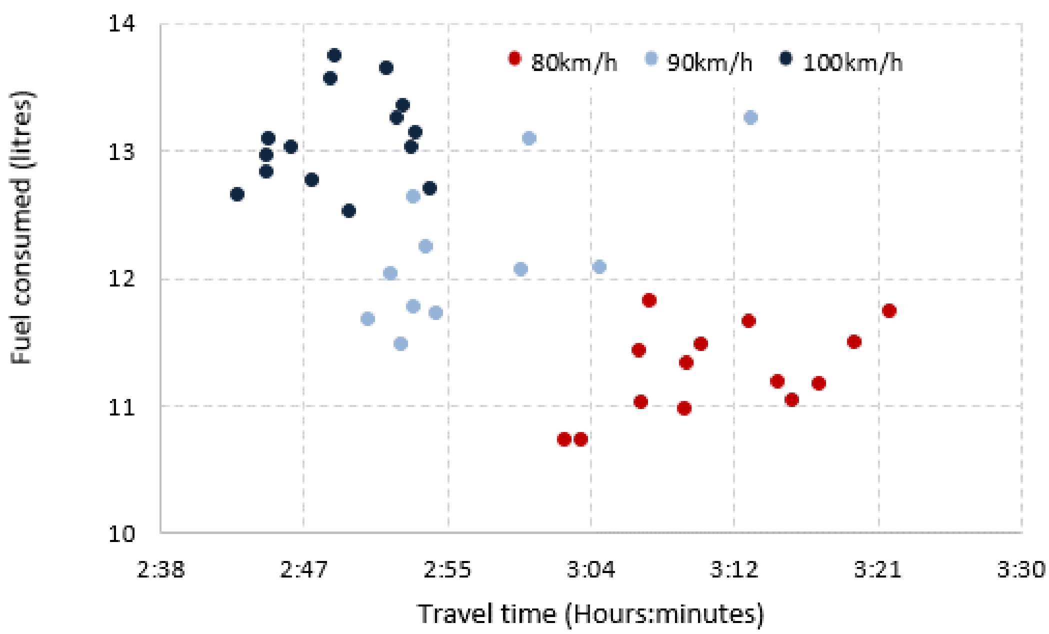
Trip maximum speed	Number of trips	Mean speed	Mean difference compared to mean speed at a maximum speed of 100km/h (95% CI)	Mean difference compared to mean speed at a maximum speed of 90km/h (95% CI)
80km/h	14	66.19 (SD = 2.19)	8.81* (6.79 – 10.84)	5.47* (3.28 – 7.67)
90km/h	11	71.67 (SD = 2.74)	3.34* (1.18 – 5.50)	–
100km/h	15	75.01 (SD = 1.82)	–	-3.34* (-5.50 to -1.18)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met ($p > 0.05$). Significant differences (one-way ANOVA, $p < 0.05$) are marked with an asterisk.

2.6.2 Combining fuel consumption and travel time

There was a strong relationship between travel time and fuel consumption on trips between Auckland and Tauranga. Some outliers, particularly in 90km/h maximum speed trips, were affected by traffic and weather.

Figure 2.30 Fuel consumption and travel time for trips between Auckland and Tauranga (n = 40)



2.6.3 Travel time by direction of travel

Travel time was significantly different between trips going from Auckland to Tauranga and from Tauranga to Auckland, with larger differences at the two lower speeds (table 2.42).

Table 2.42 Differences in travel time between trips to Tauranga and trips to Auckland (n = 40)

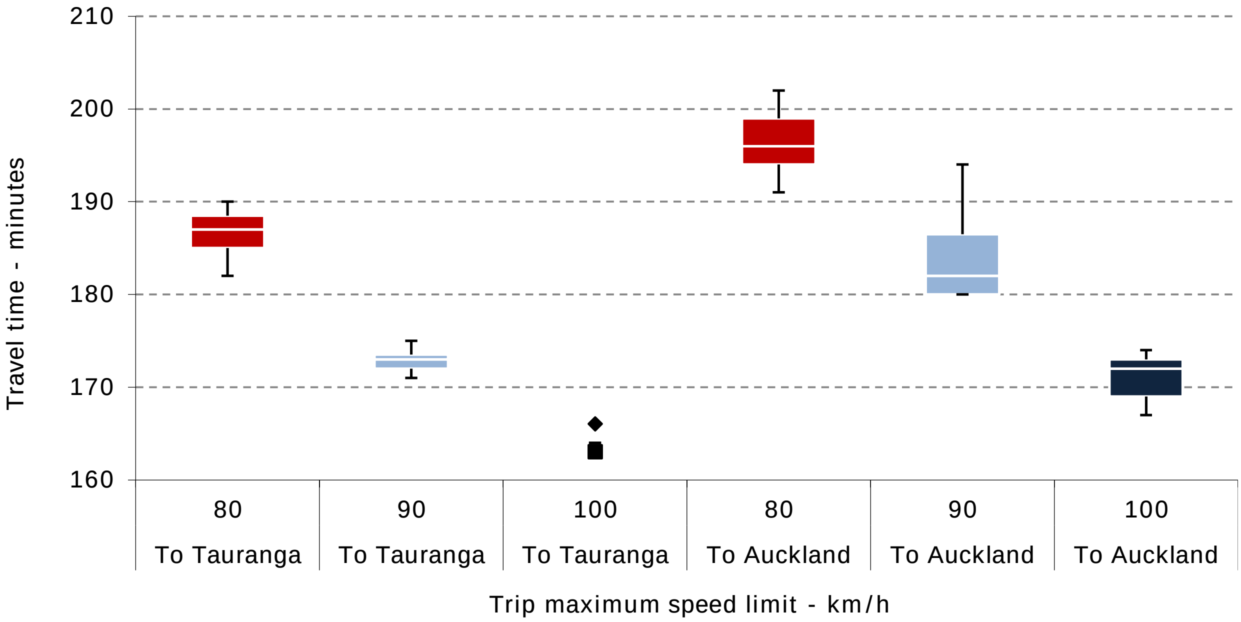
Trip maximum speed	To Tauranga	To Auckland	Mean difference in direction of travel (95% CI)
80km/h	3:07:05 (SD = 00:02:48, n = 7)	03:16:52 (SD = 00:03:48, n = 7)	-00:09:46 (-00:13:40 to -00:05:53)*
90km/h	02:53:20 (SD = 00:01:22, n = 7)	03:04:58 (SD = 00:06:24, n = 4)	-00:11:38 (-00:21:40 to -00:01:37)*
100km/h	02:46:18 (SD = 00:03:40, n = 5)	02:51:33 (SD = 00:02:30, n = 10)	-00:05:15 (-00:08:33 to -00:01:58)*

Note: Mean differences calculated using the independent samples test. Significant differences ($p < 0.05$) are marked with an asterisk. Mean differences confirm are calculated with equal variance assumed where Levene's test for equality of variances $p > 0.05$.

2.6.4 Effect of changing speed on travel time

Comparing the distributions of travel times across the three tested maximum speeds and the two different directions illustrated the lower travel time at higher maximum speeds and the higher travel times on the return trip from Auckland (figure 2.31).

Figure 2.31 Box plot showing the distribution of travel times for trips to Tauranga and to Auckland. Note that four of the six trips to Tauranga had the same travel time so the box plot does not display well. Diamonds mark upper outliers and squares mark lower outliers



One-way ANOVA examined the significance of the differences between travel time for each direction of travel and overall.

For trips to Tauranga, the differences in the mean travel times of each maximum speed were significant ($F(2,17) = 99.649$, $p < 0.001$) (table 2.43). Maximum speed had a very large effect size ($\omega^2 = 0.79$), showing that trip maximum speed accounted for 79% of the variance in travel time.

Table 2.43 Mean differences in travel time comparing trips to Tauranga at different speeds (n = 19)

Trip maximum speed	Number of trips	Mean travel time	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	7	03:07:05 (SD = 00:02:49)	00:22:14* (00:19:13 – 00:25:15)	00:13:46* (00:11:00 – 00:16:31)
90km/h	7	02:53:20 (SD = 00:01:22)	00:08:29* (00:05:27 – 00:11:30)	–
100km/h	5	02:44:51 (SD = 00:01:07)	–	-00:13:46* (-00:16:31 to -00:11:00)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met ($p > 0.05$). Significant differences ($p < 0.05$) are marked with an asterisk.

Similarly, mean travel time for trips to Auckland was different between the tested speeds ($F(2,18)= 90.458$, $p < 0.001$) (table 2.44). The effect on travel time was large, with speed explaining 89% of the variation in travel time ($\omega^2 = 0.83$).

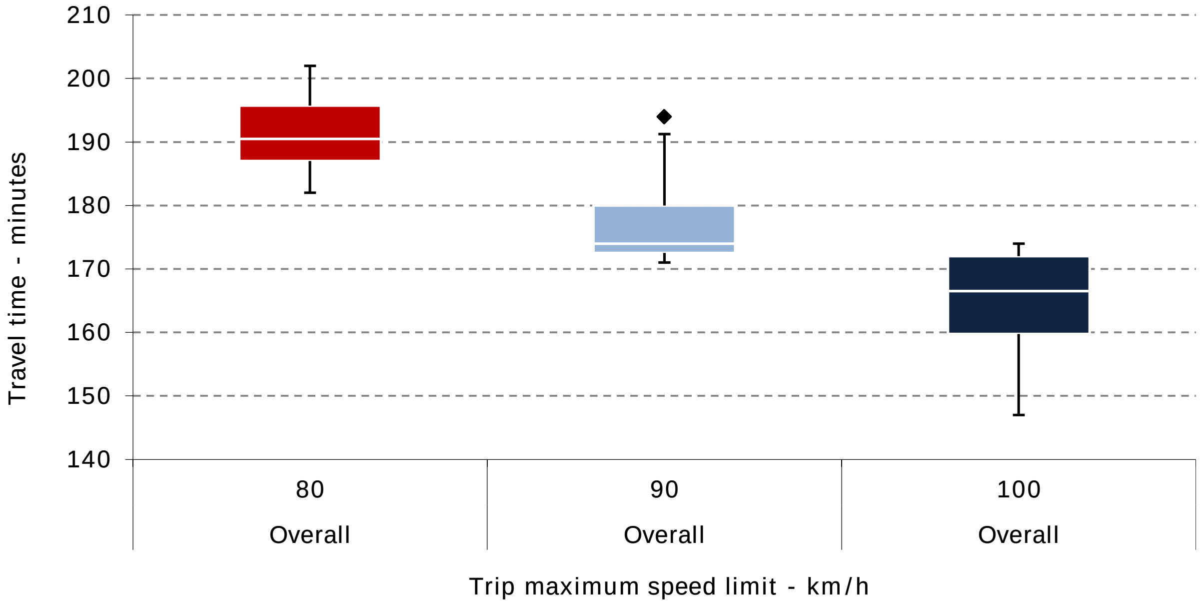
Table 2.44 Mean differences in travel time comparing trips to Auckland at different speeds (n = 21)

Trip maximum speed	Number of trips	Mean travel time	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	7	03:16:52 (SD = 00:03:48)	00:25:19* (00:20:29 – 00:30:09)	00:11:54* (00:05:45 – 00:18:03)
90km/h	4	03:04:58 (SD = 00:06:24)	00:13:25* (00:07:37 – 00:19:13)	–
100km/h	10	02:51:33 (SD = 00:02:30)	–	-00:11:54* (-00:18:03 to -00:05:45)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met ($p > 0.05$). Significant differences ($p < 0.05$) are marked with an asterisk.

Figure 2.32 shows the travel time for all trips between Auckland and Tauranga, showing the decrease in travel time as maximum speed increased.

Figure 2.32 Distribution of travel times across all trips between Auckland and Tauranga at the tested maximum speeds (n = 40). Diamonds mark upper outliers and squares mark lower outliers



Looking at trips across both directions, the mean travel times for the maximum speeds tested were not equal ($F(2,37) = 64.026$, $p < 0.001$) (table 2.44). The overall effect of maximum speed on travel time was large, with speed explaining 75% of the variation across the different speeds ($\omega^2 = 0.75$),

Table 2.44 Mean differences in travel time comparing all trips between Auckland and Tauranga at different speeds (n = 40)

Trip speed	Number of trips	Mean travel time	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	14	03:11:59 (SD = 00:06:00)	00:22:40* (00:17:35 - 00:27:44)	00:14:25* (00:08:55 - 00:19:55)
90km/h	11	02:57:34 (SD = 00:06:55)	00:08:15* (00:02:49 - 00:013:40)	-
100km/h	15	02:49:19 (SD = 00:03:54)	-	-00:14:25* (-00:19:55 to -00:08:55)

2.6.5 Idle time

There were no significant differences in idle time comparing trips completed at different maximum speeds (table 2.45).

Table 2.45 Differences in idle time between trips at different maximum speeds overall (n = 40)

Trip maximum speed	Number of trips	Mean idle time	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	14	00:03:07 (SD = 00:01:50)	-00:00:31 (-00:01:43 - 00:00:41)	00:00:08 (-00:01:27 - 00:01:43)
90km/h	11	00:03:00 (SD = 00:01:59)	-00:00:39 (-00:01:58 - 00:00:41)	-
100km/h	15	00:03:38 (SD = 00:01:18)	-	00:00:39 (00:01:58 to - 00:00:41)

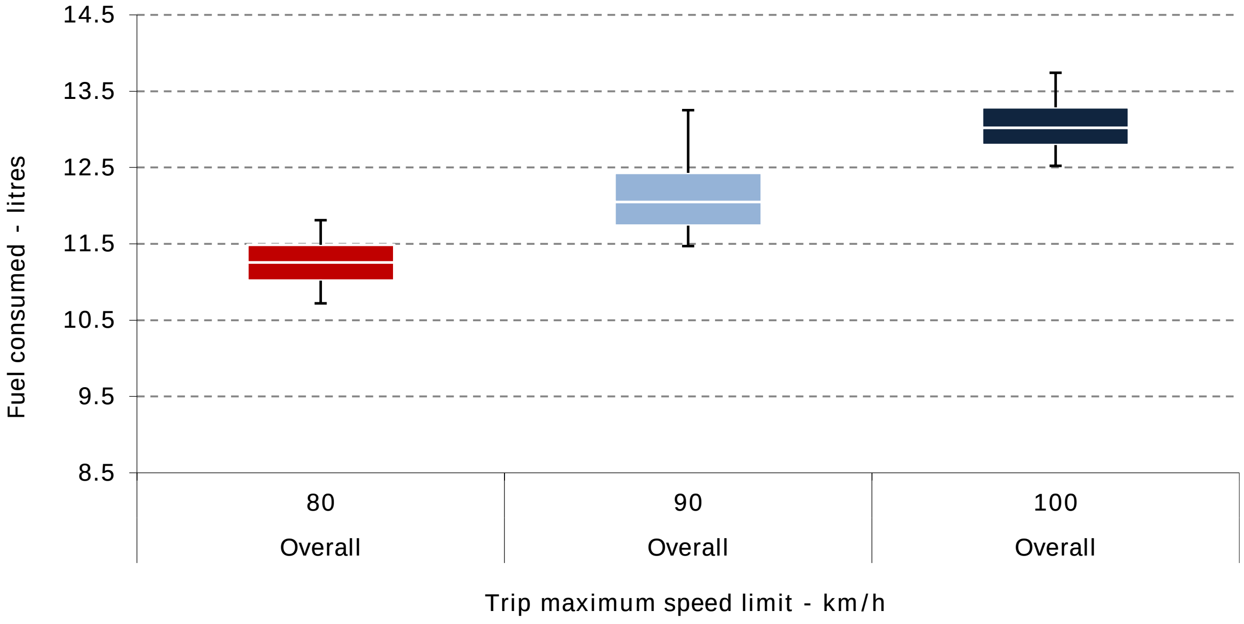
2.6.6 Fuel consumption by direction of travel

As noted above, the differences in fuel consumption between the two trip directions were not significant at any of the tested speeds.

2.6.7 Effect of changing speed on fuel consumption

Figure 2.33 shows the distribution of fuel consumption across all trips on the Auckland to Tauranga route. As trip maximum speed increased, fuel consumption increased.

Figure 2.33 The distribution of trip fuel consumption across the different maximum speeds for all trips between Auckland and Tauranga (n = 40). Diamonds mark upper outliers and squares mark lower outliers



One-way ANOVA of showed that the difference in the mean fuel consumption between the three tested maximum speeds was significant ($F(2.37) = 64.026$, $p < 0.001$) (table 2.46). Trip maximum speed accounted for 76% of the variation ($\omega^2 = 0.76$).

Table 2.46 Differences in mean fuel consumption between trips at different speeds (n = 40)

Trip maximum speed	Number of trips	Mean fuel consumption	Mean difference compared to 100km/h (95% CI)	Mean difference compared to 90km/h (95% CI)
80km/h	14	11.265 (SD = 0.350)	-1.812 (-2.203 to -1.421)	-0.913 (-1.337 to -0.489)
90km/h	11	12.178 (SD = 0.582)	-0.899 (-1.317 to -0.481)	–
100km/h	15	13.077 (SD = 0.368)	–	-0.899 (-1.317 to -0.481)

Note: Mean differences calculated using the Tukey HSD test as the assumption of homogeneity of variance was met ($p > 0.05$). Significant differences ($p < 0.05$) are marked with an asterisk.

2.6.8 Predicting travel time and fuel consumption

There was a strong correlation between maximum speed and both travel time ($R_p = -0.866$, $p < 0.001$) and fuel consumption ($R_p = 0.881$, $p < 0.001$). Multiple regression was run to predict travel time and fuel consumption using the following variables:

- maximum speed limit
- direction of travel
- traffic rating
- weather rating
- idle time

The model was significantly predictive of travel time ($F(5,34) = 130.649$, $p < 0.001$) and explained 94% of the variation in travel time across trips (adj. $R^2 = 0.943$). Higher trip maximum speed limits predicted lower travel time. Travelling from Tauranga to Auckland, higher traffic ratings and idle times predicted higher travel time (table 2.47).

Table 2.47 Multiple regression results for travel time showing significant ($p < 0.05$) predictors ($n = 42$)

Variable	B	SE_B	β
Maximum speed	-72.958	3.056	-0.932
Direction of travel	390.540	66.659	0.293
Traffic rating	131.020	45.642	0.130
Idle time	0.952	0.322	0.142

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

The model for fuel consumption was significant ($F(5,34) = 42.133$, $p < 0.001$) and explained 84% of the variation fuel consumption across trips (adj. $R^2 = 0.841$). Higher trip maximum speeds, idle time and weather rating were significant predictors, with both predictive of higher fuel consumption (table 2.48).

Table 2.48 Multiple regression results for fuel consumption significant ($p < 0.05$) predictors ($n = 42$)

Variable	B	SE_B	β
Maximum speed	0.085	0.007	0.822
Weather rating	0.128	0.061	0.152
Idle time	0.002	0.001	0.215

Note: B = unstandardised regression coefficient, SE_B = standard error of the coefficient, β = standardised coefficient.

3 Discussion of findings

This project collected information about speed, travel time and fuel consumption that has added to the existing body of literature by providing empirical evidence of the effects of adopting different maximum speed limits in real-world driving scenarios on New Zealand roads. The effects of speed on travel time and fuel consumption for the six tested routes are discussed in the following sections.

On the 10km Wellington short route one, the driver completed 105 trips, including 55 at a maximum speed of 40km/h (mean speed 27.11km/h (SD = 1.54)) and 50 at a maximum speed of 50km/h (mean speed 29.62km/h (SD = 1.87)). Decreasing maximum speed by 20%, from 50km/h to 40km/h, increased travel time by 1:54 minutes (CI±0:31) (9.1%) and reduced fuel consumption by 0.026 litres (CI±0.016) (4.6%). Both travel time and fuel consumption were closely correlated with idle time. Overall, the measured variables explained 95% of the variation in travel time and 80% of the variation in fuel consumption. Travelling at the higher maximum speed predicted shorter travel time. Increases in the driver's ratings of the effect of traffic, the traffic lights on a main section of road (Customhouse Quay), idle time and travelling into the city predicted longer travel time. Travelling at the higher maximum speed and increased idle time, more traffic light stops and travelling into the city predicted higher fuel consumption.

On the 6km Wellington short route two, the driver completed 120 trips including 59 at a maximum speed of 40km/h (mean speed 23.97km/h (SD = 3.28)) and 61 at a maximum speed of 50km/h (25.64km/h (SD = 2.53)). Decreasing maximum speed by 20% from 50km/h to 40km/h increased travel time by 1:08 minutes (CI±0:44) (7.7%) and decreased fuel consumption by 0.015 litres (CI±0.012) (3.4%). Both travel time and fuel consumption were closely correlated with idle time. Overall, the measured variables explained 92% of the variation in travel time and 74% of the variation in fuel consumption. Travelling at the higher maximum speed predicted shorter travel time. Increases in the driver's ratings of the effect of traffic, idle time and travelling into the city predicted longer travel time. Travelling at the higher maximum speed, increased idle time and driver ratings for the effect of traffic and travelling into the city predicted higher fuel consumption.

On the 12km Auckland short route the driver completed 102 trips, including 51 at a maximum speed of 40km/h (mean speed 28.50km/h (SD = 1.57)) and 51 at a maximum speed of 50km/h (mean speed 33.03km/h (SD = 3.63)). Decreasing maximum speed by 20%, from 50km/h to 40km/h, increased travel time by 3:13 minutes (CI±0:52) (14.9%). There was no significant difference in fuel consumption between trips at the two maximum speeds. Travel time was closely correlated with idle time. Overall, the measured variables explained 96% of the variation in travel time and 67% of the variation in fuel consumption. Travelling at the higher maximum speed predicted shorter travel time. Increases in the driver's ratings of the effect of traffic, idle time and travelling into the city predicted longer travel time. Travelling into the city and increased idle time predicted higher fuel consumption.

On the 197km Hastings to Levin route, the driver completed 40 usable trips, including 15 at a maximum speed of 80km/h (mean 70.73km/h (SD = 0.72)), 15 at 90km/h (mean 76.40km/h (SD = 0.88)) and 10 at 100km/h (mean 79.39km/h (SD = 1.26)). Decreasing maximum speed by 20%, from 100km/h to 80km/h, increased travel time by 18:14 minutes (CI±1:58) (12.3%) and reduced fuel consumption by 1.578 litres (CI±0.445) (14.6%). Decreasing maximum speed by 10% from 100km/h to 90km/h increased travel time by 6:02 minutes (CI±1:58) (4.1%) and reduced fuel consumption by 0.568 litres (CI±0.445) (5.3%). Both travel time and fuel consumption were highly correlated with trip maximum speed. Among the measured variables, maximum speed was the only significant predictor of travel time and fuel consumption. Travelling at higher maximum speeds predicted shorter travel time and explained 89% of the variation.

Travelling at higher maximum speed predicted higher fuel consumption and explained 65% of the variation.

On the 178km Christchurch to Kaikoura route, the driver completed 42 usable trips, including 11 at 80km/h (mean speed 68.95km/h (SD = 1.96), 15 at 90km/h (mean speed 72.94km/h (SD = 1.96)) and 16 at 100km/h (mean speed 74.84km/h (SD = 1.62). Decreasing trip maximum speed by 20%, from 100km/h to 80km/h, increased travel time by 12:17 minutes (CI±3:45) (8.6%) and reduced fuel consumption by 1.406 litres (CI±0.537) (13.7%). Decreasing maximum speed by 10% from 100km/h to 90km/h increased travel time by 3:40 minutes (CI±3:27)) (2.6%) and reduced fuel consumption by 0.661 litres (CI±0.298) (6.5%). Both travel time and fuel consumption were highly correlated with trip maximum speed. Overall, the measured variables explained 87% of the variation in travel time and 67% of the variation in fuel consumption. Higher maximum speeds predicted shorter travel time. Increased driver ratings for weather and traffic, increased idle time and travelling from Christchurch to Kaikoura predicted longer travel time. Higher maximum speeds and higher weather ratings predicted increased fuel consumption.

On the 211km Auckland to Tauranga route, the driver completed 40 usable trips, including 14 at 80km/h (mean 66.19km/h (SD = 2.19)), 11 at 90km/h (mean 71.67km/h (SD = 2.74)) and 15 at 100km/h (mean 75.01km/h (SD = 1.82)). Decreasing maximum speed by 20%, from 100km/h to 80km/h, increased travel time by 22:40 minutes (CI±5:04) (13.4%) but decreased fuel consumption by 1.812 litres (CI±0.391) (13.9%). Decreasing maximum speed by 10%, from 100km/h to 90km/h, increased travel time by 8:15 minutes (CI±5:25) (4.9%) but decreased fuel consumption by 0.899 litres (CI±0.418) (6.9%). Both travel time and fuel consumption were highly correlated with trip maximum speed. Overall, the measured variables explained 94% of the variation in travel time and 84% of the variation in fuel consumption. Higher maximum speeds predicted shorter travel time. Increased driver ratings for traffic, increased idle time and travelling from Tauranga to Auckland predicted longer travel time. Higher maximum speeds, idle time and weather ratings predicted increased fuel consumption.

3.1 Effect of maximum speed on mean speed

This project focused on the effect of setting a maximum speed limit for the drivers. Decreasing trip maximum speed decreased the mean speed on all trips but by a lower proportion. For example, decreasing the maximum speed on the long routes by 20% from 100km/h to 80km/h decreased mean speed by between 8% and 12%. The same percentage decrease in maximum speed on the short routes (20%, from 50km/h to 40km/h) decreased the mean speed by 9% on Wellington short route one, 7% on Wellington short route two, and 14% in Auckland.

Change in travel time matched changes in mean speed. Decreases in fuel consumption tended to be greater than decreases in the mean speed for the longer, higher-speed routes. On the two Wellington short routes, fuel consumption decreased by a lower proportion than the mean speed, while there was no significant decrease on the Auckland short route.

3.2 Effect of maximum speed on travel time

Results across all of the routes tested in this study consistently demonstrated that decreasing maximum trip speed led to an increase in travel time. However, the extent to which travel time increased varied.

On the long routes (ie those between 178 and 211km), even though drivers spent much of their driving time at cruising speeds close to the maximum speed for each trip, travel time increased by a smaller proportion than the reduction in trip maximum speed. When maximum speed was decreased by 20% (from

100km/h to 80km/h) travel time increased by between 9% and 13% on average. When speed was decreased by 10% (from 100km/h to 90km/h) the travel time increase varied from 3% to 5%.

The potential effects of other factors (traffic and weather) on speed and travel time were explored but most of the travel time variation was explained by the change in maximum speed. While trip maximum speed and travel time did not change in the same proportions, they were strongly correlated on all three long routes. Regression models for travel time all included trip maximum speed as a significant predictor with the strongest effect and the models explained between 87% and 94% of the variation in travel time.

The other factors rated subjectively by drivers, such as weather and traffic, were significant predictors of travel time on some routes but not others. The unexplained variation in travel time within each route may be attributed to the effect of traffic and other conditions not adequately captured by the drivers' ratings. For example, at the lower tested speeds, particularly at 80km/h, drivers were generally travelling more slowly than other traffic on the road. They were required to pull over from time to time to let faster drivers past. This happened frequently on the longer routes and while the effects of identified stops were removed from the data, events where the driver only slowed down were not as readily identifiable as those where the driver came to a complete stop. For example, slowing to 60km/h to let another driver past was difficult to distinguish from normal driving. Only the complete stops to let traffic past were identifiable.

On the Wellington and Auckland short routes, the mean overall travel time increases were 8%, 9% and 15% when decreasing the maximum speed from 50km/h to 40km/h. Overall, travel time was highly correlated with the idle time recorded for each of the three short routes, but the idle time was not significantly different between the tested speeds. The drivers' traffic ratings were significant in predicting travel time on the Wellington short route one. The Wellington short routes included a rating for the effect of traffic lights, which was also a significant predictor of travel time. It is also worth noting that Wellington short route one contained a large section with a 40km/h speed limit (around Oriental Parade) which would have reduced the difference in travel time between the 50km/h and 40km/h trips.

The large difference in travel time on the Auckland short route may in part be attributed to some difficulties experienced by the driver that were not present on the Wellington routes. The Auckland driver reported that other road users were aggressive when he was travelling at lower speeds, requiring him to pull over and let them pass regularly. These events were difficult to identify in the data cleaning process as they happened often and were difficult to distinguish from stops for traffic lights, pedestrian crossings, traffic and other events unrelated to the driver's maximum speed. In the driver's words:

> *The main difference was other motorists, they were not too happy following me at 40 rather than 50. I got used to it, I figured out where to stop. I'd normally have to stop and pull over maybe once or twice on each trip. But I could quite often just pull over to the side and slow down and let people go past. Sometimes the road was wide enough that they would just overtake.*

While such events were identifiable on longer routes, it was more difficult to identify them on the Auckland route. If all users were travelling at the same lower speeds and drivers did not have to adjust their behaviour to let traffic past at regular intervals, the travel time differences may have been smaller.

Taken together, the results show that trip maximum speeds have a strong effect on travel time on longer routes. Mean speeds decrease (and therefore travel time increases) by smaller proportions than the decrease in maximum speed. Other factors, such as traffic and number of controlled intersections, have stronger effects on travel time on urban routes. On the short routes, idle time had a strong correlation with travel time and this was observed on two of the three longer routes, but there was no significant difference in the amount of idle time when comparing the tested speeds.

The evidence for a strong and consistent relationship between travel time and maximum trip speed on long routes in real driving conditions provides useful information for understanding the effect that speed limit modifications may have on drivers' fuel consumption and travel time.

The results from this study of driving in real driving conditions on New Zealand roads were consistent with those of a similar study in France (ZELT 2004, as cited in OECD 2006). In that study, a 40% reduction in maximum speed led to a smaller proportion increase in travel time of 20%.

3.3 Effect of maximum speed on fuel consumption

Results across all of the long routes showed that a decrease in speed produced a decrease in fuel consumption. Decreasing the maximum travel speed from 100km/h to 80km/h produced consistent fuel savings across the long routes of 14% to 15%. Decreasing maximum travel speed by only 10%, from 100km/h to 90km/h, produced smaller decreases from 5% to 7%.

Fuel consumption was highly correlated with trip maximum speed on all three of the long routes and was a significant predictor of increased fuel consumption on these routes. Higher ratings for the effect of weather predicted increased fuel consumption on two of the three long routes and idle time predicted higher fuel consumption on one route. The findings suggest that factors such as weather and traffic may have an effect that could be more substantial if they were recorded with more sensitivity. However, it is clear that adopting the higher speeds had a strong and consistent effect on fuel consumption.

On the short routes, there was less consistency in fuel consumption decreases. There was no significant difference identified from decreasing speed on the Auckland short route, but 5% and 3% differences were identified on the Wellington short routes. As with travel time, factors other than maximum speed had a greater effect on the short routes than on the long routes. Traffic, traffic light stops and idle time were important variables in understanding fuel consumption. Increased idle time predicted increased fuel consumption on all three short routes. The higher trip maximum speed predicted increased fuel consumption on the two Wellington short routes but not the Auckland short route. The Auckland short route in particular was dominated by the effect of factors causing the driver to come to a complete stop such as traffic lights and pulling over for other drivers. While idle time was an important factor in predicting fuel consumption, there was no significant difference in the amount of idle time recorded on trips with different maximum speeds.

Changing the trip maximum speed on the Auckland route led to a greater difference in mean speed than on the Wellington short routes. It may therefore be expected that the difference in fuel consumption would also be greater. That there was no significant difference detected in fuel consumption may also be a result of the measures the Auckland driver had to take to avoid frustration from following traffic. At the lower maximum speed tested, which would be expected to have a lower fuel consumption, pulling over to allow traffic to pass may have increased fuel consumption as decelerating then accelerating are costly in terms of fuel consumption compared to maintaining a cruising speed for the same distance covered. If these pull-over events were avoided, as they were on the Wellington routes, a significant difference in fuel consumption between the two tested maximum speeds may have been detected.

On the two Wellington short routes, trip maximum speed, idle time, traffic ratings and the effect of traffic light stops were significant predictors of overall fuel consumption. Together these variables explained 80% and 74% of the variation in fuel consumption on Wellington short routes one and two respectively.

3.4 Variation within and between routes

There was more variation recorded in fuel consumption and travel time on shorter routes compared with longer routes. On the short routes, idle time and traffic ratings had an effect on fuel consumption, highlighting the influence of factors other than trip maximum speed. The direction of travel was also an important variable. That these factors were significant emphasised the effect that small variations in the drivers' experience on each trip had on fuel consumption and travel time. Short delays, such as those caused by a traffic light or another driver parking, could have relatively large effects on the measurements for those trips. These factors affected the results for longer routes too, but were smaller in size in comparison to the length and duration of the trips. While idle time was often closely correlated with travel time, there were no significant differences detected when comparing the amount of idle time recorded across the tested maximum speeds.

Differences across routes may be attributable to factors which were not controlled for by the method adopted for this project. While the vehicles were of the same model, driver technique can play a role in the amount of fuel consumed and travel time. As the drivers were different for each route, differences in the figures for fuel consumption and travel time savings between routes could be a result of differences between the drivers. Driving style can account for variance in fuel consumption.

For example, Gonder et al (2012) found that alternating between aggressive driving, normal driving and energy conscious driving led to a 30% spread in the minimum fuel consumption of the energy conscious driver and the maximum consumption of the aggressive driver style on the city route and a 20% spread on the highway route.

There was also variation in the type of terrain covered by each of the routes. All three long routes had sections through the outskirts of major cities and tortuous sections where the nature of the road limited speed. For example, the Christchurch route had a section of lower speed while leaving the city but included a climb through the Kaikoura mountain range. The Auckland route had a longer period of motorway driving but also passed through a tortuous climb with logging truck traffic before reaching Tauranga. The Hastings route did not spend as much time in the city but passed through the Manawatu Gorge which limits driving speed due to the winding nature of the road. These variations contribute to the variation in the results across the different routes.

The Environmental Protection Agency in the United States estimated that such conditions (wind, low tyre pressure, rough roads, hills, snow or ice, carrying cargo and variance in fuel quality) can collectively reduce fuel economy by 10% (EPA nd). The extent of the impact of each of these factors can vary greatly with the conditions of each route. Differences in the conditions between the tested routes in this study should be kept in mind when comparing results across routes.

The size of the difference between trips at different speeds may be different in scenarios where other traffic is travelling at the same mean speed. In this project, the drivers were driving to a lower speed limit (for example, 40km/h or 80km/h) while the rest of the traffic on the road was travelling to the normal speed limits (50km/h and 100km/h respectively). Their travelling at a mean speed different from other road users meant that measures such as pulling over to let traffic past had to be adopted to travel safely and considerately. If all road users were travelling at the same lower speeds, then travel time costs might be lower and fuel savings higher.

4 Conclusions and recommendations

4.1 Conclusions

The results of this study demonstrate that decreasing maximum travel speed results in decreases in mean speed but by a smaller proportion than expected theoretically. Decreasing maximum speed increases travel time but by a smaller proportion than the decrease in maximum speed. Fuel consumption decreased on five of the six tested routes as the maximum speed was reduced. The proportion by which fuel consumption decreased was less than the proportionate decreases in mean speed on two of the three short, urban routes but was greater than the proportionate decreases in mean speed on all three long routes.

This information will inform the discussion on the costs and benefits of different speed limits. It is, however, important to note that any discussion about the costs and benefits of different speeds on travel time and fuel consumption takes place in the context of the well understood safety consequences of increased speed. Speed plays a part in every crash. Speed determines the impact of the crash and the severity of the injury.

This project has provided evidence that for six different New Zealand routes in real driving conditions the benefits of reducing fuel consumption and the costs of additional travel time as a result of decreasing maximum speed were less than expected based on the theoretical prediction of travel time.

4.2 Recommendations

The effect of changes in trip maximum speed, mean speed, fuel consumption and travel time should be considered when discussing changes to speed limits. Matching the characteristics of the discussed route to the routes used in this project may give the most accurate indication of the fuel savings and travel time increases.

The effect of fuel consumption and travel time on changes to maximum speed for all drivers, not just individual drivers, should be further investigated.

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