System dynamics investigation of freight flows, economic development and network performance

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Abbreviations and acronyms

AHT	Auckland – Hamilton –Tauranga triangle
AWB	Auckland – Waikato – Bay of Plenty region
BVAR	Bayesian vector autoregressive (model)
CGE	computable general equilibrium (models)
GTC	generalised transport cost
HPMV	high performance motor vehicle
IO	input-output (tables or models)
LUTI	land use transport interaction
MARS	multimodal assessment of revenue allocation strategies (model)
NUTS	nomenclature des unités territoriales statistiques (units of geographical coding)
OD	origin-destination
PC	principal components
SAMGODS	Swedish national freight model system
SD	system dynamics
SH	state highway
SCGE	spatial computable general equilibrium (models)
Transport Agency	New Zealand Transport Agency
VAR	vector autoregressive (model)

Contents

Executive summary

The purpose of this research was to investigate if and how systems dynamic (SD) modelling could be used for understanding traffic flows at an inter-regional (state highway) level, in the context of improving understanding of the relationship between economic activity, the demand for freight, and the performance of the rail and road network. We have used the Auckland – Hamilton – Tauranga (AHT) triangle as a pilot case study.

Achieving the purpose of the research involved the design and construction of three models: two simple Bayesian vector autoregressive models to forecast economic activity and freight flows within the AHT region and, more significantly a high-level SD model for simulating freight flows along the main roads in the region. The key strength and hence the foremost reason for selecting an SD model for this latter task, is that time is explicit. This means the SD model can simulate processes such as traffic flows, encompassing delays, congestion and capacity constraints.

The SD model is a scenario model not a forecasting model. An SD model emphasises structural accuracy (correct variables and the dynamics of stocks, flows and feedbacks) over statistical accuracy (functional form and econometrically estimated parameter values). Structure is absolutely central to simulation models as their main use is to provide insight and understanding into how the real world works.

Our findings from the economic model suggest that by 2025 inter-regional freight flows in the AHT triangle may be around 60% greater than in 2012. The rate of growth of inter-regional trade exceeds each region's GDP growth rate.

Mapping the growth in freight to the three main road routes in the AHT triangle in the SD model, shows that in the absence of road improvements, travel times for southbound traffic would increase by around 5–10 minutes, but on the SH1–SH29 route the increase at peak time is almost 30 minutes. For northbound journeys the largest increase is on the SH2 route where the maximum difference is over an hour. The SH1–SH29 route has a much flatter profile, providing more travel time reliability.

A selection of alternative scenarios looking at the Waikato Expressway, more use of very large trucks and a constraint on driver working hours (which doubles as a scenario on road–rail substitution), suggests road improvements are crucial to dealing with the likely growth in freight. However, if traffic is induced to move from parts of the network that are not upgraded, the initial benefits could be negated without corresponding benefits along the routes that lose traffic.

Substitution from road to rail has virtually no effect on mean travel times, but it is possible our scenario was not ambitious enough. Longer and heavier trucks reduce the number of trucks on the road, but the total number of vehicles is barely affected, being dominated by small vehicles. Hence the effect on congestion is negligible and is also offset by the increase in the mean length of vehicles, which raises following distances.

Overall the research has demonstrated that the SD approach can be used to model traffic flows, congestion and ways to ease congestion, at a high level. We would, however, recommend that if the model is ultimately to be applied to more real world questions, priority should go to testing the robustness of the model to a wider range of traffic patterns and input assumptions.

It is important to emphasise the modelling system developed here is specific to the issues and location for which the project was commissioned. The model will not immediately be applicable to other areas, nor to all issues within the AHT area. Nevertheless it is envisaged the modelling system would be amenable to being adapted to consider other areas and other spatial disaggregation, albeit this would require more data gathering and model testing.

Abstract

The purpose of this research was to investigate if and how systems dynamic (SD) modelling could be used for understanding traffic flows at an inter-regional (state highway) level, in the context of improving understanding of the relationship between economic activity, the demand for freight, and the performance of the rail and road network. We used the Auckland – Hamilton – Tauranga (AHT) triangle as a pilot case study.

The research involved the design and construction of three models; two simple Bayesian vector autoregressive model to forecast economic activity and freight flows within the AHT region, and a high level SD model for simulating freight flows along the main roads in the region. The key strength, and hence the main reason for selecting an SD model for this latter task, is that time is explicit. This means the SD model can simulate processes such as traffic flows, encompassing delays, congestion and capacity constraints.

The SD model can be used to ask 'what if' questions around future freight growth and infrastructure planning. Examples include road improvements along the Waikato Expressway and the Kaimai Range, greater use of larger (HPMV) trucks, changes in driver working hours and road–rail substitution.

1 Introduction

The purpose of this research was to investigate if and how systems dynamic (SD) modelling could be used for understanding traffic flows at an inter-regional (state highway) level, in the context of improving understanding of the relationship between economic activity, the demand for freight, and the performance of the rail and road network. We have used the Auckland – Hamilton – Tauranga (AHT) triangle as a pilot case study.

Causation runs in multiple directions: economic growth requires more freight, which requires a road and rail infrastructure network. But a poor network can undermine economic growth through lowering the productivity of the freight industry, while investment in the network can attract new industry and new migrants, thereby acting as a facilitator of growth.

Other types of models could, and have been used to study transport–economy interactions. For example the Waikato regional transport model is a very comprehensive (though not readily accessible) model to assist transport planners with understanding the effects of changes in land use and economic activity on transport, but with less emphasis on fright.[1] There are also spatial computable general equilibrium models of the type explored in Byett et al (2016), which are used to analyse the wider economic benefits of better connectivity, encompassing the effects of people and businesses shifting location. Neither model, however, focuses on high-level congestion. In contrast, in an SD model time is explicit. This means SD models can simulate processes such as traffic flows, encompassing delays, congestion, constraints and feedback effects. These variables can also be readily linked to other types of variables; in this case the economic drivers of demand such as population, exports and fuel prices.

The pilot SD model presented in this paper relates to freight flows in the AHT triangle, which dominates upper North Island freight flows. Thus it is complementary to Byett et al (2016).

The SD model cannot simultaneously be both a forecasting model and a simulation model. They are fundamentally different roles. In a forecasting model little care is given to structure; the emphasis is firmly on prediction with a minimum number of input assumptions. In contrast, structure is absolutely central to simulation models as their main use is to provide insight and understanding into how the real world works. We focus on the SD model as a simulation tool designed to answer 'what if' questions. It nonetheless has capacity for forecasting freight demand, but the forecasts will only be as good as the exogenously specified input assumptions drawn from the forecasts produced from two Bayesian vector autoregressive (BVAR) models (or from any other forecasting models from other parties) that are also developed in this paper.

A formal and automatic link between the SD model and the BVAR models that would capture the feedback effects from the road network to economic activity and freight flows was beyond the ambit of the project's resources. Nevertheless the output of the SD model does provide insights about how increasing traffic (generated by greater economic activity) affects travel times, and about the sensitivity of travel times to different aspects of the road system in general – investment in better roads, more freight carried on large trucks and so on. Alternative scenarios can be tested in a relatively quick and communicative manner.

[1] https://wrtm.org.nz/about

2 Literature review

There is not much literature on transport–economy models with a SD focus on the former component – transport. In this section we review two major reports (the first of which is a review in its own right) that were of most relevance to our project, looking particularly for advice, lessons and pitfalls to be avoided. Less relevant literature is briefly discussed in a section at the end of the chapter.

2.1 Model review by de Jong et al

De Jong et al (2002) provide a comprehensive review of UK and European freight transport models, encompassing:

- the Swedish national freight model system (SAMGODS) – see also below
- the Norwegian national freight model system
- the Walloon region freight model system in Belgium
- the Italian national model system, which for freight uses input-output (IO) models and disaggregate mode choice models
- the Dutch transport economic model and strategic model for integrated logistic evaluation. The former uses input-output methods, the latter has make-use tables and a logistic module for the location of distribution centres
- models used in the UK for national freight transport forecasts, such as those based on the strategic multi-modal modelling project
- the scenarios for European transport (SCENES) and NEAC[2] models for Europe
- models for specific international corridors, such as fixed link projects in Scandinavia and alpine crossings.

They find freight transport models are better developed at international and national levels than at urban and regional levels, with the latter overlooking economic processes. Most transport models are based on a standard four-stage model approach:

1. Trip generation: Determine exports to and imports from each zone, without distinguishing each destination and origin respectively – the borders of an origin-destination (OD) matrix. Magnitudes are expressed in physical units such as tonnes, perhaps derived from value units. (See the SAMGODS review below in this regard.)
2. Trip distribution: Determine the cells of the OD matrix
3. Trip modal split: Determine the mode of transport
4. Trip assignment: Determine the transport routes (with tonnes converted to vehicle units).

[2] NEAC was developed by NEA which was a partnership between the Dutch Scientific Institute of Transportation (Nederlands Vervoerwetenschappelijk Instituut, NVI), the Economic Bureau for Road Transport (Economisch Bureau voor het Wegvervoer, EBW) and the Administrative Centre for the Road Transport Sector (Administratief Centrum Beroepsvervoer, ACB).

2.1.1 Model types for stages 1 and 2

Various types of model are identified for these stages:

- time series models, whether univariate or multivariate
- SD models, such as the assessment of transport strategies (ASTRA) model (see section 2.2). Most such models do not have sufficient spatial disaggregation to simulate finer inter-zonal flows
- zonal trip rate models
- IO and general equilibrium models, perhaps with a spatial dimension, perhaps using gravity models and generalised transport cost (GTC) to obtain spatial disaggregation.

2.1.2 Stage 3

Typical approaches include the following:

- elasticities applied to changes in relative modal costs, relative to a base configuration
- multinomial logit choice models for relative modal shares
- firms' cost functions based on economic theory
- econometric demand modelling
- surveys of transport operators' preferences (stated and revealed)
- microsimulation: conversion of tonnes to shipments, nodes, carrier type and vehicle type
- multi-modal networks: simultaneous determination of mode and route choice, using cost minimisation and non-linear programming models.

2.1.3 Stage 4

If not already addressed in stage 3, stage 4 involves converting trucks into passenger car equivalents or something similar (such as container equivalents). Many models do not include this stage as it is more relevant at finer levels of spatial disaggregation.

De Jong et al (2002) recommend for international freight or freight between 'not too small' regions in a single country, two models should be used with different degrees of resolution. The first is a detailed high-resolution model based on:

- regional IO tables to determine an OD matrix, although this involves converting from values to tonnes
- a disaggregated choice model for mode and shipment size. Different groups of commodities related to degree of time sensitivity and handling characteristics
- an assignment stage: linked with a passenger model.

The second model would be a fast-executing, low-resolution policy analysis model, recommended to be an SD model with variables for the macro-economy, land use, transport and the environment – analogous to ASTRA. De Jong et al (2002) opine that IO models are too data hungry and require long execution times, although one should recall that this review was written in 2002. An advantage of SD models is their ability to incorporate feedback loops and time paths.

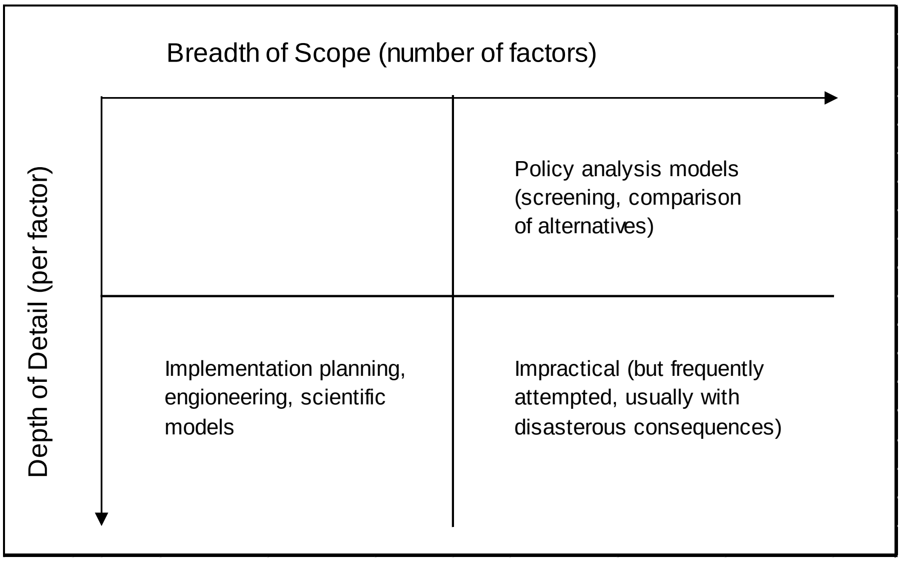
In all cases of course, the desired uses of a model determine its design. There is usually a trade-off between depth and scope. As illustrated in figure 2.1 (from de Jong et al), models that try to combine depth and scope usually fail. The SD model we developed in this research is in the top right corner of figure 2.1.

2.1.4 Relevance to this project

The review, although somewhat dated, provides a good summary of the different approaches to modelling freight transport systems. It is comforting to see SD modelling of freight transport is widespread. Based on their review the authors recommend an SD model for low-resolution modelling of the links between the wider economy and the transport sector, with disaggregated choice modelling and related techniques for high resolution issues.

From the perspective of (four-stage) transport modelling our focus in this project is reasonably low resolution, but from the perspective of economic modelling the spatial resolution is quite high. Accordingly, while an SD model constitutes the core component of our modelling system (which is after all the project's main objective) it may not be the best approach for all the joint economy-freight modelling system.

Figure 2.1 Model types



Source: De Jong et al (2002)

2.2 ASTRA model

Fermi et al (2014) describe the ASTRA modelling system. It is the largest economy-transport SD model we have found, covering most EU countries, 25 industries and 30 years. It was designed to analyse the long-term effects of the EU Common Transport Policy, not only for the transport system but also for the most important other systems connected to transport. The project resulted in the development of a system dynamics model for integrated long-term assessment of European transport policy with a spatial representation. The model is extremely comprehensive covering links between transport, the economy and the environment. It encompasses six modules:

1 Population: household types and income groups

2 Economy: IO tables, government, employment and investment

3 Trade

4 Transport: demand estimation, modal split, transport cost and infrastructure networks

5 Vehicle fleet

6 Environment: pollutant emissions, CO2 emissions.

Although the scope of the model is much larger than we can replicate here (even if we wanted to), it does have features that are relevant to our research, notably the economy and transport modules. We discuss these below in sections 2.2.1 and 2.2.2.

2.2.1 Economy module

Fermi et al (2014) comment that the model is not like a computable general equilibrium (CGE) model, but it actually contains many of the features of a CGE model, although not changes in IO coefficients in response to changes in prices.

Industry production, actually potential production, is a Cobb-Douglas function of labour, capital and (exogenously specified) natural resources. Intermediate IO coefficients are fixed so the ratio of value added to gross output is also fixed. However, there seems to be some adjustment to transport-related IO coefficients although it is not entirely clear how this is accomplished.

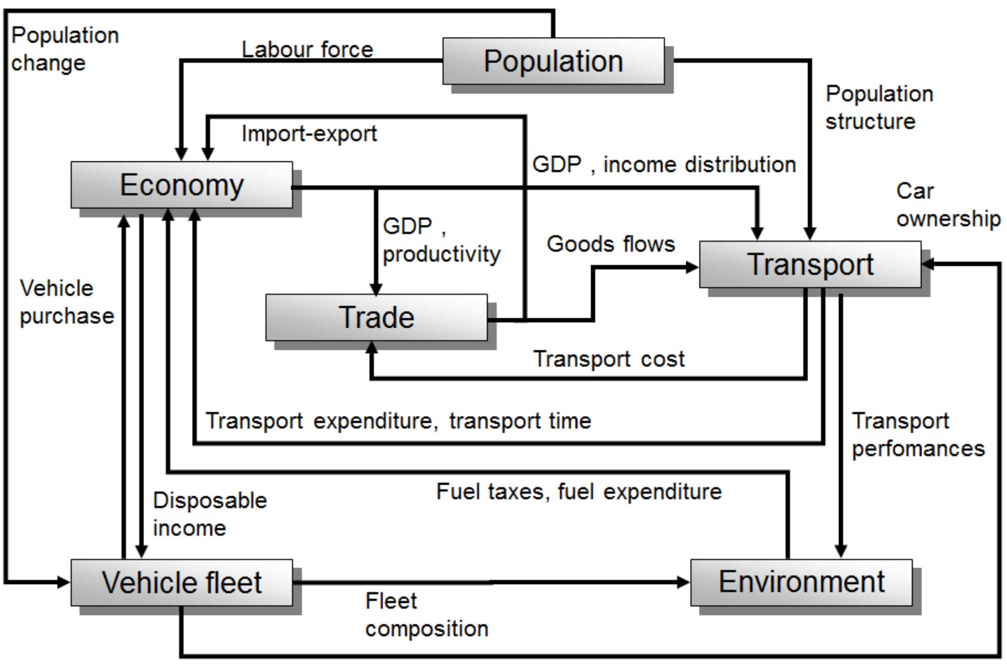
The standard components of final demand are included and are largely endogenous to the model – private consumption, government consumption, investment and exports:

- Fiscal closure is modelled with various revenue and spending equations.
- Private consumption is split by age and income groups.
- For exports, the accessibility of passenger and freight transport are explanatory variables.

Total factor productivity is a function of labour productivity, freight time savings and improved organisational performance – proxied by investment in the 'other market services' industry. The last of these is a fairly novel feature in economic models.

Final demand when run through the IO matrix determines demand for gross output, which determines value added and subsequently the demand for labour. Income feeds back into final demand and so on.

Figure 2.2 ASTRA model



Source: Fermi et al (2014)

2.2.2 Transport module

There is considerable discussion of how passenger transport is modelled as many of its structures apply to freight transport as well. Most equations are of the form shown in equation 2.1 where the dependent variable in a given period is a function of its previous value (or its value in the base period) plus the change in some other variable, usually GTC, GDP or a simple time trend. Some elasticities and coefficients are also determined in this manner.

$$\Delta Y_t = \propto + \beta \Delta X_t \qquad \text{(Equation 2.1)}$$

Passenger transport demand is disaggregated to varying degrees by age group, income group, zone, reason for travel, distance band, (local, short distance, inter-country etc) and mode. Base year shares for many of these variables (eg modal shares) are frequently adjusted using an equation such as above.

As might be expected, changes to shares necessitate much re-scaling and renormalisation so the behavioural simulation routines collectively become rather messy. This essentially stems from the proliferation of equations of the type above – reduced form change equations rather than structural equations. Certainly this has the advantage of not having to assume a particular functional form with all of the (implicit) restrictions that this frequently entails, but the cost of this is the need for many ad hoc adjustments to ensure internal model consistency.

The demand for freight transport covers the first three stages of the standard four-stage model.

1 Demand generation

2 Trip distribution: origin-destination

3 Mode split

4 Route assignment.

It does not include route assignment as the model is not designed with that degree of spatial disaggregation, which is typically at Nomenclature of Territorial Units for Statistics[3] level 1 or 2.

2.2.2.1 Demand generation

The value of trade and production (for international and domestic freight respectively) is converted to tonnes. Unit prices are considered volatile and unpredictable so the model uses equations of the above type to adjust base year freight volumes by elasticities applied to changes in the value of trade and production. Maxima and minima constraints are also imposed to avoid unrealistically large changes. Again this is consequence of adopting the above form of equation. That form is also used to adjust location shares within broader regions by changes in trade/population in origin zones.

Freight is split into three commodity types: bulk, unitised and general.

2.2.2.2 Demand distribution

Base flows between origin and destination are adjusted by coefficients applied to relative changes in GTC, using the above equation type. GTC includes labour, maintenance, fuel etc, plus time multiplied by the value of time.

[3] English translation of *Nomenclature des unités territoriales statistiques* (units of geographical coding), an EU standard.

2.2.2.3 Mode split

The model identifies the main mode used for each OD flow, but not (it seems) combinations of more than one mode. Mode shares changes according to relative GTC and trend, again using the above type of equation.

2.2.3 MARS model

The multimodal assessment of revenue allocation strategies (MARS) model is related to the ASTRA model. See Doll (2004). It is a small transport sector specific, system dynamics model. Its purpose is to provide a partial analysis of revenue allocation scenarios within a self-financing transport sector.

The model contains several feedback loops between traffic volume, travel speeds and congestion, as well as links between these variables and revenue from congestion charges, budgets and infrastructure deterioration and capacity. It identifies four transport modes and can accommodate different pricing (tolls, taxes etc) and financing schemes. It also has some interesting feature such as a welfare measure based on 'rule of half', stochastic deterioration of networks by time and traffic load, and user time costs that depend on network quality.

2.2.4 Relevance to this project

As noted at the start the ASTRA model is very comprehensive with considerable spatial and transport disaggregation. However, it is not disaggregated enough to simulate capacity constraints along particular freight transport routes, although the associated MARS model can do this at a broader level. Consequently it does not provide any new insights regarding the application of SD models to the simulation of traffic flows. It does though reinforce our initial preference to pursue an approach to the economics components of the modelling that imposes less demand on the user with respect to both theoretical economic expertise and the need to stipulate assorted ad hoc adjustments to behavioural equations. Stochastic deterioration of networks by time and traffic load could be a useful feature in a transport–economy model.

2.3 Benaich congestion model

Benaich (2015) is a rare example of SD being used to model actual traffic flows in space and time. An approach known as the cell transmission model is adopted, whereby a continuous section of road is divided into a number of discrete cells. Generally speaking, the cells correspond to the links and intersections that characterise a road network.

Each cell is a stock through which a flow of vehicles transits. The rate of flow for any particular cell depends on the occupancy and characteristics of receiving and emitting cells – much like any stock-flow model (refer section 4.1). Intersections and motorway on/off ramps are treated as merging or splitting flows, subject to standard stock-flow constraints.

Different 'time constants (dT)[4] for the model are discussed, but all are fractions of a minute. This raises the solution time of the model considerably, but in combination with fine spatial disaggregation enables the model to be used for simulating short-lived, very localised congestion, which is the aim of the model. It is applied to a case study of the Brussels ring-road system for which it has 164 cells. (This is much finer than we envisage for the AHT model.)

[4] An SD model is essentially a set of first order differential equations that are converted from continuous time to discrete time by identifying a suitably small discrete time period.

One challenge encountered in the study was dealing with the 'first in first out' problem which relates to the allocation (order of priority) of batches of vehicles converging at intersections. The author cautions he is not entirely happy with the model in this regard as the allocation process is unstable. Overall though, he concludes SD modelling is a promising approach for analysing congestion.

2.4 Other papers

2.4.1 Model review by Shepherd (2014)

Shepherd (2014) provides a more recent review than that by de Jong et al (2002) covering more than 50 journal papers published since 1994. The review classifies the papers into six fields:

1 Modelling the uptake of alternate fuel vehicles

2 Supply chain management with transportation

3 Highway maintenance/construction

4 Strategic policy at urban, regional and national levels

5 Airlines and airports

6 Emerging areas (such as traffic safety, shipping markets and ports).

Of most interest to our project is the fourth category. Strategic policy models share features with land use transport interaction (LUTI) models, but trade off less detail against greater scope, and operate over different time scales. They are generally designed to look at how the structure of cities and regions (land use) interact with transport and associated infrastructure as the population and economy change.

Most models incorporate modules or groups of equations that deal with variables such as population and migration, household structure, employment, GDP, land use, vehicle ownership, travel demand and congestion. Some also have environmental indicators such as greenhouse gas emissions. The mix of endogenous and exogenous variables differs from model to model. SD is a common modelling approach.

Shepherd cites the example of the ASTRA model (see section 2.2) commenting it is encouraging to note that even though four-stage transport models still dominate the market, the EU is also using other approaches such as SD. Shepherd also suggests SD models are not suited to traditional network assignment problems. (The main reason for this is SD models do not optimise.)

2.4.2 SIMTRANS

Salini et al (2010) describe the SIMTRANS model; an SD model designed to analyse the dynamics of the French freight transportation market across the modes of road, rail and inland waterways. Intermodal substitution is a key focus of the model, with three factors determining mode attractiveness:

1 Means: capacity of trucks, trains and boats, and investment in new capacity

2 Mode productivity: travel time, route options

3 Quality: merchandise damage, on time delivery.

The model can be used to analyse the effects of changes in relative modal costs, fuel efficiency, carbon emissions reduction policies, congestion and so on. It is very much a model of the transport system and logistics, not an economy–transport model. Most macroeconomic variables such as industry growth are exogenous and it contains more detail on the transport system than is appropriate for our project because inter-modal substitutability and route choices are much greater in France than in New Zealand. Nevertheless its inclusion of congestion demonstrates the viability of using an SD model for this purpose.

2.4.3 SAMGODS model

Williams et al (2002) look into the feasibility of spatial computable general equilibrium (SCGE) models for transport analysis. Although an SCGE model is not our focus in this report, the paper provides some useful advice for linking transport models and economic models.[5]

1. The demand for transport stemming from economic growth is a function of consumer and producer behaviour. LUTI models do not capture this. Thus it makes sense to develop OD matrices for producer to consumer pairs first, and then determine OD matrices in terms of actual pair-wise shipments. The latter is the focus of four-stage transport models. Such models do not deal with forces external to the transport sector.
2. Even LUTI models have been focused more on passenger movements than on freight movements.
3. Relatively coarse spatial aggregation in economic models can make it difficult to model congestion, which tends to be specific to more finely defined spatial zones and time periods. We propose to deal with this by modelling the mean and variance of quarterly average daily traffic.
4. OD matrices need to be related to the monetary costs of travel, time and service quality.
5. To convert from inter-zonal flows in monetary units to OD flows in tonnes, international trade price indices, which tend to be reasonably detailed, could be used, although this works better for traded commodities such as logs and oil than for general freight (which probably constitutes most of the truck traffic in our AHT region of interest).

2.4.4 Miscellaneous

The following papers are of interest as they deal with a range of applications of transport modelling that are peripherally relevant to the project. They do not provide much insight for the development of our intended models but they do illustrate some topics to which transport and SD models have been applied, topics that could perhaps be analysed with our proposed modelling system. The topics include larger vehicles, logistics, interactions with container port hubs, fleet modelling and transport system disruptions.

- Christidis and LeDuc (2009)
- Gacogne (2004)
- Imai and Papadimitriou (2009)
- Kühn and Krail (2013)
- Vischio (2010)
- Macmillan et al (2014) – applying SD to the health benefits of cycling in New Zealand

2.5 Conclusion

Examples of SD models applied to inter-linked transport–economy issues are rare. Where they do exist they tend to be used for modelling economic behaviour, with LUTI type approaches used for modelling traffic flows. This is almost the opposite of what we wish to do. Like Benaich (2015), who is an exception,

[5] The development and application of an SCGE model for the AHT region is described in Byett et al (2016).

we wish to develop an SD model to simulate traffic flows and congestion, and use econometric models for the economic components and transport–economy links.

It is important to emphasise that the modelling system developed here is specific to the issues and location for which the project was commissioned. The model will not immediately be applicable to other areas, nor to all issues within the AHT area. It is envisaged, however, the modelling system would be amenable to being adapted to consider other areas and other spatial disaggregation, although this would require more data gathering and model testing.

3 Model system

3.1 Introduction

Figure 3.1 shows the structure of the model system, where each model is represented by a rhombus.

The economic models are used to produce OD matrices for future years to feed into the SD model. However, the SD model is entirely neutral with respect to the source of its data. It need not come from the models developed here. OD projections from other sources, such as from the Ministry of Transport (2017) *New Zealand transport outlook* for freight, could easily be substituted.

3.2 Economic models

The economic models take us through projections of GDP by industry to projections of GDP by region, which in turn lead to projections of OD matrices.

There are two vector autoregressive (VAR) models and one principal components (PC) model in the model system. A VAR model has a very loose theoretical specification in the sense that every variable is a function of its own lag and of every other variable. No parameter restrictions are set. For example we do not specify that the construction industry is affected more by the manufacturing industry than by the agriculture industry. Strictly speaking, however, our VAR models are Bayesian VAR (or BVAR) models which means there are a few ‘hyper-parameters’ we are able to control, such as whether the influence of lagged values declines geometrically or harmonically and how much influence we expect own lags to have compared with other variables.

3.2.1 VAR model of GDP by industry

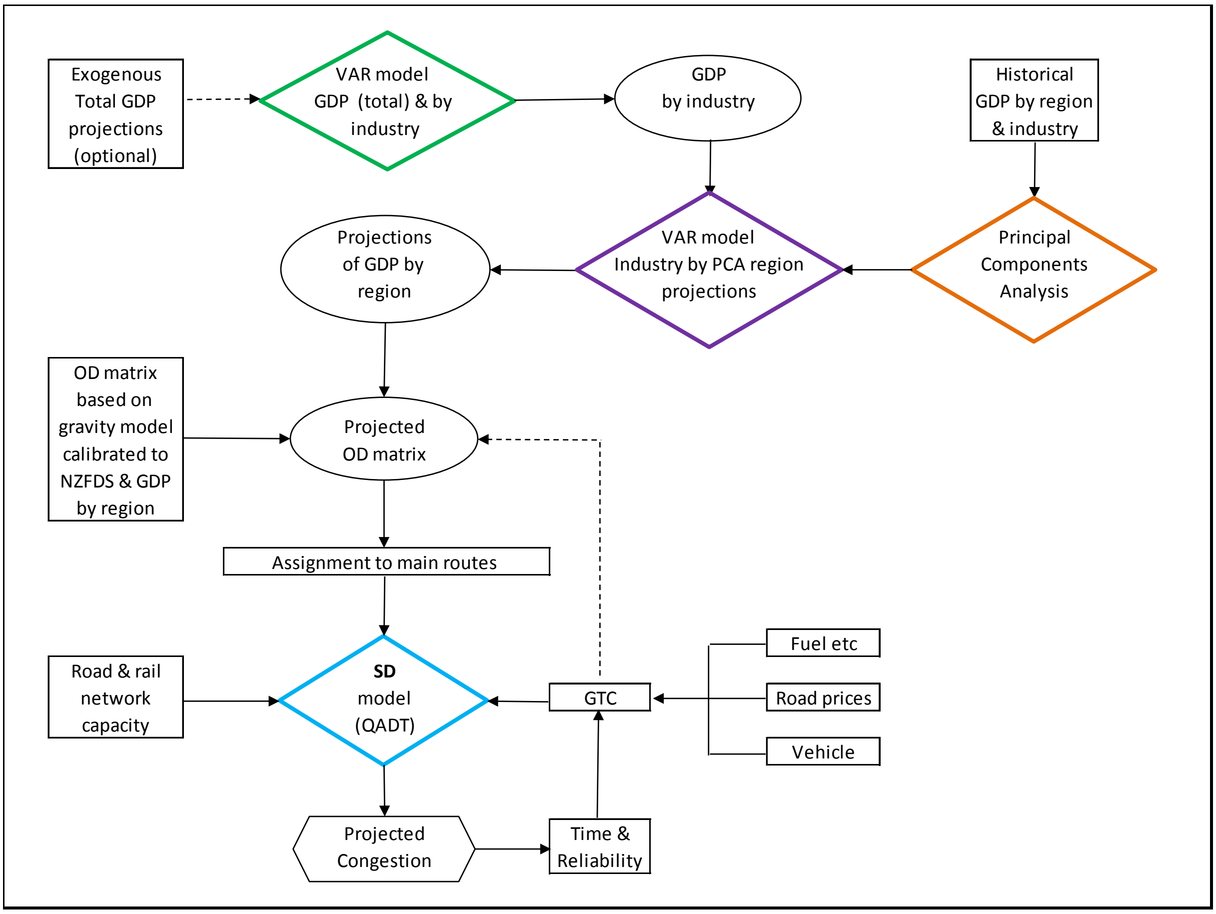
The first VAR model (green rhombus) projects industry shares of GDP and the level of aggregate GDP based on 16 years of data. The level of GDP can either be endogenously determined by the VAR model or set exogenously, for example, to align with Treasury projections. To lessen the complexity of the model we define eight industry groups, condensed from an initial group of about 55 industries:

1 Agriculture and food processing
2 Forestry and forestry products
3 Mining, petroleum, basic chemical and non-metallic mineral products
4 Rest of manufacturing
5 Construction and utilities
6 Trade and accommodation
7 Other services
8 Transport services.

The last industry is omitted from the estimation process to avoid over-determining the system. While any industry can technically be omitted, for this exercise the omission of transport services is conceptually appealing as it is an activity based on derived demand (for freight) that comes from the other industries.

Next we need to convert the projections of GDP by industry to projections of GDP by region. The first step in this task is to construct a suitable Industry by region coefficient matrix and the second step is to construct a model to project that matrix over time as it is unrealistic to assume a fixed matrix.

Figure 3.1 Model system for freight- economy study



3.2.2 Principal components model

While our interest is focused on the Auckland, Waikato and Bay of Plenty (AWB) regions (the regions that contain the AHT triangle), we cannot sensibly ignore the rest of the country when projecting economic activity in the AWB area. However, 15 regional councils and eight industries constitute a rather large model with more detail than we need.[6] One option would be to aggregate the rest of New Zealand into one region, but such a heterogeneous grouping is unlikely to have stable relationships with the AWB region. It would also restrict our ability to properly model freight that passes through the AWB regions, but which neither originates in, nor ends up in the AWB region. This is discussed further below.

As the relationships between regions are likely to be dominated by proximity and industry composition, we seek to reduce the number of regions by PC analysis to reduce potential multi-collinearity, represented by the orange rhombus in figure 3.1. That is, we wish to reduce an initial matrix of eight industries by 15 regions (by 16 years of data) to a matrix of eight industries by one or two PC-regions (by 16 years). Hence the PC analysis is run eight times, once for each industry. This produces an 8x16 matrix for the set of first principal

[6] There are actually 16 regions, but our dataset has amalgamated Nelson and Tasman.

components (PC1) which typically capture 95% of the variation by region. Adding the second principal component (PC2) raises the explanatory power to 99%. Hence the other principal components are ignored.

The PC model needs to be run only when the base data is updated. All it does is reduce the size of the 'industry by region' matrix that has to be projected and remove multicollinearity from the forecasting VAR model in the next step. It should therefore also yield more robust projections than would a model with 15 regions of highly variable size.

3.2.3 VAR model of GDP by PC region

The second VAR model (purple rhombus) uses the output from the PC model, notably PC1 and PC2 to obtain projections of industry by PC region share matrices, again with 16 years of data. These projections are then converted back into the full 15 regions by using the eigenvectors from the PC model. Applying the projected industry by region share matrices to the projections of GDP by industry from the first VAR model, yields projections of GDP by region in level form – as desired for input into the SD model.

As might be expected the projected regional shares of GDP are not guaranteed to add to 100%, so they are adjusted pro rata. Experience with the model to date shows in most cases the sum of the shares is within 100% ± 2% and very rarely outside ±5%.

3.3 Origin-destination matrix

For projecting inter-regional trade in the AWB regions we use the standard gravity model, with regional GDP as the measure of economic mass and road distances between regional main cities as the measure of connectivity.[7] The model is calibrated to reproduce actual inter-regional trade for 2012 as estimated in the *National freight demand study* by Deloitte et al (2014).

Because our ultimate interest is in freight movements along the main routes in the AHT triangle we need to account for freight that passes through the area of interest, but which does not come from, nor is destined for any location within the AWB region. Hence the OD matrix must begin with eight regions, the three core regions plus five that are contiguous with the core regions. These are:

1 Northland

2 Auckland

3 Waikato

4 Bay of Plenty

5 Gisborne

6 Hawke's Bay

7 Taranaki

8 South – all other regions from Manawatu-Whanganui south, including the South Island.

The gravity model is given by equation 3.1.

$$T_{ij} = \alpha M_i M_j / d_{ij}^2 \quad \text{(Equation 3.1)}$$

[7] A good description of gravity models, albeit in the context of migration, is given in Omoniyi et al (2016).

T_{ij} denotes trade between regions i and j, M_i and M_j are the economic masses (GDP) of the two regions and d_{ij} is the distance between them. Distance could be replaced with travel time, and in fact we simulate changes in travel time as changes in effective distance. In the SD model travel time is explicit.

Once inter-regional trade is calculated between these eight regions, the flows are aggregated to the four prime locations in the SD model. See figure 3.2. Specifically:

1. Trade between Northland and all other regions except Auckland is treated as coming from or going to Auckland.
2. Trade between Taranaki and the Northland, Auckland and Bay of Plenty regions is treated as coming from or going to Waikato.
3. Trade between Gisborne and the Northland, Auckland and Waikato regions is treated as coming from or going to Bay of Plenty.
4. A fourth region 'South' is included to account for trade between the AWB region plus Northland, and all regions to the south including Hawke's Bay.

It is assumed (in the meantime) that trade between the Bay of Plenty and Hawke's Bay, between Bay of Plenty and Taranaki, and between Gisborne and Taranaki does not pass through the AWB region.

Table 3.1 shows the estimated freight flows for 2012. For example 3.1 million tonnes moved from Auckland (including freight from Northland) to Waikato. Total inter-regional trade in 2012 that travelled through the region of interest was 28.3 million tonnes. Intra-regional trade is excluded.

Table 3.1 AWB freight flows (million tonnes) 2012

From\to	Auckland	Waikato	BoP	South	Combined
Auckland		3.1	3.9	6.3	13.3
Waikato	4.7		3.1	0.5	8.3
BoP	2.2	1.9			4.1
South	2.2	0.4			2.6
Combined	9.1	5.4	7.0	6.8	28.3

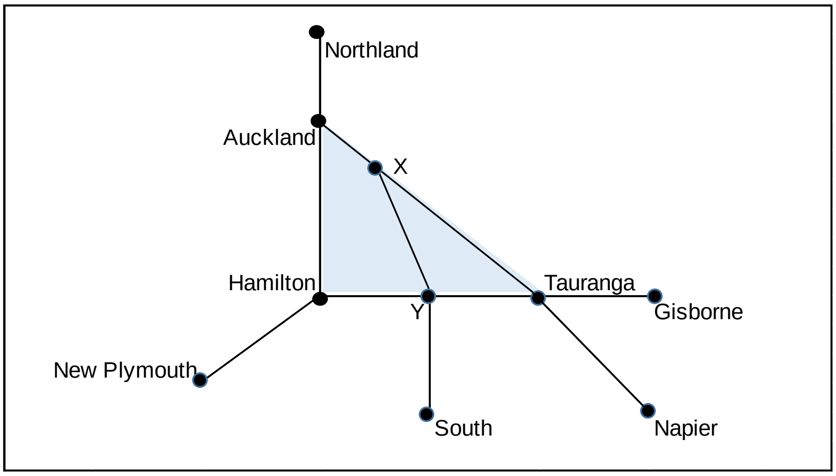
Source: compiled from Deloitte et al (2014)

3.4 Route assignment

The SD model does not endogenously assign routes. They are an input which could come from any source. With regard to the diagram in figure 3.2 below, there are six routes in which we are interested:

1. Auckland to X (AX), where X is the intersection between SH2 and SH27
2. X to Y (XY), along SH27
3. X to Tauranga (XT), along SH2 via Waihi
4. Auckland to Hamilton (AH), along SH1 and the Waikato Expressway
5. Hamilton to Y (HY), along SH1. where Y is a general representation of various intersections in the area; 27 and 29, 1 and 29, 1 and 5, 5 and 28, 1 and 28, and 28 and 29.
6. Y to Tauranga (YT), along SH29.

Figure 3.2 Route schematic



Translating the OD trade matrix into bi-directional flows along the six routes is reasonably straight-forward. Only two main decisions are required for south or east flowing traffic:

1 From Auckland to anywhere south or east, the split between AH and AX

2 At point X, the split between routes XT and XY (south-bound freight must use XY).

These choices are determined from NZ Transport Agency (the Transport Agency) telemetry data. Based on truck movements for August 2016 the proportions weighted by truck length (as a proxy for cargo mass) are 56.3%/43.7%% and 44.9%/55.1% respectively. For the opposite directions the SH2–SH29 split leaving Tauranga is 45.9%/54.1%, while the split at SH1–SH27 (point Y) is 67.1%/32.3%.

Note for SD modelling purposes these proportions are adjusted to accommodate non-freight vehicles, which is required for modelling congestion.

The detailed calculations underlying the derivation of the OD matrix and associated segment flows are in a spreadsheet file that is available from the authors.

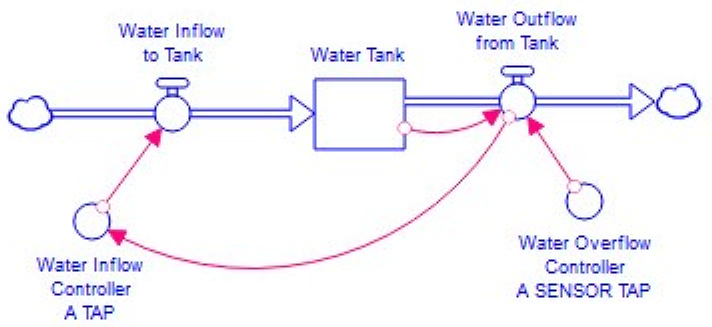
3.5 System dynamics model

The SD model is represented in figure 3.1 by the blue rhombus. It takes the growth in freight and thus (absent exogenous shocks) the growth in truck traffic on each route and applies it to base year traffic on each route. The following chapter is dedicated to the SD model.

4 System dynamics model

SD models are a representation of naturally existing systems incorporating stocks, flows and feedback loops between various entities that interact with each other over time. Figure 4.1 is a very simple system dynamics model in which water flows into a tank controlled by an inflow tap. The outflow controller is a function of the level of water in the tank and this is used to control the rate of the inflow.

Figure 4.1 A simple SD stock- flow model



4.1 SD model of AWB traffic

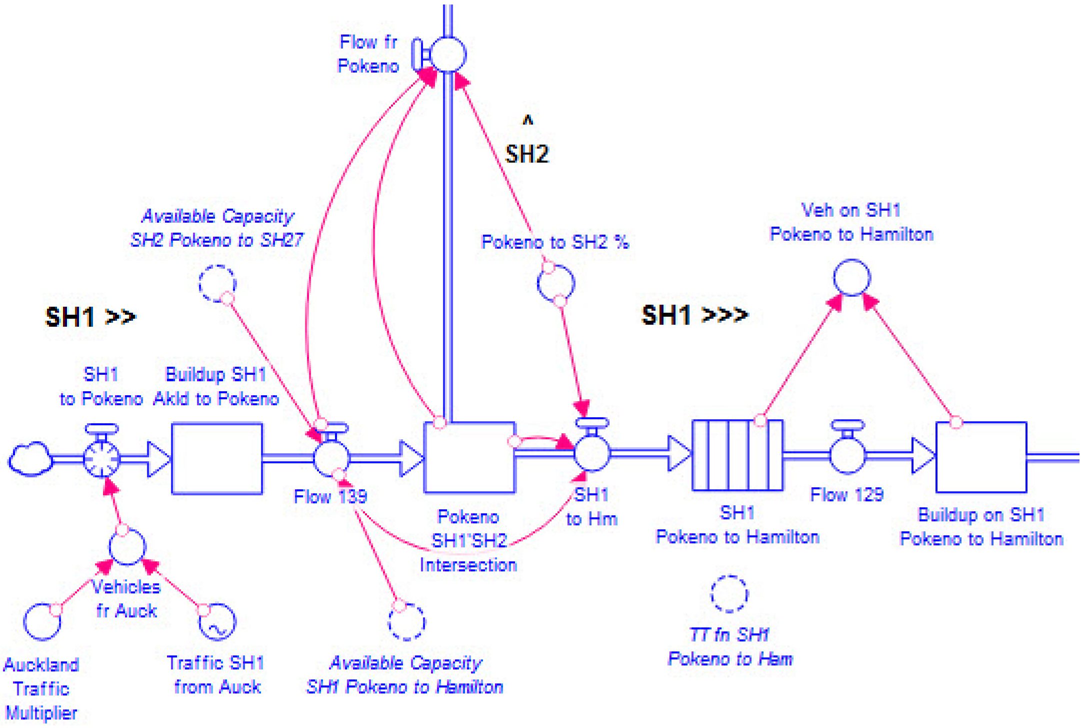
Figure 3.1 in the previous chapter shows where the SD model of traffic in the AWB region fits within the overall modelling framework. It is represented by the blue rhombus.

Figure 4.2 shows a detailed section of the SD model relating to traffic leaving Auckland. There is an initial inflow of traffic from Auckland on SH1 for a typical day in 15 minute pulses, which feeds into a build-up stock, allowing for the possibility of congestion leading up to the SH1–SH2 intersection at Pokeno. Whether a build-up of congestion occurs here depends on whether there is available capacity (maximum capacity is set exogenously) on the early sections of SH1 and SH2 after the intersection, which will allow vehicles to move on. Movements at the intersection are determined by the settings on the 'Pokeno to SH2 %' controller which exogenously sets route selection. In the model, vehicles moving along SH1 to Hamilton first meet a 'conveyor' the travel time of which represents the rate at which vehicles are able to move. This takes into account potential congestion on the section of road in conjunction with its available capacity. The number of vehicles within the conveyor and the build-up stock in relation to the overall vehicular capacity of the section of road determines the travel time of the conveyor, in this case represented as 'TT fn SH1 Pokeno to Ham'. As the available capacity reduces due to congestion ahead, the travel time of the conveyor decreases, allowing fewer vehicles onto the section of road. In simple terms, new vehicles are allowed onto the section of road only when vehicles leave the congested build-up stock.

It is important to recognise that congestion on one section of road can push back onto traffic movements on earlier sections of road. Notably, in this regard, the road sections are not independent, but are part of a wider inter-related system of traffic flows.

The full model, for traffic moving from north to south is shown in figure 4.3. A clearer version is embedded within the model software.

Figure 4.2 Section of SD model of AWB traffic



The model is a high-level simulation model. The segments of road are as depicted in figure 4.2. That is the limit of the spatial resolution. So when congestion arises along segment XT for example, it could be anywhere between the SH2–SH27 intersection by Mangatawhiri and Tauranga.

Other key features of the model are:

1 The model's time frame is configured to represent a 24-hour period for a typical day. This can be varied by quarter to capture seasonal effects. An example for traffic leaving Auckland at Bombay in August 2016, including weekend days (our base case) is shown in figure 4.4 in quarter hour blocks (starting times shown in graph). Solid lines denote mean daily traffic while the bars represent ± one standard deviation.

2 To handle vehicles of different sizes we define a composite vehicle which is a weighted average of four classes of vehicles: one class for light passenger vehicles and three for trucks. Each class has a mean length and the weights correspond to the mix of traffic leaving an origin (such as Auckland) at different times of the day (for example there are more trucks at night). The weights can be exogenously adjusted for future changes in the vehicle mix. They are not endogenous to the model.

3 A simple exponential function is used to model the relationship between traffic volume and travel time, allowing also for the size of vehicles in the road. Refer appendix A for details.

4 For each section of road the model has an efficiency factor, again set by the user, which can be applied to simulate the effects of road improvements such as passing lanes, curve realignment and by-passes. Similarly reductions in efficiency could occur because of events such as crashes or road damage.

5 Any section of road can be entirely blocked off by redirecting traffic at intersections.

Figure 4.3a SD model of AWB traffic

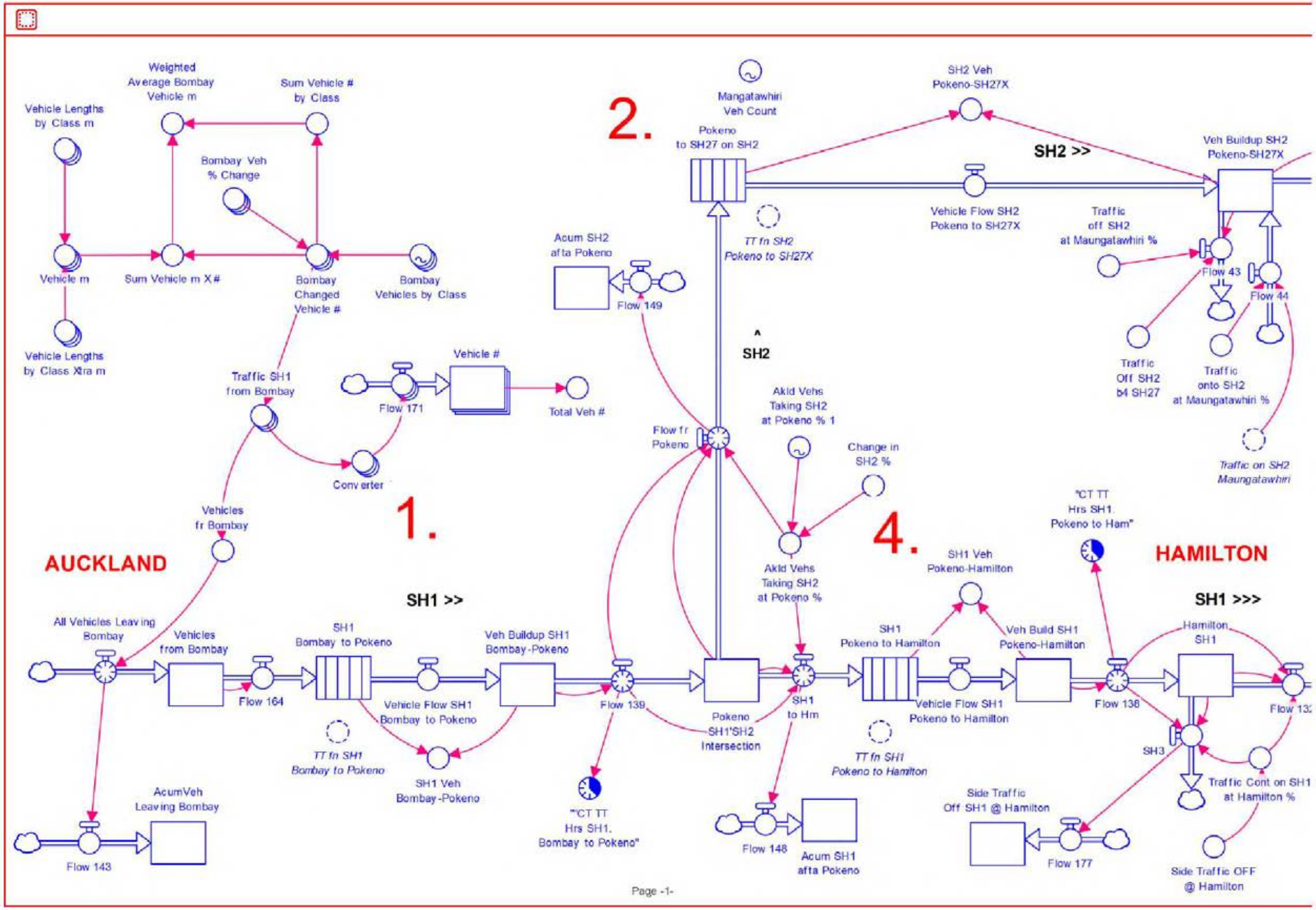


Figure 4.3b SD model of AWB traffic

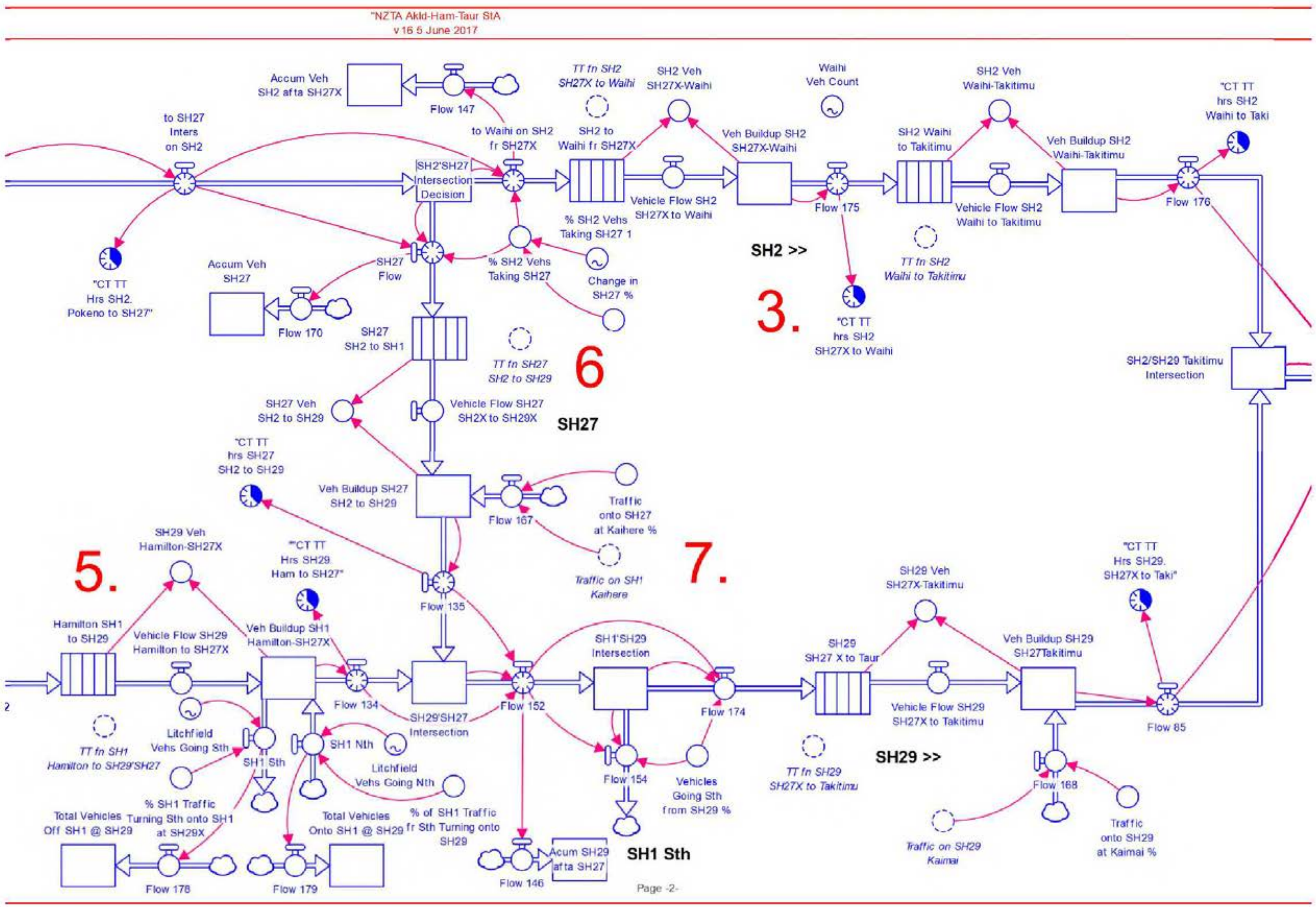


Figure 4.3c SD model of AWB traffic

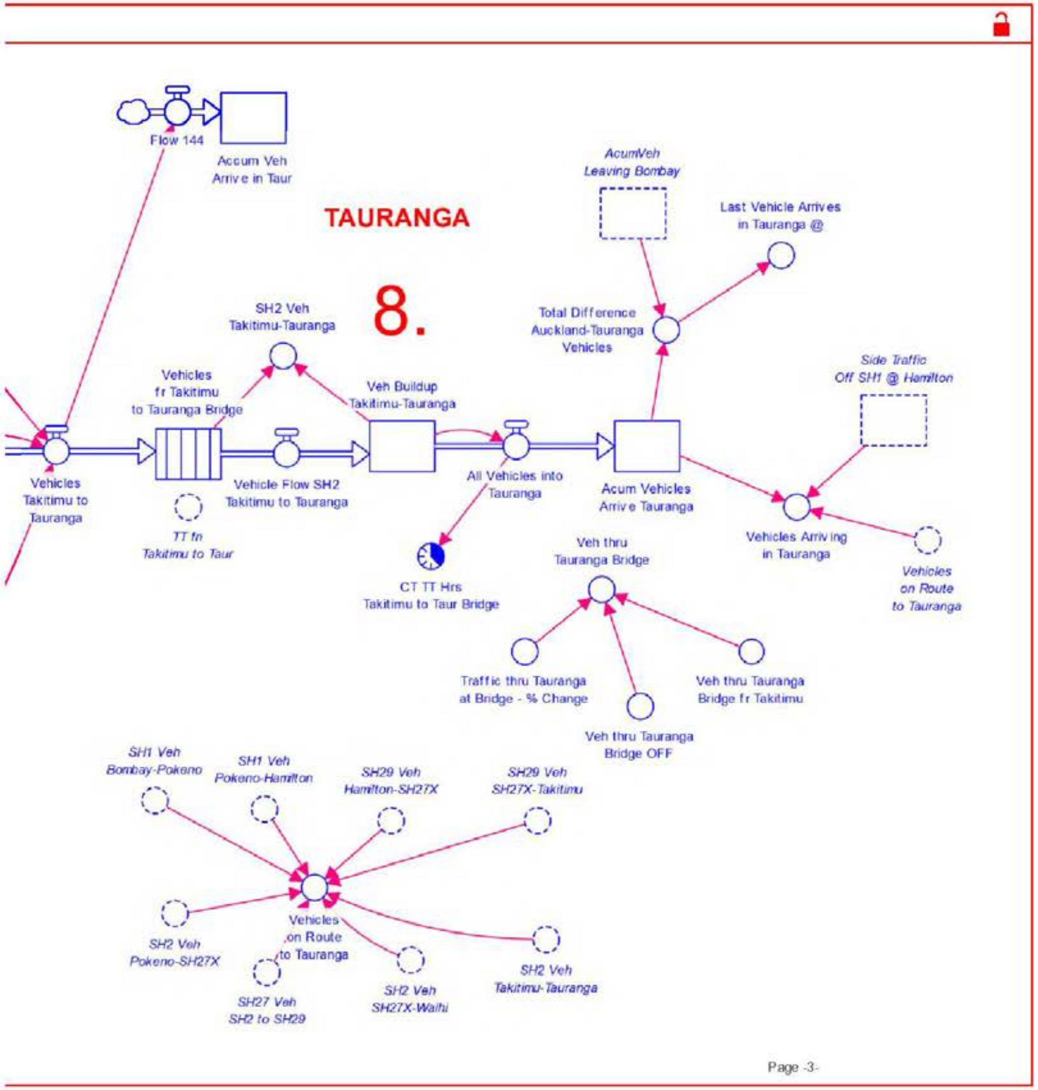
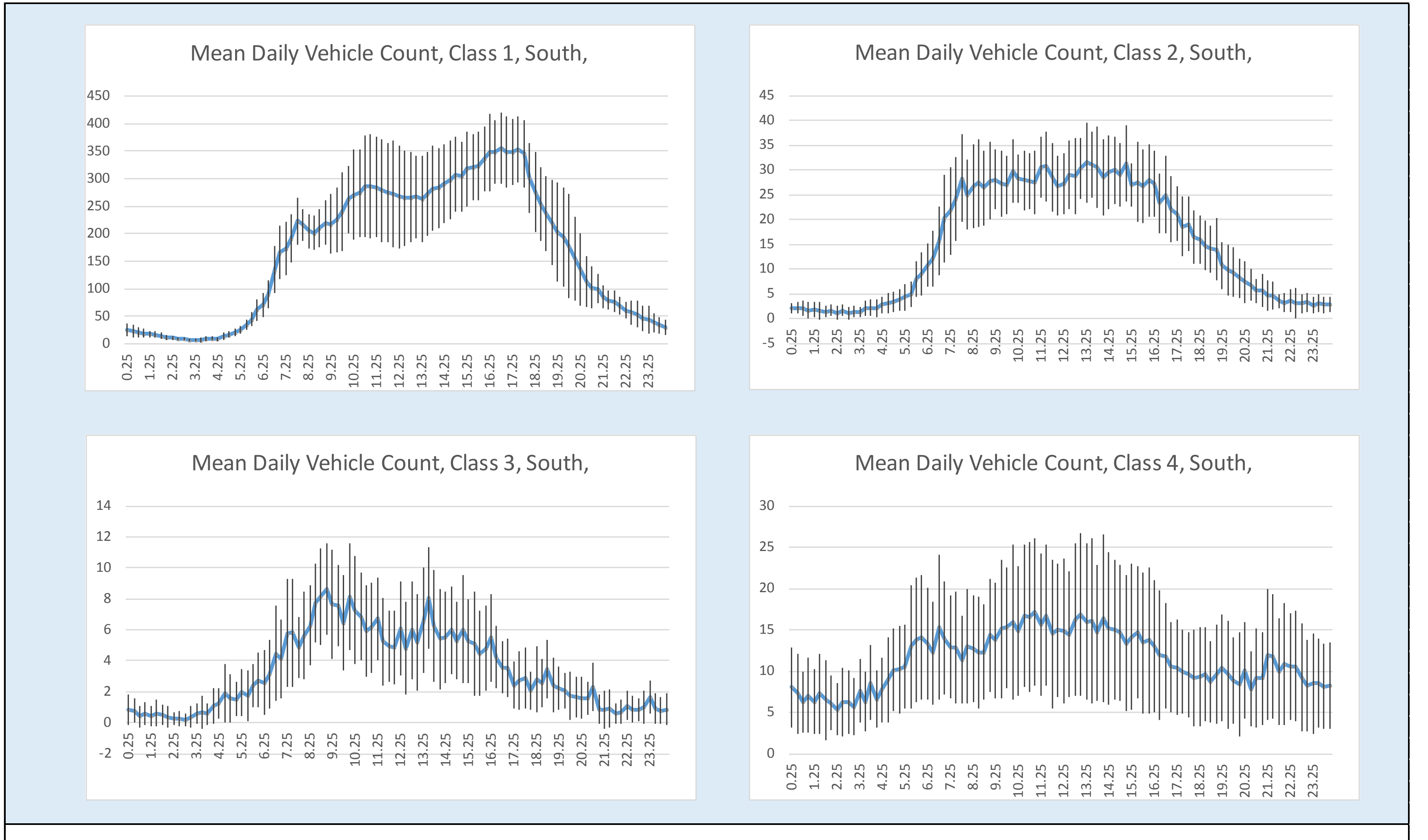


Figure 4.4 Example of mean daily traffic (Bombay, August 2016)



August 2016 Site: 01N10474 (BOMBAY - Telemetry Site 72 - SB) location: 461/12.790

5 Baseline projection

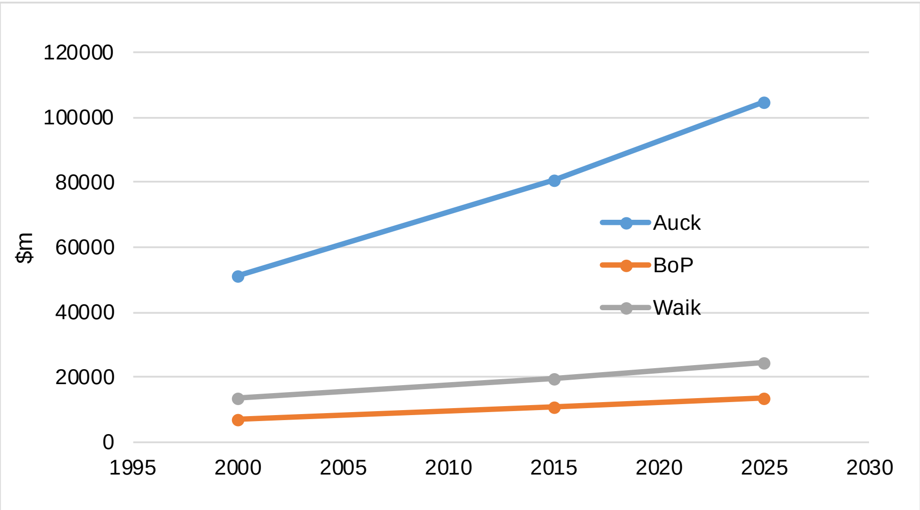
A default set of projections has been produced using the suite of models described in chapter 4. While they are intended to represent reasonably plausible pictures of 2025, they are not intended to be best forecasts. As discussed previously, users can replace any of the default projections (total GDP, GDP by industry, GDP by region, or OD trade flows) with projections from other sources. For the default scenario total GDP is taken from Infometrics Ltd's forecasts to 2021 (as at January 2017) and an assumed growth of 2% per annum (pa) from 2021 to 2025. This forecast is applied to the projected GDP shares from the VAR model to obtain projected levels of GDP by region.

Figure 5.1 shows projected real GDP growth to 2025 for the three AWB regions. Between 2012 and 2025 average annual growth is 2.6% in Auckland, 2.5% in the Bay of Plenty and 2.3% in Waikato. The regional composition of each industry and the industry GDP composition of the three AWB regions are illustrated in graphs in appendix C.

Even though current roading projects in the AWB region will reduce travel times (for example by 'up to 35 minutes' in the case of the Waikato Expressway[8]) we need a baseline scenario which can then be used as a basis for exploring other case study scenarios such as the Waikato Expressway (see chapter 6). Thus we assume the network is largely as it was in 2012 so in the absence of infrastructure improvements future travel times across the region would be higher by 10% by 2025. This is probably conservative.

Applying the gravity model produces the projected regional OD flows for 2025 shown in table 5.1. Total freight is 44.9 million tonnes, an increase of 59% or 3.6% pa on 2012 – from table 3.1. Thus trade growth is about 40% faster than GDP growth. Interestingly Stephenson and Zheng (2013) estimate an elasticity between GDP and freight in the range 1.0–1.4%.

Figure 5.1 Real GDP by region to 2025



[8] www.nzta.govt.nz/projects/waikato-expressway/

Table 5.1 Projected AWB freight flows 2025 (million tonnes)

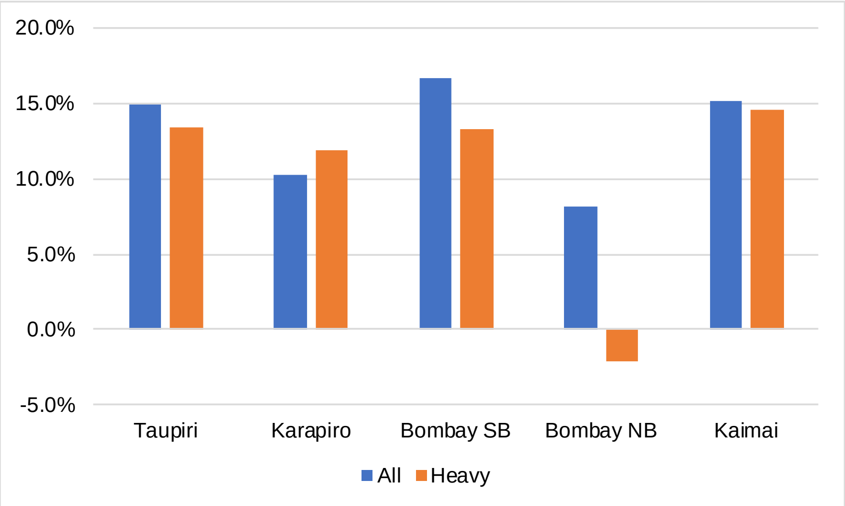
From\to	Auckland	Waikato	BoP	South	Combined
Auckland		5.00	6.16	10.19	21.35
Waikato	7.50		4.71	0.76	12.97
Bay of Plenty	3.48	2.87			6.36
South	3.59	0.60			4.20
Combined	14.57	8.48	10.87	10.96	44.88

Freight growth of 3.6% pa is slower than in the past. Simic and Bartels (2013, p28) show various measures of road freight rising at about 4.1% pa from 1992 up to the global financial crisis in 2008, with little net growth between 2008 and 2011. Deloitte et al (2014) expect growth of only about 2.2% pa to 2025.

Vehicle counts at the main telemetry sites in the AWB region between 2012 and 2015 typically rose by around 13% (4.2% pa) for heavy vehicles and somewhat more for all vehicles and in Auckland (see figure 5.2). Growth in tonne-kilometres from 2012 to 2014 was 11.3% (5.5% pa).[9] Changes to how data is collected mean there are no estimates of tonne-kilometres after 2014.

Overall these figures suggest the model's baseline projections of the growth in inter-regional trade within the AWB region are plausible. Again they are not intended to be forecasts. The effects of alternative baselines are easy to examine.

Figure 5.2 Growth in AADT 2012 to 2015 at selected sites



Source: NZ Transport Agency (2016)

Table 5.2 shows the impact on freight flows along each of the route segments illustrated in figure 3.2, assuming existing route choices. The changes span a fairly narrow range, from 54.0% (west from Tauranga to intersection Y) to 61.6% (north along SH27). The differences are probably spurious so for modelling purposes we assume a uniform 60% increase. The same increase in applied to all four classes of vehicle. We also assume for this first run that route assignment is fixed; that is the proportion of trucks (and other vehicle)s travelling along each route remains the same irrespective of relative changes in travel times.

The model's results are illustrated in figures 5.3 and 5.4.

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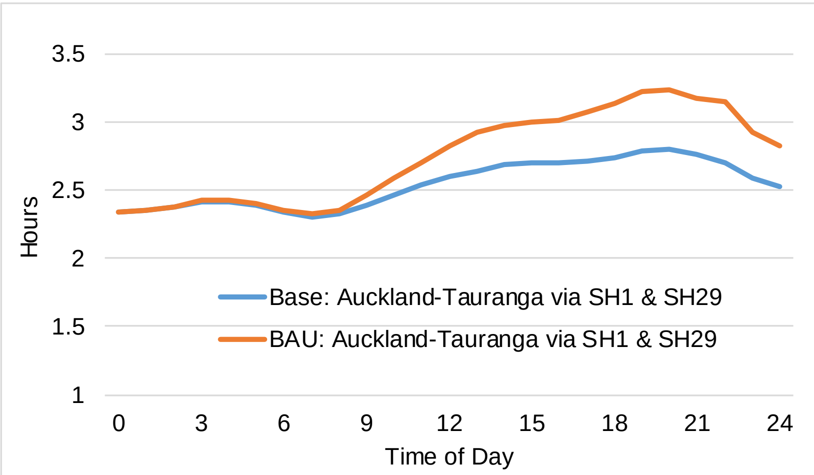
[9] Ministry of Transport, New Zealand vehicle fleet model

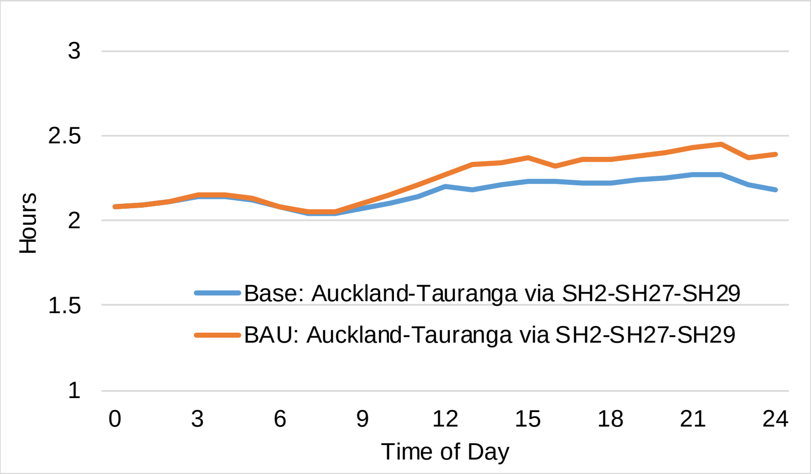
Table 5.2 Changes in freight flows 2012–2025 by AWB route segment

Route	Direction	Change
AH	S	60.7%
	N	60.2%
HY	E	57.1%
	W	56.4%
AX	S	60.3%
	N	60.0%
XY	S	60.8%
	N	61.6%
XT	S	57.9%
	N	58.2%
YT	E	55.0%
	W	54.0%

All three main routes for southbound travel between Auckland and Tauranga show increases in average travel times between the base year and 2025, from about 8am onwards. The increases are generally around 5–10 minutes but on the SH1–SH29 route the increase at peak time is almost 30 minutes, extending into the evening. In reality this would likely persuade some drivers to change routes and/or travel times. Recall that the baseline is merely a *ceteris paribus* projection of 60% more traffic.

Figure 5.3 Projected travel times for Auckland to Tauranga (2012 base and 2025 baseline)





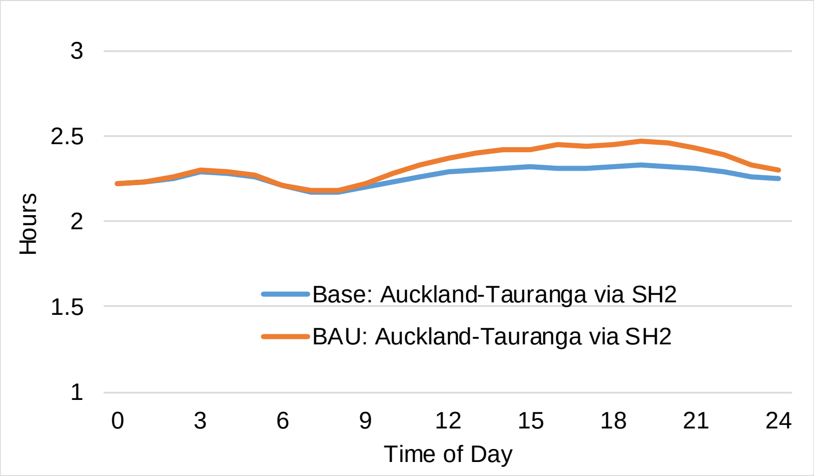


Figure 5.4 shows the northbound journeys. Again all three main routes show increases in travel times between the base year and 2025 baseline from about 8am onwards. However, the largest increase for this direction is on the SH2 route where the maximum difference is over an hour. The segment of road between Tauranga and Waihi is mostly responsible, although the following segment between Waihi and Paeroa encompassing the Karangahake Gorge also contributes. More traffic slows travel speeds (the speed of the conveyors in the model).

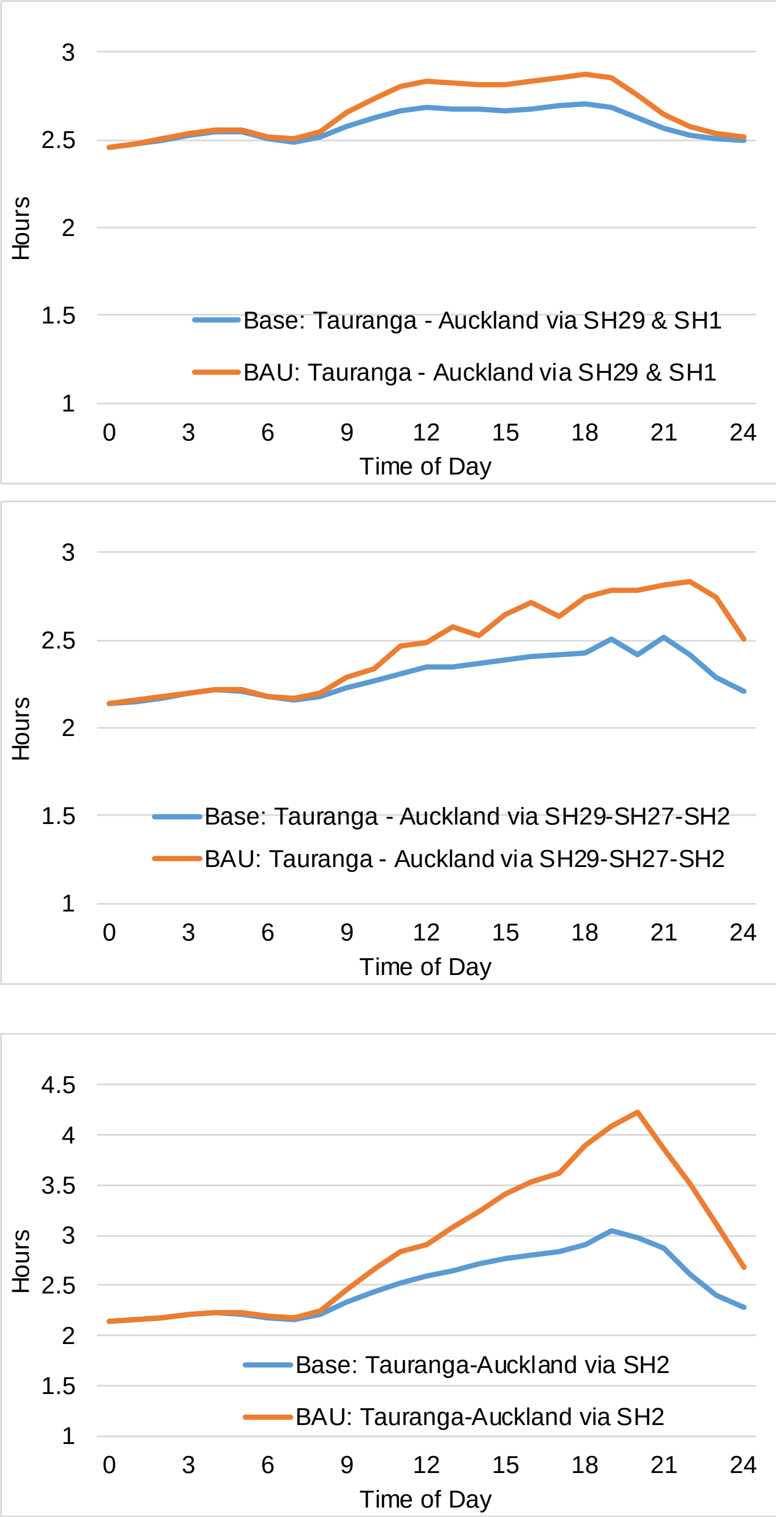
Again in reality we would expect to see a driver response regarding route choice and time of travel. In essence though we can infer that even if the numbers in the baseline scenario are most unlikely to eventuate, there is an underlying potential for significant congestion if nothing is done.

The SH1–SH29 route has a much flatter profile, providing more travel time reliability, and presents a more realistic outcome. Travel times on the SH29–SH27–SH2 route are affected by the merging traffic from SH2, but the time increment on the base case is less at around 20 minutes compared with an hour on the SH2 route.

We tested some additional scenarios (not reported here) where the number of class 1 vehicles was reduced by up to 50% between 8am and 6pm. The main result is to dramatically reduce the late afternoon and early evening peaks on SH1–SH29 for southbound traffic, and on SH2 for northbound traffic.

In chapter 6 we look at some alternative scenarios.

Figure 5.4 Projected travel times for Tauranga to Auckland



6 Scenarios

We look here at a few scenarios that are intended to accomplish two objectives:

1 Illustrate an SD model can be used for simulating inter-city freight flows and changes in infrastructure capacity.

2 Hopefully provide some insights into actual questions that are currently of interest to the Transport Agency.

6.1 Scenario outline

6.1.1 Potential Waikato Expressway and Kaimai Range improvements

In this case study, we look at two variations of a scenario (scenarios 1 and 1a), which approximate some of the projects completed, planned or proposed for the SH1–SH29 route, including the recently opened Cambridge bypass. The Kaimai improvement is a tunnel. It has not been built and to our knowledge is not currently planned. The same road improvements were examined in Byett et al (2016).

Table 6.1 shows the estimate reductions in travel time and distance. Time savings are calculated at the posted speed limits.

Table 6.1 Time and distant reductions to model

	Time saving	Distance saving
Between Pokeno and Horotiu turnoff to Hamilton, on SH1	-14min	-3.0km
Between Horotiu turnoff to Hamilton and Cambridge South, on SH1/SH1B	-10min	-2.5km
Between SH24/SH29 intersection and bottom of old Kaimai road	-7min	-2.5km

The total time saved for a journey along SH1–SH29 between Auckland and Tauranga is just over 30 minutes, which would make this the fastest route between Auckland and Tauranga. We know, however, that for various reasons not all traffic takes this route. Thus in our first scenario we assume no change in route choice. We then look at putting more traffic onto the SH1–SH29 route.

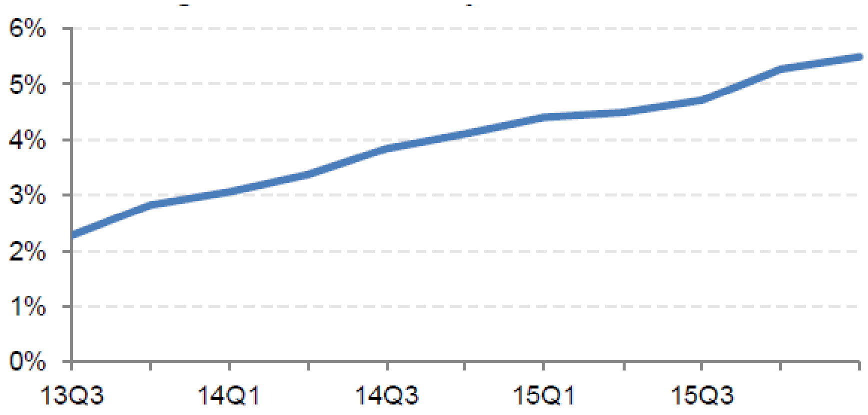
6.1.2 More HPMVs

Scenario 2 looks at a shift to greater use of high productivity motor vehicles (HPMVs); freight vehicles that can carry more freight per trip as they are two to five metres longer than other truck combinations and/or operate at heavier weights, typically:

- 50MAX (up to 50 tonnes being longer and heavier and with significant network access issues)
- proforma HPMVs (operating at 22–23m at the standard 44 tonne weights and having almost full network access)
- full HPMVs (up to 58/62 tonnes and with limited access on some routes and the high productivity freight network – mostly the busiest state highway freight routes).

Analysis supplied by the Ministry of Transport estimates, without HPMVs on the road, travel by other trucks (44 tonne combinations) would have been 5.5% higher by the first quarter of 2016, if cargo mass was the only consideration – see figure 6.1. This estimate is based on the average productivity benefits of mileage reduction, of 14–20%.

Figure 6.1 Extra truck travel without HPMV



Source: Ministry of Transport, unpublished

For scenario purposes it is assumed that by 2025 greater use of HPMVs will reduce truck travel by 15%. Other values could easily be tested. In the model this is simulated as 15% fewer class 3 and 4 trucks on the road, but with a corresponding increase in the length of the model's composite vehicle. The effect on mean travel time will be interesting; fewer vehicles will alleviate congestion, but larger vehicles take up more road space.

6.1.3 Driver working hours

When simulating congestion or indeed any sort of traffic interruption it is common to treat travel time and thus its associated GTC as a continuous variable. In fact the effects could be quite discontinuous if delays push truck drivers over their allowable working hours without a break. For example an increase in travel time from five hours to six hours could not legally occur without a 30-minute break after 5½ hours, so the 60-minute delay becomes a 90-minute delay. If the driver had been working (which includes time spent loading and unloading, not just driving) for 13 hours, a break of 10 hours is required. Hence these threshold effects can generate considerable extra cost.

Our high-level model is too coarse to accurately simulate crew scheduling and operator timetables, and how these might change if expected travel times throughout the AWB region become longer. For modelling purposes we assume an average 30% increase in travel time which leads to a 20% increase in price. Again a different value could easily be tested. Based on an assumed road–rail elasticity of substitution of 1.25 (see appendix C) the ratio of road-rail quantities (tkm) would decline by 25%. We apply this to classes 3 and 4 as scenario 3.

Note there is a degree of circularity here. If GTC for road freight is raised, road freight flows will fall, which will reduce GTC for vehicles that remain on the road, which will induce more traffic, and so on. The process should converge and is a feedback that could be included in a more sophisticated model.

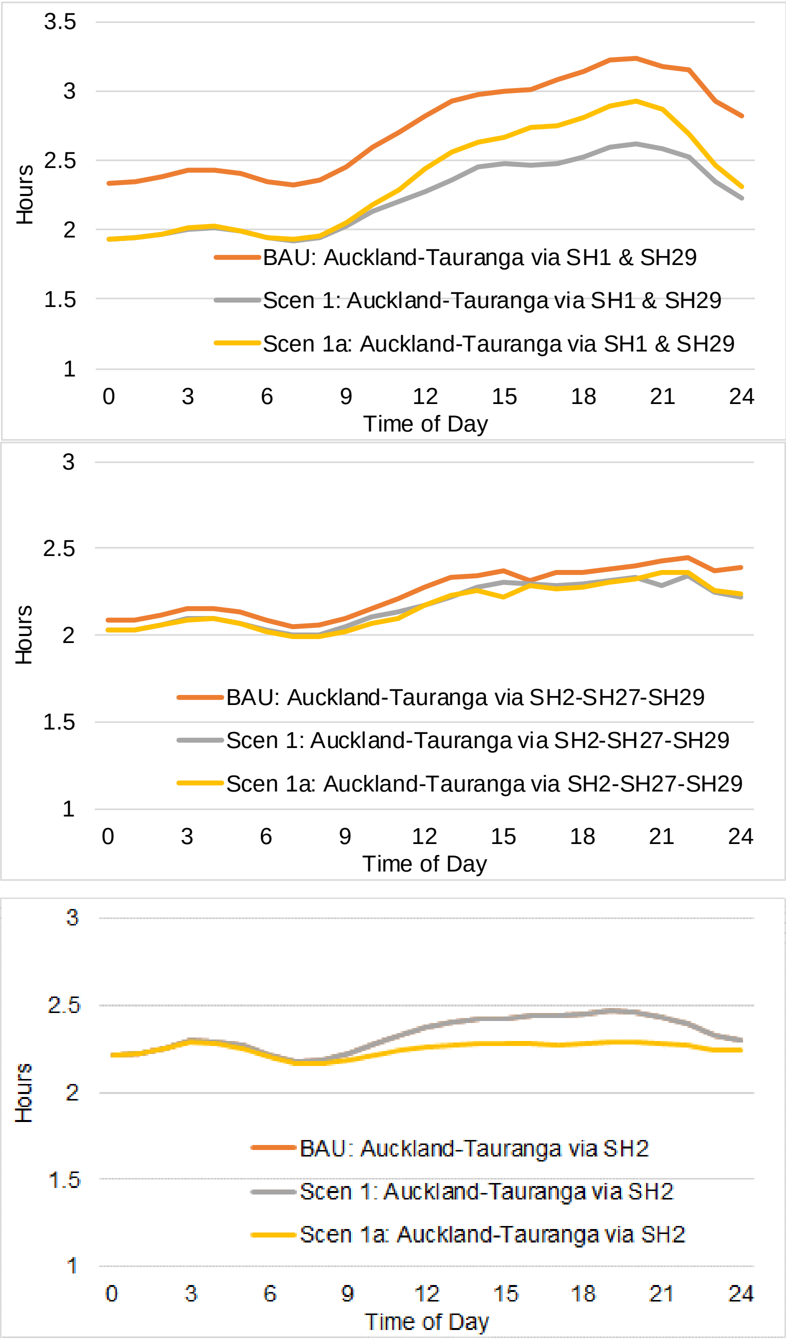
6.2 Scenario results

6.2.1 Scenario 1: Waikato Expressway and Kaimai Range improvements

Figures 6.2 to 6.5 compare the route travel times between the baseline (annotated as BAU) for 2025 and scenario 1. Looking first at figure 6.2 for southbound traffic, travel times decline considerably, unsurprisingly, along the SH1–SH29 route, frequently by more than half an hour – consistent with the input assumptions above. Such a marked decline might encourage more traffic onto that route. The model does not optimise route assignment so in scenario 1a it is assumed 50% of the traffic that usually selects SH2 at Pokeno instead opts for SH1, and traffic turning into SH27 from SH2 also rises by 50%.

On the SH1–SH29 route the benefit achieved in scenario 1 is halved at peak travel times. The SH2–SH27–SH29 route shows a reduction in travel time in scenario 1 (although somewhat smaller than the input assumption), but little sensitivity in scenario 1a – the net effect of less traffic taking SH2 at Pokeno, but more of what is left taking SH27. Along SH2 there is a difference between the BAU and scenario 1 (as expected), but travel time improves by about 10 minutes in scenario 1a when some traffic moves to SH1.

Figure 6.2 Scenario 1 travel times, Auckland to Tauranga



Note the travel time gains at off-peak times might be overstated. It would be possible to configure the model to adjust the effectiveness of extra road space by time of day.

Figure 6.3 shows two segments along the SH1 route southbound: Pokeno (Auckland) to Hamilton and Hamilton to the SH27–SH29 intersection. It is apparent the increase in travel time in scenario 1a along the SH1–SH29 route (top graph in figure 6.2) is caused by the Hamilton to SH27–SH29 segment, where travel time rises by about 12 minutes during peak times. In contrast the Waikato Expressway easily copes with the increase in traffic between scenarios 1 and 1a.

(The BAU and scenario 1are identical for the Hamilton to SH27–SH29 section of road as by assumption there is no re-routing of traffic).

Figure 6.3 Scenario 1 travel times, Pokeno to Hamilton to SH27-SH29

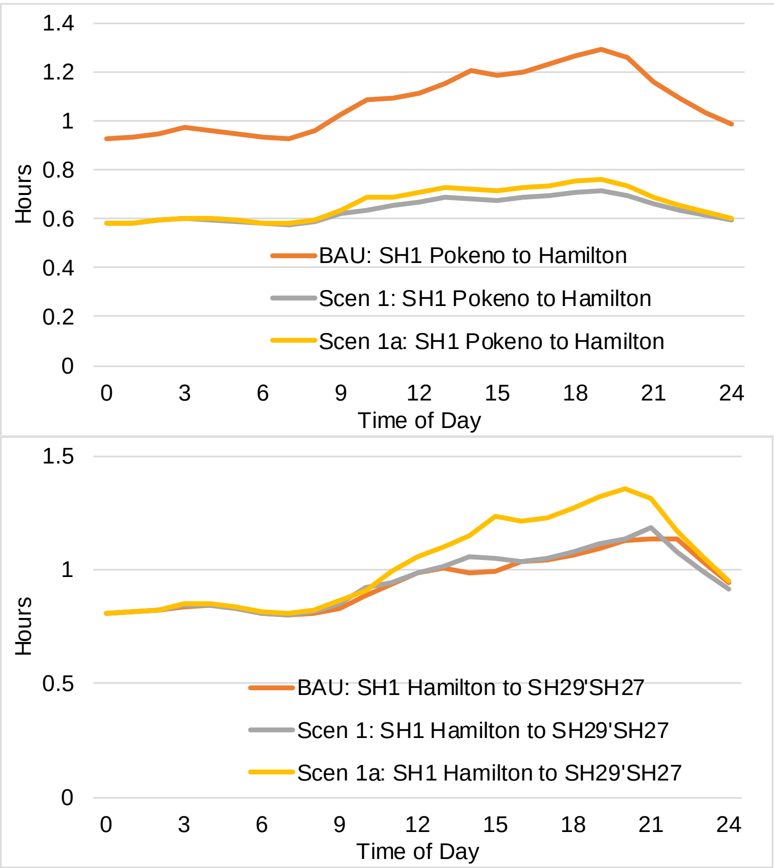


Figure 6.4 shows the results for northbound traffic from Tauranga to Auckland. Again there is a substantial 30-minute effect on SH1–SH29 travel times in scenario 1. In scenario 1a, 50% of traffic leaving Tauranga that previously went via SH2 selects SH29 instead, and of the traffic that previously selected SH27 after crossing the Kaimai range (at point Y in figure 3.2) 50% more now selects SH1. This increase in traffic volume along SH1 completely negates the travel time improvement in scenario 1 between the hours of 2pm and 9pm – a much larger effect than for southbound traffic.

Along the SH29–SH27–SH2 route, the changes in travel time are much as expected with small savings in scenario 1. It is similar for scenario 1a except for the period after 8pm where the time saving is 20–25 minutes. Along SH2 there is of course no effect in scenario 1 (hence the BAU line coincides with the scenario 1 line and is therefore not visible on the graph), but when some traffic is moved onto SH29–SH1 the improvement in travel times is frequently more than an hour, again much more than in the reverse direction and offsetting the congestion evident in the BAU (and scenario 1).

Figure 6.4 Scenario 1 travel times, Tauranga to Auckland

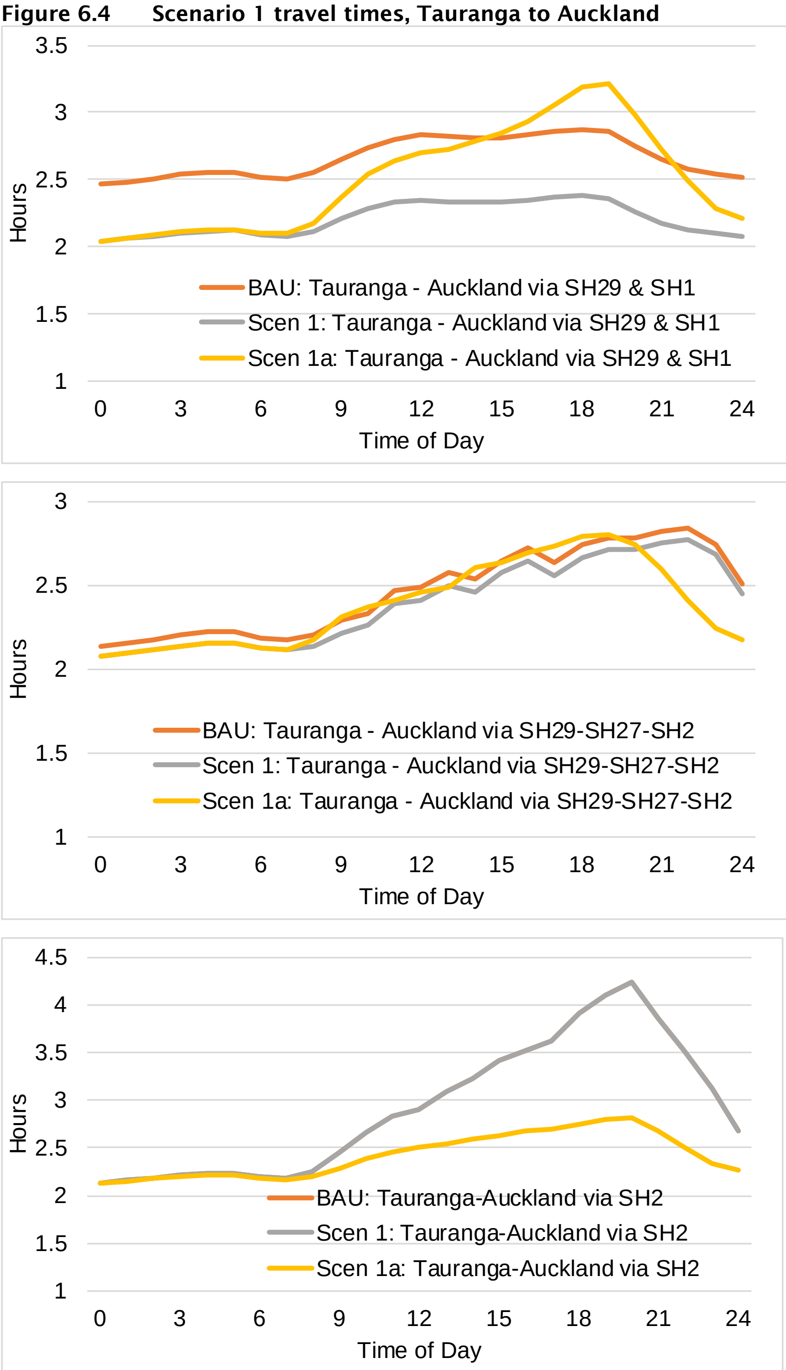
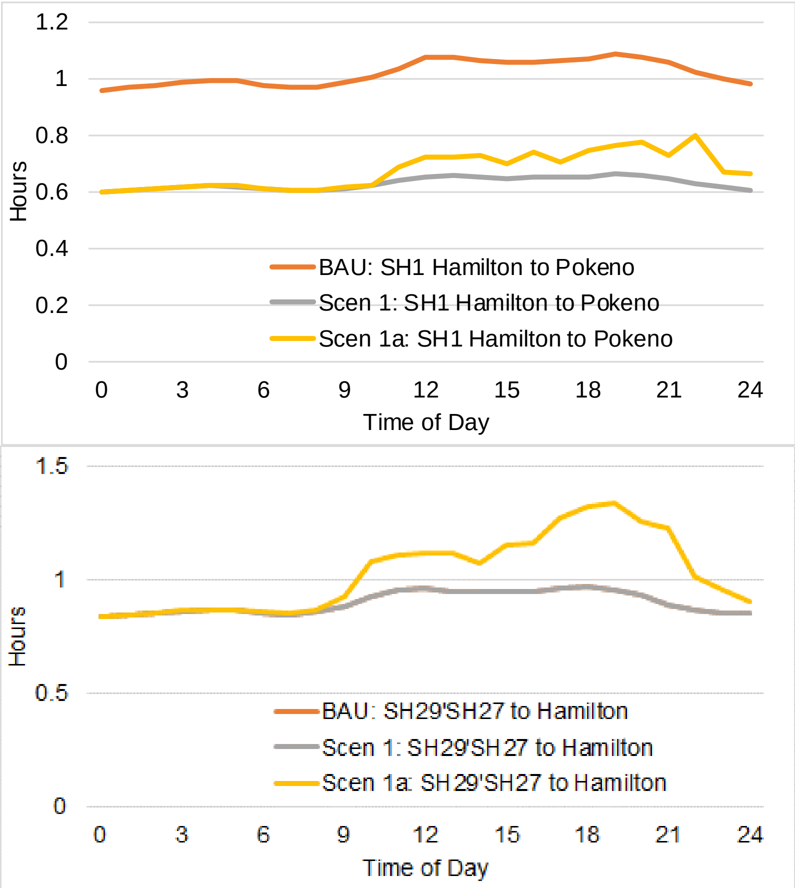


Figure 6.5 shows the same two sections of road along SH1 as figure 6.3, but for northbound traffic. Again the Waikato Expressway easily copes with the increase in traffic, although the effect is somewhat more noticeable than for southbound traffic. The SH27–SH29 to Hamilton becomes considerably more congested in this direction, with travel times being up to 20–25 minutes higher.

Again in reality, some drivers, faced with these kinds of delays would sacrifice the gains from the expressway and traffic flows would equilibrate to some extent. Nevertheless the results illustrate a potential problem when parts of a network are improved in isolation.

We emphasise that scenario 1A is not a forecast. It is merely a 'what if' scenario. Large differences in travel times along different routes are unlikely to persist, although as the base year scenario in chapter 5 illustrates, they do not vanish as travel time is not the only reason for choosing a particular route.

Figure 6.5 Scenario 1 travel times, SH27–SH29 to Hamilton to Pokeno

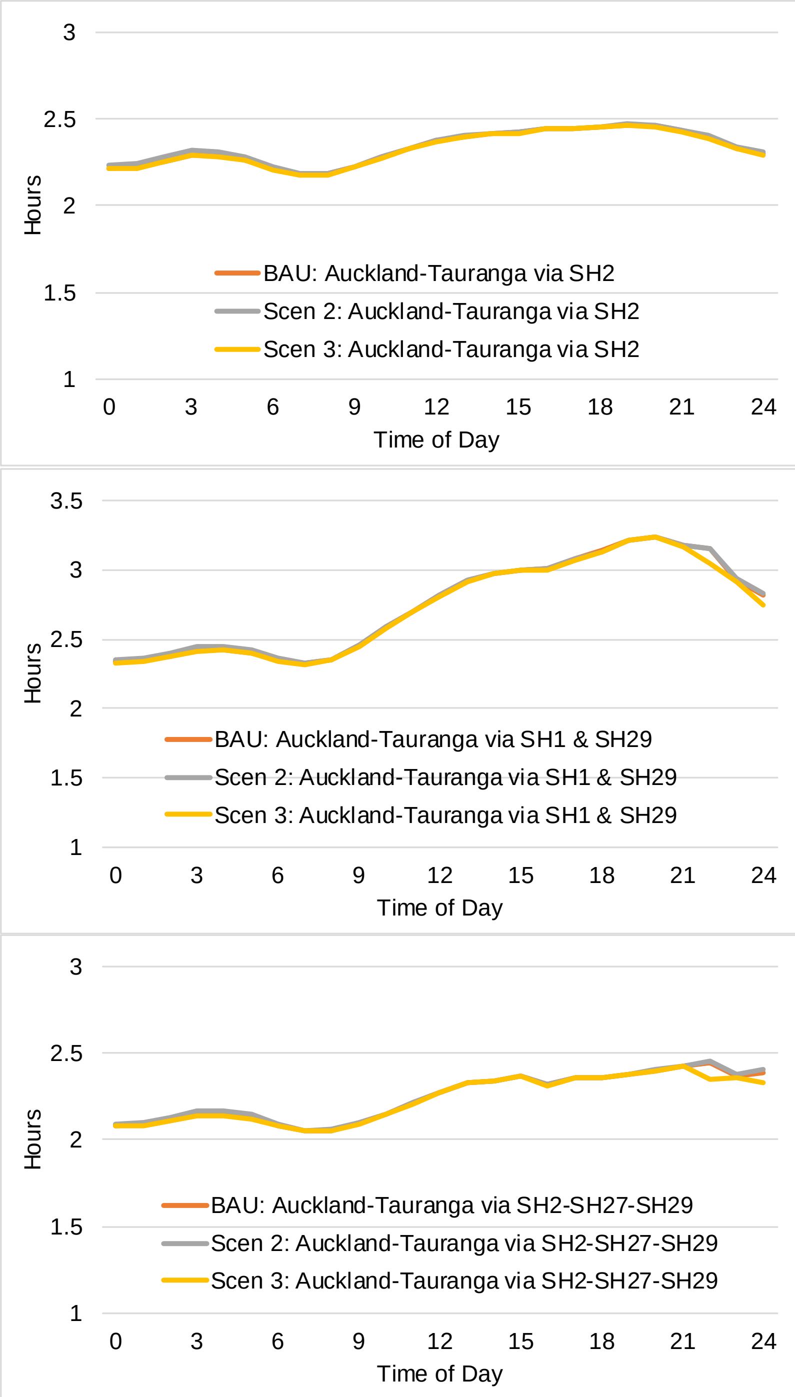


6.2.2 Scenarios 2 and 3: HPMVs and driver working hours

We look at the results for scenarios 2 and 3 together. Only at the end of the day on route SH1–SH29 is there a very small increase in travel time in scenario 2, indicating the longer length of class 4 vehicles just offsets the lower number of trucks. On the other routes the effect is imperceptible. Under scenario 3 there is a very small negative effect on travel time at the end of the day on the SH2–SH27–SH29 route. On other routes the effect is again imperceptible, implying no gain in travel time by road from shifting 25% of freight carried by class 3 and 4 vehicles onto rail.

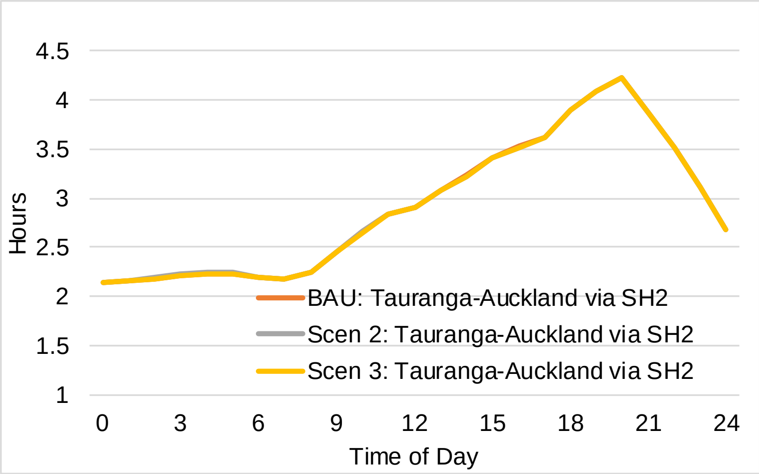
As class 1 and 2 vehicles are by far the dominant type of vehicle on the road and have a higher incidence of night travel, even quite large changes to the number or length of class 3 and 4 vehicles have a negligible effect on total traffic and mean vehicle length, and thus on mean travel times. An interesting scenario might be to look at the effects of restricting HPMV licences to night travel only, or perhaps proscribing large/HPMV trucks from travelling on SH2 between Paeroa and Tauranga during the day.

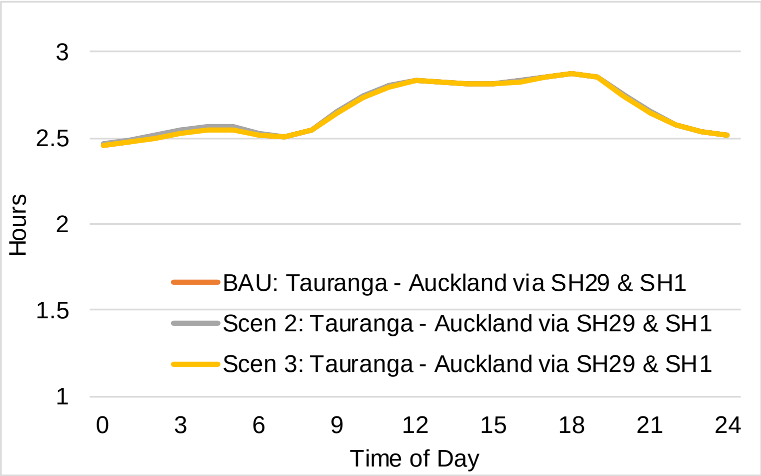
Figure 6.6 Scenarios 2 and 3 travel times, Auckland to Tauranga

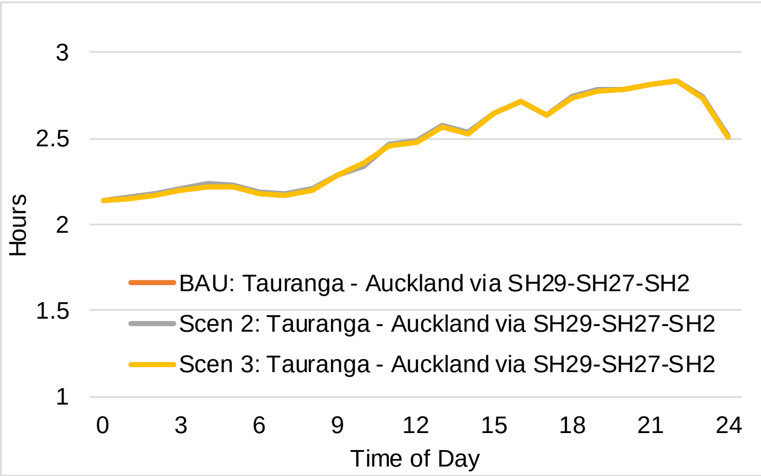


Results for the northbound trips are presented in figure 6.7 and show no effects – travel time differences are generally less than two minutes which is too small to be noticeable on the graphs, and well within random volatility in travel times.

Figure 6.7 Scenarios 2 and 3 travel times, Tauranga to Auckland







6.3 Conclusion

While all models are abstractions of reality, it is suggested by the above scenarios (and perhaps has always been evident to those in the freight industry) that the main determinant of travel time for trucks is the space on the road; a combination of the total number of vehicles (notably class 1 vehicles) and road capacity. There are of course other factors that affect the productivity and profitability of the freight industry; factors such as truck type and loading (HPMVs versus other types of trucks) and driver working hours, but they seem to have little influence on average travel time across all vehicles. Scenario 1 demonstrated a strong effect on travel times from the on-going improvements to the Waikato Expressway, but also provides (in scenario 1a) a warning that induced traffic could offset some or all of the benefits without necessarily generating a compensatory reduction in travel times on alternative routes. The impression one gains is that the whole road network needs to be efficient, not just selected parts of it. Perhaps pricing and/or regulation may be useful as ways to support infrastructure developments.

Scenario 2 showed more use of HPMVs may well reduce the number of trucks, but its potential effect on easing congestion is, in the first place, very small because of the dominance of small vehicles and second, offset by an increase in mean vehicle length.

Scenario 3 doubled as a scenario of substitution of some road freight (25% of that carried by class 3 and 4 vehicles) onto rail. It too had an inconsequential effect on mean travel times. We suspect that for road–rail substitution to have a meaningful effect on road travel times the amount of freight transferred would have to be much larger, or perhaps be removed from particular segments of the road network at particular times. This may be totally uneconomic.

The model has a number of control panels that make it easy for the user to examine a wide range of scenarios. It also provides more output than has been summarised here, including travel times along different road segments. In our opinion, if the model is ultimately to be applied to more real world questions, priority should go to testing the robustness of the model to a wider range of traffic patterns, picking up for example the variation evident in figure 4.4.

7 Conclusions and recommendations

The core purpose of this research was to develop an experimental or pilot SD model of traffic flows along the main road routes within the AHT triangle. The question of interest is whether such a model could be useful in understanding how increases in economic activity, particularly freight flows affect the demand for road space and, in reverse, how road space affects travel times.

The validity of the model has been tested to an extent. It was calibrated to measured traffic flows from telemetry sites along the AHT network, for the month of August 2016. As a result the model produced plausible profiles of travel times during a 24-hour period. It is possible, however, that other months (or particular weeks or days) could yield quite different travel time profiles which the model may or may not be able to reproduce. This means that when the model is used to produce counter-factual scenarios that diverge from the base case by a considerable margin, some extra caution is advised. Hence our first two recommendations for further research are:

1 Test the model with data from other months (or weeks) and randomly shock the traffic flows according to the distributions depicted in chapter 4.

2 If possible, compare the results with output from the Waikato regional transport model.

With regard to the validity of the VAR models used to project the economy, while these models could undoubtedly be refined, they are less important as the SD model can be primed with data on traffic growth and inter-regional trade patterns (OD pairs) from any source.

Another aspect of validity is robustness. Even if we have confidence in the representativeness of results, are they robust with respect to key assumptions such as those relating to route assignment at intersections, road capacity and the build-up of congestion, the 15-minute pulsing of traffic, the mean vehicle lengths in the four vehicle classes, the length of each road segment (conveyor and associated travel time function), the OD matrix and so on? The 'first in, first out' issue noted by Benaich (2015) could also be relevant if more detailed simulation of intersections is envisaged. Our next recommendation is therefore:

3 Undertake sensitivity testing of the aforementioned variables and parameters to determine which are relatively important.

The research has focused on how economic activity, notably interregional trade, affects the future demand for freight transport and road space. How important are the input assumptions in this regard? There is also scope to more formally examine feedback effects from changes in travel time such as occur in scenario 1. The simplest mechanism is via changes in the denominator in the gravity model, but as illustrated in chapter 3, a more explicit GTC function would be better. Accordingly some recommendations are:

4 Test the sensitivity of the results to different scenarios of freight growth.

5 Where scenarios produce large changes in travel time, analyse possible demand-side reactions.

6 More ambitiously, establish whether a larger, more sophisticated (SD) model of the types discussed in Section 1 such as ASTRA, is worth developing.

Of course all recommendations for further research, but particularly the last one depend totally on what sort of questions the model is intended to answer, and how it might be applied, whether by the Transport Agency or by others.

As it stands the model is designed to look at high-level congestion resulting from increased traffic – all the time, not on particular days or during specific time periods. It is in effect a model of pressure on road space and how this pressure might be alleviated through different types of intervention such as more road space, re-assignment of routes, and changes in the mix of vehicle types. Perhaps other issues are more important and undoubtedly there will be questions related to the movement of freight that are not capable of being analysed with this model. The model is complementary to other models such as the Waikato regional transport model, which has strengths in other areas, such as route assignment for example. Both should be used to investigate overlapping issues.

It is important to emphasise the modelling system that is developed here is specific to the issues and location for which the project was commissioned. The model will not immediately be applicable to other areas, nor to all issues within the AHT area. Nevertheless it is envisaged the modelling system would be amenable to being adapted to consider other areas such as the lower North Island (Wellington – Palmerston North – Napier) and other spatial disaggregation, albeit this would require more data gathering and model testing.[10]

Also, the SD model developed here has complicated internal mechanisms, but a user friendly interface designed to answer a wide range of questions easily and quickly. Additional documentation can be incorporated into the interface and in the model's 'plumbing'. Again though, depending on how the model might be used and by whom, there is scope to tailor the interface to specific user needs.

The research team has appreciated the support provided by the Steering Group and looks forward to further discussion with the Transport Agency on the possibilities of SD modelling being another tool in the Transport Agency's portfolio of instruments used to analyse investment in the land transport system.

[10] Pfaffenbichler et al (2010) describe how the MARS model (refer chapter 1) was transferred from Vienna to Leeds.

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Appendix A: Travel time in the SD model

A1 Core travel time equation

Travel time in the model is simulated by a simple nonlinear function that expresses travel time as a function of the number vehicles on the road. In its most basic form:

$$T = ae^{\beta N} \quad \text{(Equation A.1)}$$

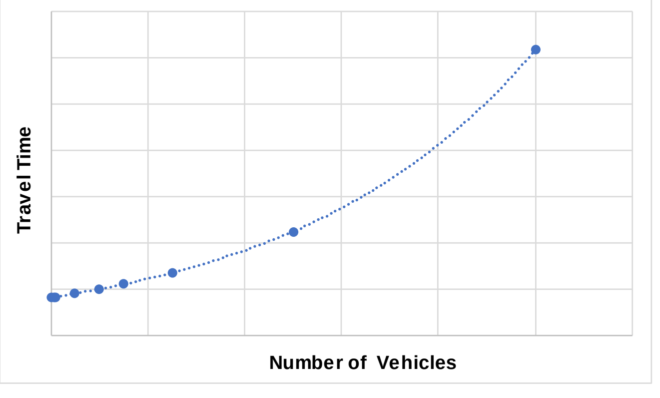
is travel time along a given road segment

N is the number of vehicles on that road segment

α and β are parameters that depend on free-flow speed and segment distance.

The general shape of the function is illustrated in figure A.1, with the degree of curvature depending largely on and the position of the curve on α. Travel time can be sensitive to the parameter values at certain volumes

Figure A.1 Travel time function



The parameters α and β are initially calibrated to observed traffic count data from telemetry sites and travel times based on data provided by Beca to the Transport Agency for travel times in Waikato.[11] However, the result does not quite meet our needs as the SD model has to allow for the fact that a longer segment of road can accommodate more vehicles. So clearly β has to reflect this for each road segment. Then the value of α also needs to correspond to the time taken to travel distance D at speed V, or T=D/V.

These two conditions give rise to the following expressions for α and β:

$$\beta = \mu / D$$

$$\alpha = T / \lambda$$

Our calibrated values for λ and μ are:

λ=1.01045

μ=0.01039

[11] To put a workable anchor point into the calibration it is assumed if there is one vehicle per kilometre it can travel at the free-flow speed over the entire distance of the road segment. More vehicles (and longer vehicles) will reduce speed and thus increase travel time, slowly at first, but rising nonlinearly.

These values enter the model as constants for all road segments, with the model then determining α and β specific to each road segment.

A2 Capacity and different vehicle lengths

A longer class of vehicle implies less capacity on the road. The curve in figure A1shifts upwards. Thus the model actually needs to compute equation A.1 for the vehicle mix (the four vehicle classes) that are put onto the road with each pulse. We use the following equation:

$$C = \frac{D}{L + {}^{V}\!/_{\eta}}$$ (Equation A.2)

C is road capacity along a segment at some speed V

D is the distance of a road segment

L is the length of a vehicle of given class type (class 1: 2–5.5m; class 2: 5.5–11.0m; class 3: 11.0–17.0m; class 4: over 17.0m; with mean lengths of 4.5m, 8.5m, 12.0m and 21.0m respectively).

η is a factor based on the following distance. For the two second rule its value is 1.8, being 3,600 seconds in an hour, divided by 1,000 (to be consistent with speed units), divided by 2. In the model we assume a one-second rule for speed up to 10km/h, increasing linearly to two seconds as speed rises to 30km/h, after which it remains at two seconds.

The denominator is the effective length of road required by a vehicle of a given class type travelling at the assumed (in this case recommended) safe distance behind another vehicle at a given speed. Calibration leads to an adjustment factor that is applied to equation A.1 of:

$$T' = \sqrt{\frac{C^{4.5}}{C^{L}}}\,T$$ (Equation A.3)

$C^{4.5}$ is capacity for class 1 vehicles and C^{L} is capacity for the weighted mean vehicle length (L) which differs (in the model) by time of day and road segment.

As may be appreciated the travel time functions in the model are drawn very much from observed data coupled with a plausible theoretical relationship. Refinement is certainly possible. For example a gamma function could be used to relate speed (rather than travel time) to the number of vehicles. However, we wish to avoid incorporating the very complicated dynamic behaviour that can generate short, sharp traffic queuing, nonlinear waves of congestion and jamitons over short sections of road, as that type of congestion simulation is not the purpose of the model.[12]

[12] See for example Kowszun (2013) for a non-technical description of jamitons and Flynn et al (2009) for a more challenging analysis.

Appendix B: Regional projections

The various diagrams on the following pages illustrate projections of the regional composition of each of the eight industries in the model, and the industry compositions for the AWB regions.

Figure B.1 Regional composition of industries (% of GDP)

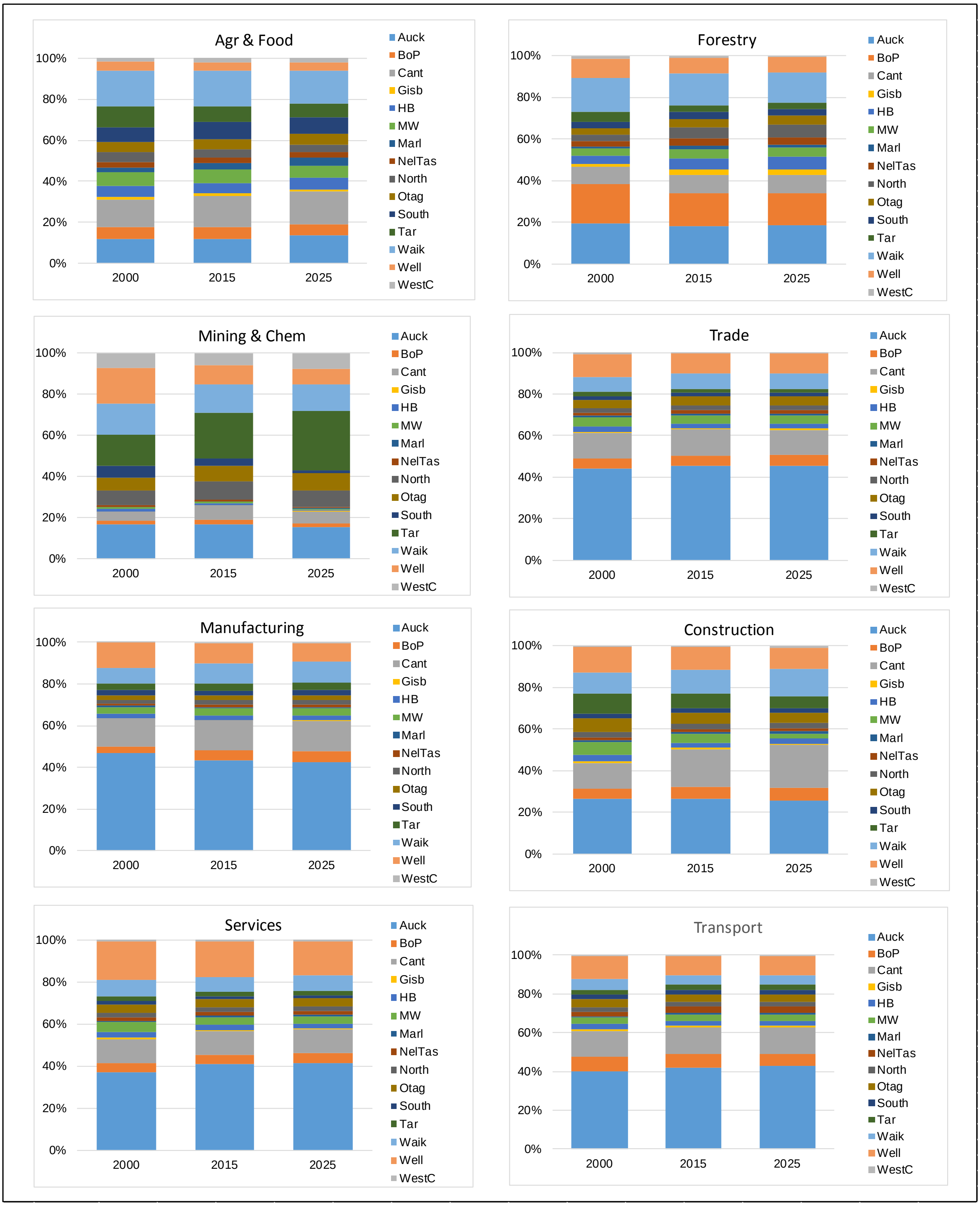
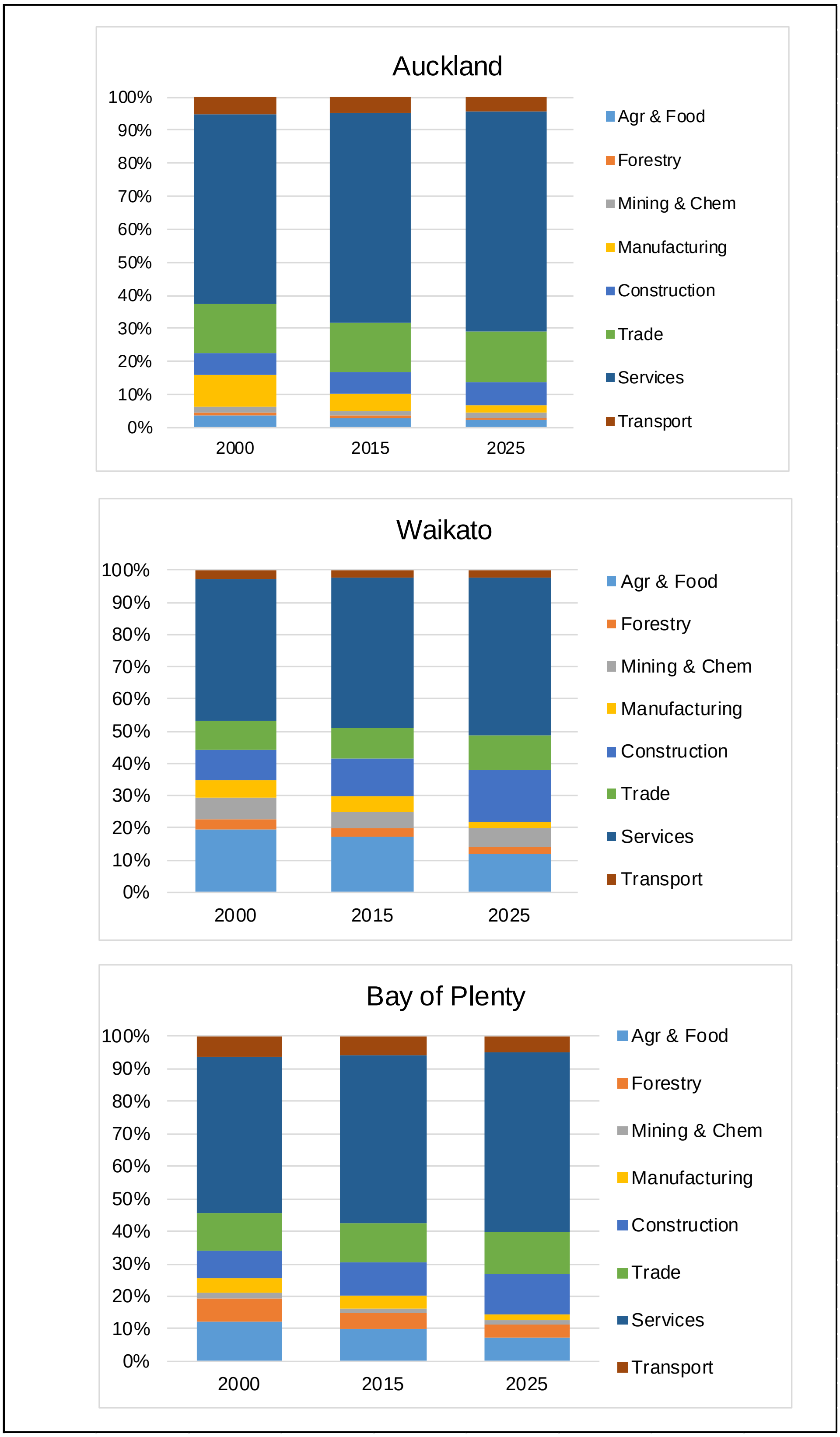


Figure B.2 Industry composition of AWB regions (% of GDP)



Appendix C: Rail

While we are not explicitly simulating rail in the model, we are interested in the extent to which it can realistically absorb a meaningful proportion of the expected growth in the demand for freight in the AHT triangle over the next few decades. Assessing this involves considering:

1 The main commodities that are currently on, or could be on the rail network in the region

2 The capacity issues that exist in the region and those that can be readily addressed

3 Mode substitution and the role of inland ports.

C1 Commodities and growth

Rail freight in the region is dominated by:

- dairy exports, primarily from Hamilton to Port of Tauranga
- steel, Auckland to Tauranga.
- general import–export, manufactured goods etc.

Forestry is also a major user of rail, but even though most of it is outside our region of interest it is not irrelevant. The volume of wood shifted from forests south of Tauranga to the port does potentially provide a competing demand for both rail and road space into Tauranga from the south, including on infrastructure close to the port.

Coal transport by rail is also outside our region of interest, but in any case will soon no longer be going to the Huntly power station.

In our assessment dairy and steel lack long term high volume growth potential. Dairying in particular is an industry which, at the margin, does not cover the environmental cost of the resources it uses. Steel relies on cheap energy and substantial free allocation of emission units under the NZETS. Expansion would also require significant new investment. Longer term we do not expect these industries to continue to be the beneficiaries of munificent policy.

General freight on the other hand is likely to see substantial growth, notwithstanding that economic growth is progressively more service industry oriented.

C2 Capacity

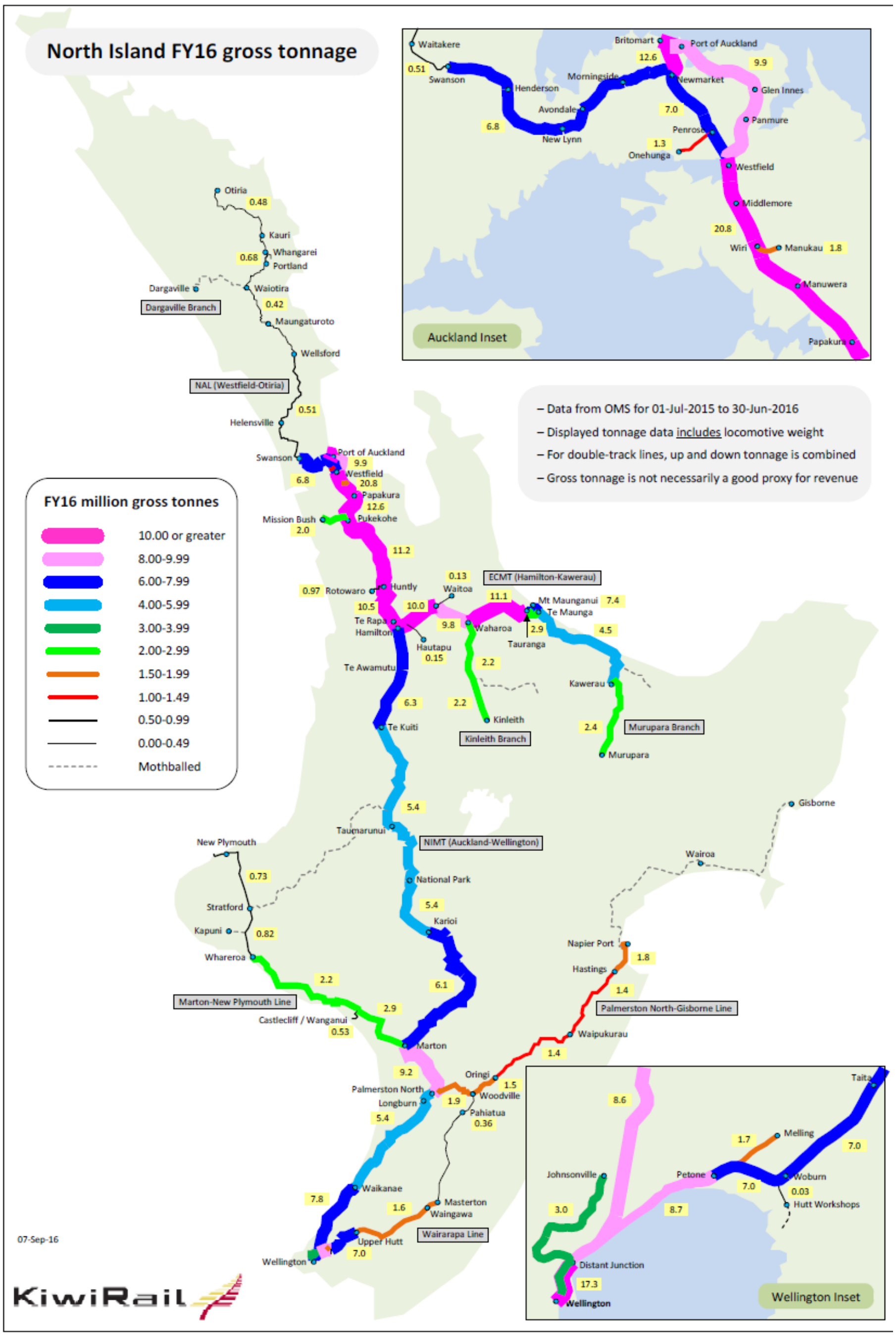
Capacity is fundamentally about the number of trains that can operate per day throughout the AHT region, but train length cannot be ignored. It is limited by the mass of the load, locomotive power and the strength of the track base. Most wagons in the AHT region are flat top for containers, which weigh 65–80 tonnes (including the wagon), subject to a maximum train weight of approximately 2,400 tonnes.

Capacity is also affected by double versus single track. In that regard the Auckland–Hamilton segment has mostly double track. However, rail freight in the greater Auckland area is being impacted by the growth of metro (passenger) rail. Both freight and passenger rail are contesting the same rail corridor. Although there are plans to triple track Westfield to Wiri (next five years) and Wiri to Papakura (next 15 years) and Papakura to Pukekohe (next 25 years) there is no guarantee of funding. The single track segments are unlikely to be an issue for a decade or so.

The Hamilton to Tauranga segment is mostly single track (notably in the Kaimai tunnel) albeit with long crossing loops. Still, capacity is constrained. Double tracking is not on the immediate horizon and the Kaimai tunnel track requires significant work to be able to carry heavy loads. Currently 72 tonne (gross) weight wagons can be accommodated, which is the same as the vast majority of the triangle network. A very small section is being operated at 80 tonne gross for a 45km journey carrying steel.

Figure C.1 provides an indication of tonnage being hauled per annum in the area of interest. It is clear that the Auckland – Hamilton – Tauranga route is by far the busiest rail freight corridor in all of New Zealand.

Figure C.1 North Island rail tonnage



Source: KiwiRail

C3 Mode substitution

Generally the potential for mode substitution relies on inland ports – existing and planned, especially if port rationalisation occurs; eg Singapore or Brisbane becomes a New Zealand hub for very large vessels. MetroPort (with Coda, a joint venture between Port of Tauranga and Kotahi) is in a growth phase which may well accelerate with larger container ships calling at Tauranga. Expansion at Wiri is probably dependent on triple tracking to accommodate more commuter rail. This is also an issue at Metroport at morning and evening peaks. On the other hand, increased rail activity implies more and longer delays at railway crossings, raising the cost of transport by road. Horotiu (north of Hamilton) and Ruakura (east of Hamilton) could be major players.

Rail is usually competitive for low unit value, bulk products that are not time-sensitive. However, the distances involved (in the AHT region) are not long, which means that mode transfer costs can be relatively significant. Much the same is true of coastal shipping so over some routes rail and shipping compete more with each other than with road.

If dairy exports do expand we would expect to see rail capture most of the growth, with Fonterra's Crawford St hub playing a central role. There could also be some potential for bulk milk to go by rail as happens between Hawke's Bay and Taranaki.

We also expect rail to maintain its share of general freight (including import-export cargo) in the region, with perhaps an increase for longer distances to Palmerston North, Wellington and (eventually) the South Island. Again though this depends on suitable hubs. The other issue is that there is currently only one ferry that carries trains across Cook Strait. An alternative is to transfer container freight at each end, but this may not be more cost effective. The proposed switch from electric to diesel locomotives through the centre of the North Island will not significantly alter costs.

Kaikoura earthquake

Due to the Kaikoura earthquake of November 2016 freight between the North Island and Christchurch can currently travel only by road (and ferry) or coastal shipping. KiwiRail containers can still travel inter-island (by transfer to truck) but the extent to which this occurs is likely to be limited. Hence coastal shipping and road are the predominant modes on this route until the rail link is re-opened. Assuming it is opened within the next few years, the situation is likely to return to what it was pre-earthquake, which nonetheless has rail with significantly less market share than road on this corridor.

KiwiRail are specifically targeting increased market share on this route. However significant gains are unlikely without substantial investment in infrastructure to improve transit time and service reliability. This might requires a second rail ferry or an alternative operation with efficient transfer of rail containers between modes, and additional main trunk and rolling stock enhancements.

C4 Costs

Table C.1 shows pricing on various routes for an average loaded container of 20 pallets, each approximately one cubic metre weighing 800kg, so 16 tonnes total. In reality this type of domestic freight is almost entirely transported by road between Auckland and Tauranga (and in reverse). This is not the case for import/export cargo on this route. The prices are approximate for the following reasons:

- Prices for road transport vary between operators.
- Discounts are usually available for repeat or high volume business.

- The costs of loading and unloading a container were estimated and added to the purely rail transport (railhead to railhead) price. Freight forwarders complete these operations at their depots so those costs are included in the price paid by the customer.

Table C.1 Price comparison (per container, hub to hub)

	KiwiRail	Road	Difference
Auckland – Wellington	1,540	3,373	219%
Wellington – Auckland	1,300	1,865	143%
Auckland – Tauranga	1,175	1,407	120%
Tauranga – Auckland	1,175	1,320	112%

The data shows that it is more expensive to use road instead of rail by a factor of 1.1 to 2.2, depending on the origin-destination pair. The journey times between each origin and destination are roughly equivalent ie 'overnight' between Auckland and Wellington and 'overnight or same day' between Auckland and Tauranga. In reality a B-train will be faster than a train by two to three hours and is likely to receive priority over rail containers when being unloaded at the destination.

However, the comparison is not entirely pure. Freight forwarders send pallets by road or rail depending upon mode availability. They utilise rail containers and have spaces reserved for them each night on freight trains, so they endeavour to optimise modal allocation.

Clearly the road-rail price differences are not sufficient to encourage a large shift from road to rail. The two modes are not perfect substitutes as they do not provide exactly the same service in all cases. Price is only one factor that consumers consider, along with speed, reliability of delivery, convenience of schedules, and so on. As noted above, heavy freight, less time-sensitive freight, and less fragile freight is likely to go by rail. Premium customers are likely to have goods transported by road.

We do not know of an average freight road-rail elasticity of substitution for New Zealand. Indeed given the various non-price factors such an elasticity may not have much relevance to any given situation. Estimates of cross price elasticities for Australia are given in BTRE (2009), from which it is possible to calculate (Allen partial) elasticities of substitution that range from 1.1–1.4,[13] but Mitchell (2010) reports a wider range including some that are negative, implying a complementary relationship. Because the distances in Australia are so much longer and transport options are so case-specific one hesitates to assume applicability to New Zealand. Nevertheless for modelling purposes we assume a value of 1.25, readily conceding that it is merely a starting point.

C5 Impact on scenarios

The price (really generalised cost of transport) by rail is unlikely to fall unless there is a significant change in the approach to rail funding or, as discussed above, inland ports enhance overall efficiency. Thus our overall assessment is that the most likely scenario is that rail will not increase its market share of freight transport in the AHT triangle. There may, however, be a scenario where more use of inland ports enables the main rail line from south of Auckland through Hamilton to capture proportionately more of the expected increase in general freight between Auckland and Wellington.

[13] The Allen partial elasticity of substitution (σ_{ij}) between two goods i and j is the percentage change in the ratio of the two quantities divided by the percentage change in the ratio of the two prices. It is related to the cross price elasticity (η) as: $\sigma_{ij} = {}^{\eta_{ij}}/_{S_j}$ where S_j is the cost share of j.