Assessing induced road traffic demand in New Zealand

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Abbreviations and acronyms

AADT	annual average daily traffic
BCR	benefit-cost ratio
CBA	cost-benefit analysis
CBD	central business district
DfT	(UK) Department for Transport
do-min	do minimum (scenario within an appraisal)
DoT	(US) Department of Transportation
FTM	fixed trip matrix
GHG	greenhouse gases
GPS	(NZ) Government Policy Statement (on Land Transport)
GTC	generalised transport cost
ICE	internal combustion engine
MBCM	Monetised Benefits and Costs Manual (of NZTA)
MSA	(US) metropolitan statistical area
NCST	(US) National Centre for Sustainable Transportation
NZTA	NZ Transport Agency Waka Kotahi
OD	origin-destination (matrix)
ONF	One Network Framework (of Te Ringa Maimoa Transport Excellence Partnership, formerly Road Efficiency Group)
ONRC	One National Road Classification (of Road Efficiency Group)
PT	public transport
RAMM	road assessment and maintenance (manual of NZTA)
RCA	road controlling authority
SH	(NZ) State Highway (numbered 1, 2, 3, …)
SACTRA	(UK) Standing Advisory Committee on Trunk Road Assessment
TAG	transport analysis guidance (of DfT)
TDM	travel demand management
TLA	territorial local authority
VERPAT	VisionEval Rapid Policy Assessment Tool
VKT	vehicle kilometres travelled
VMT	vehicle miles travelled
VOC	vehicle operating cost
VTM	variable trip matrix
VTT	vehicle travel time

Contents

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Executive summary

This project sets out to find the evidence, and causes, of induced road traffic in New Zealand. It also set out to develop a tool to predict the likely magnitude of induced traffic and the likely effect of mitigation methods.

A review of local and international literature and a (brief) survey of local stakeholders revealed limited evidence of induced traffic demand in New Zealand but does offer good reasons to believe induced demand has been happening. In particular, road projects that lead to large reductions in generalised travel costs (GTC) are expected to lead to higher demand, such as those that reduce congestion and more generally shorten or quicken trips, especially where more travel from the city fringe is facilitated.

A small number of existing tools are available to estimate induced traffic demand, but these tools were judged to be too restrictive in terms of road classes considered and failed to consider contextual matters such as the magnitude of GTC savings.

Therefore, a new tool was developed by the research project team that built on the lane-km elasticity approach at the core of the few induced traffic tools available. The excel-based tool entails five steps that a relatively novice user is likely to be able to apply, with user and background notes and guides as assistance.

The first step is an application of the lane-km elasticity approach, using New Zealand regional road data for 2019/20. This acts as (a) a filter to exclude projects mooted to be of likely minimal induced VKT effect, such as small GTC savings or low volume roads, and (b) as a starting point for a more complete consideration of the factors that have strong influence on any VKT effect. The second step considers the travel cost reduction likely to be created by the project and offers a customised lane-km elasticity to build into steps 3 and 4. These two steps then further adjust the lane-km elasticity, first, for public transport (PT) and land-use influences, and second, to capture the effect of traffic diversion – from other road classes in the region and potentially from other roads in other regions, should people choose to migrate to the project city. The fifth and last step presents a point estimate of the induced traffic demand for the project which, it must be stressed, sits within a wide range of possible outcomes and provides a context for the VKT effect. By way of illustration, the estimated VKT effect of the project is also placed within this step into one of three broad ranges for transport projects in New Zealand: 'Top of range' (similar to a large Auckland motorway project), 'Mid-range' (similar to a large Christchurch motorway project); and 'Bottom of range' (generally similar to smaller projects).

Each step can be traced back to international research and/or NZ Transport Agency Waka Kotahi's (NZTA) Monetised Benefits and Costs Manual (MBCM). But the broad nature of the assumptions required to make the calculations imply that the result is indicative. Instead of accurate forecasting, the process of forming the estimate has several intentions:

1. to provide the user with insights into the key influences, the sensitivities to influences, and the potential for mitigation
2. to provide a perspective on the magnitude of VKT effects probable
3. to inform on project refinement ahead of more extensive transport modelling.

Abstract

In an age of concern about climate change it is important to understand the induced traffic to be expected following the building or extension of a road. A review of international literature was undertaken on induced demand, along with an examination of the very limited evidence available in New Zealand. A search was also made for an induced demand tool suitable for use within the early stages of business case development – that is, before more extensive projects are defined and transport modelling sought. The few tools available did not incorporate the contextual information that the international research revealed as important, so a tool was developed by the project team. Important findings included that key determinants of induced travel are the travel-cost reduction achieved by new lanes and the base road network used to infer VKT growth. The tool combines a lane-km elasticity with a cost elasticity approach to guide the user through the logic and calculations to indicate a potential range of induced VKT to expect from the proposed additional road lanes. Rules were applied to indicate the scale of land-use effects on VKT.

1 Introduction

1.1 Aims of research

NZTA set out the objectives of the research (1–4 below), and the scope of the research (a–d), as follows:

1. find evidence of induced traffic in New Zealand
    a. including whether induced traffic, defined as the law of road congestion findings by Duranton and Turner are applicable to New Zealand
    b. and whether induced traffic is adequately assessed in New Zealand
2. identify the causes of induced traffic in the New Zealand incidences
    c. including identifying the conditions under which induced traffic arises in New Zealand
3. develop a tool to predict induced traffic for planning and decision-making purposes and at the pre-business case stage
    d. including developing a tool for assessment of induced traffic for planning purposes
4. and identify what can be done to avoid induced traffic on new and improved roads.

The project team and steering group interpreted these objectives to include ‘improving the industry understanding of induced traffic and the standardisation of terminology and definitions’.

1.2 Context

The ‘law of road congestion’ pertains to a hypothesis researched by Duranton and Turner (2011), plus others, which posits that building more highways and major urban roads will lead to increases in traffic that may ultimately fill the new capacity.[2] Duranton and Turner presented evidence to support the contention that 1% more highway or urban roads within a region led to 1% more vehicle kilometres travelled (VKT). This research will be discussed in Chapter 2. In short, they found that any one project will likely induce extra traffic but the magnitude of the increase, if any at all, will vary by project.

That extra road lanes may increase VKT poses several challenges to policy makers. First, it questions the viability of reducing congestion by simply increasing road capacity. Second, it leads to questioning whether the external effects of more traffic, such as safety, enjoyment of a space, and air and noise pollution, might outweigh the internal benefits of more travel. Third, while still in the age of internal combustion engine (ICE) vehicles, extra traffic also implies extra greenhouse gas (GHG) emissions and hence raises the question of whether increases in road capacity are aligned with wider aims to reduce GHG.

One policy response in New Zealand, and elsewhere, is to consider VKT reduction targets, relative to actual – or to the counterfactual – VKT expected to emerge, either at a city level and/or nationally. These policies are not explored in this report but rather the focus is on the relationship between extra road lane capacity and subsequent VKT. The research is intended to assist planners considering road capacity projects.

Planners in large cities also have access to transport models to estimate such VKT effects. However, these models can be expensive and slow to run and are not available for many of the smaller cities and districts in New Zealand. Hence, this research is aimed at assisting planners where access to transport models is not available. It may also serve as a guide to when more extensive transport modelling is to be recommended, or to provide a method for validating other modelling. In other words, the tool developed is not expected to

[2] This research is complicated by busy routes typically being selected for road projects, often in anticipation of growth in surrounding activity – both factors that increase correlation but cloud the causation inference.

replace fuller modelling but rather give early indication of VKT consequences and what might be done to mitigate the potential for extra VKT.

There are several limitations to this approach, the foremost being that the international evidence gathered largely relates to a potentially large set of projects within an area, whereas often, a planner wishes to consider the effect of one project. It is simply not possible to be precise about the effect of any one project based on the relatively crude approaches inherent in an induced demand tool. Thus, the benefit to any user of the tool will not necessarily be in the *amount* of VKT to expect, but rather in providing a framework, and access to research results, that can be used to inform any consideration of induced demand.

This project's focus is on road vehicle travel and the induced traffic effects of providing extra road capacity for these vehicles, whether they be light or heavy, private or public. The project does not consider other sources of induced road demand such as extra traffic arising from reduced road charges or arising from increased PT fares or journey times. Induced traffic is often associated with the release of suppressed travel demand – the suppression of demand due to high transport costs. The project also considers suppressed demand, but only insofar as it is bound up with induced traffic.[3]

1.3 Summary of approach and findings

This research project follows a relatively standard approach of a literature review (Chapter 2), the specification of a model (Chapter 5) and then the building of a model (Chapter 6). However, two extra steps were judged to be required, owing to a lack of New Zealand research and a general lack of international research tying modelling approaches together. The interim steps were, firstly, interviewing a small number of New Zealand planners and modellers to gauge their thoughts on induced demand and an induced tool (Chapter 3), and, secondly, exploring and testing elasticity approaches (Chapter 4), including against a more complex transport model, before fully specifying a tool.

In analysing the literature, we identify key implications for what this may mean for the development of an induced demand tool. These are shown in italics (#1 to #34) in Chapter 2 through 4. A list of these implications is repeated in Appendix A.

It is anticipated that content within this report will be required as part of the background explanation of the tool; some content has been written with this in mind, and hence has gone into more or simplified detail than normally required for a research report of this type.

The research undertaken into induced demand confirms that induced demand is likely to occur when capacity is added to congested roads but that the size of the induced demand response is more variable, and less well understood, in non-congested situations.

Further, we find that a tool that relies on lane-km elasticities is unlikely to capture the variation between projects that is to be expected and that factoring in key contextual user-supplied data, such as road class and expected GTC reduction, will lead to a less biased VKT estimate, albeit still having a large confidence interval, and will provide a framework that will be more insightful for the tool user.

With these findings in mind, a tool was developed (Chapter 6) using generalised cost elasticities and information on road lane-kms. **Note, the term 'costs', 'transport costs' and GTC are used interchangeably within the report – these should be taken to mean GTC unless otherwise specified, which for this report we take to be measured in New Zealand dollars (as opposed to generalised time).**

[3] It is possible to use the tool to follow the logic of interventions to suppress VKT but the elasticities assumed have been based on induced demand so the estimated VKT effect may be biased.

The tool is innovative and includes a rule that indicates the magnitude of land-use effects resulting from a road project, and is thus likely to involve further iterations. However, the tool does take the user through a logical and methodical process to assess the extent of induced traffic demand.

2 Literature Review

This chapter first considers what is induced demand and investigates why and how it might occur, drawing on international and New Zealand research, public reports and business cases, and ends with a look at a range of tools currently available internationally.

2.1 What is induced demand?

An insightful framework for considering induced demand is the relatively static framework of supply and demand curves. These enable a step-by-step consideration of the occurrences and causes of induced traffic demand. Key uncertainties will be indicated as each step is discussed.

At this stage, this report purposefully avoids definitions of induced demand provided by institutions, including NZTA, and instead builds up a more generic approach that provides the context for those existing institutional definitions.

2.1.1 An economic framework

Induced demand is the name given to the additional demand that is created by an increase in supply and corresponding reduction in price (to use the generic term). This is illustrated in the left-hand side of Figure 2.1. Here an increase in supply, shown by the shift down and out in the supply curve from $S^X{}_0$ to $S^X{}_1$, leads to a price reduction from $P^X{}_0$ to $P^X{}_1$. As a result, demand increases from $Q^X{}_0$ to $Q^X{}_1$.[4] This increase is known as the *induced demand*. In the application of the framework to road travel, the price axis would depict the *generalised cost of travel* (GTC), which largely consist of travel-time reductions, alongside reductions in fuel costs and other vehicle costs, and could also include reduced costs due to improvements in comfort or reliability. A generalised cost reduction can also occur with a reduction in out-of-pocket costs (eg, fuel prices). The scope of this project is on the impact of new infrastructure. The report therefore focuses on a change in supply of new infrastructure.

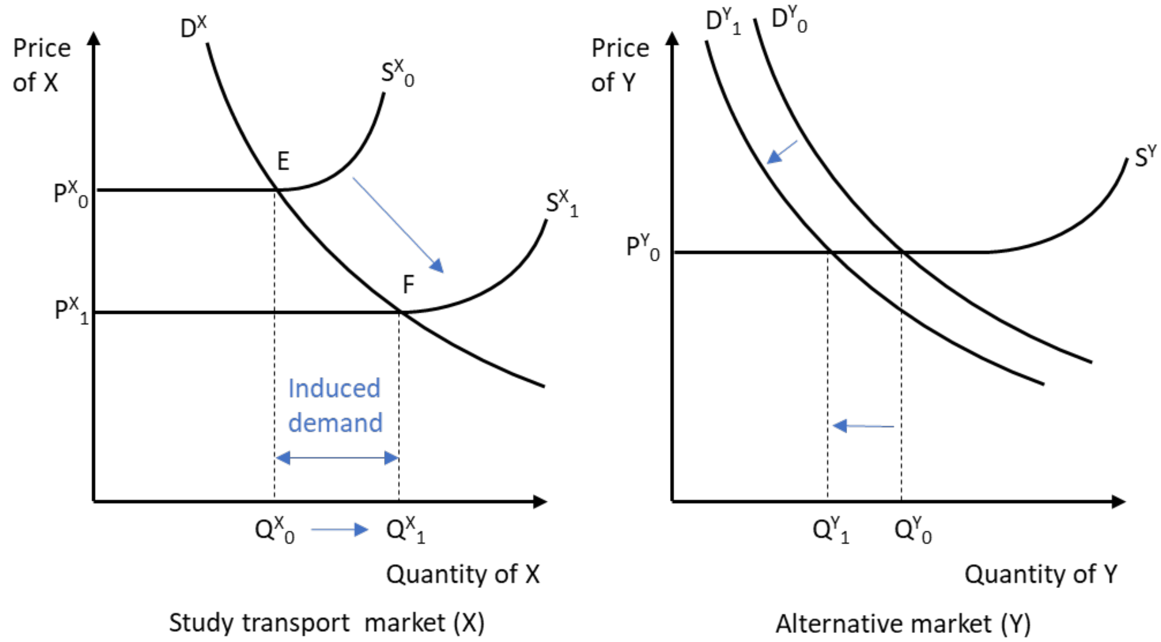
The induced demand arises through a mixture of substitution effects and income effects. The reduction in the price of X makes it more attractive and some consumers switch from consuming Y to X. This is shown in the right-hand side of Figure 2.1, as a leftward shift in the demand curve for Y (D^Y). The substitution of X for Y does not fully explain the induced demand. The reduction in the price of X, also gives a 'real' income increase which also increases the demand.[5] The net increase in demand for X (at different prices) is described by the demand curve D^X.[6]

[4] The exception to this rule is a Veblen good. This is a particular type of luxury good for which demand increases with a price rise. This is due to the status associated with the good.

[5] As 'spare' time is a good which people value, then a reduction in journey time gives both a substitution effect (eg, between modes) and a 'real' income effect.

[6] D^X is the Marshallian demand curve for X. That is the quantity demanded as a function of its price, consumers income, and prices of other goods.

Figure 2.1 The theoretical underpinning of induced demand



The basic notion is that a transport market exists to allow travel from one place to another – or between the origin and destination zones, to use the traffic modelling terminology – with the supply and demand curves determined independently of each other. It is further assumed that other transport markets exist for other zone-to-zone travel. Travel between zones can be further disaggregated by mode and even time of day. This representation of multiple transport markets thus enables consideration of interaction between the markets, for example, how travel between zones C and D, say, using PT would be expected to be affected by travel between zones A and B by car, and in particular by any change in the cost of travel between zones A and B. The interaction effect could be a substitution, as will be extensively discussed below, or complementary (eg, more demand between both zone pairs) or independent (ie, no interaction, which would typically be the case if the zone pairs are in different parts of a city). The consideration of interest to this research project is whether travel demands increase as the cost of travel is reduced on a road because a new road or road section is created or significantly improved.[7]

These travel markets, in turn, are considered part of a set of markets which make up the wider economy – New Zealand in our case. A key distinguishing feature of travel markets is that they are considered primary markets, while demand for travel is derived from secondary markets (Jara-Diaz, 1986). For example, a person might choose to travel from A to B because they want to source groceries for their home. The relatively rare travel for its own sake is ignored and instead it is assumed travel is a derived demand, effectively a required (costly) task undertaken to enable satisfaction of demands in the wider secondary markets (other examples being for work, education, or leisure activities at another location).

A third feature of this framework is that factors like population, production, income, technology and consumption within the economy (ie, New Zealand) are assumed exogenous to the system of interest but we can consider how demand would change if only prices were to change. The underlying assumption is that people will optimise their utility by reorganising their demand if prices change. Such reorganisation in the

[7] Note, this project takes the decisions of the road network managers (ie, NZTA and local and regional authorities) to be exogenous to the level of induced traffic (eg, building a new road now will not necessarily cause the road to be widened in the future). If, however, road managers are tasked with maintaining certain levels of service, and induced traffic reduces the level of service below the targeted level, then induced traffic may lead to further rounds of road widening (ie, the decisions made by road network managers are endogenous to the level of induced traffic).

context of the following discussion includes changing routes if a new or improved road offers cheaper/faster travel. It can also include shifting location from, say, Palmerston North to Auckland if lower generalised travel costs were to reduce the cost of living in Auckland (but there would still need to be an underlying demand to migrate as well, as we are only considering the price effect here). Over time, other non-price (exogenous) factors will also change and we can then reconsider the set of supply and demand curves that would match the new circumstances. This is commonly experienced as a shift of demand curves to the right as population and incomes increase. For example, if population and incomes increase, then the demand curves in Figure 2.1 would, in a subsequent time, be to the right of that depicted at the moment. This is further discussed below as background growth and depicted in Figure 2.4. A key challenge to this supply and demand framework, and to any model of land use, is whether migrations of people and businesses occur for reasons other than travel costs. Put another way, is the endogenous travel cost effect on land-use minor relative to the other – exogenous – changes? This will also be discussed further below.

Last, the price and quantity axes in the supply and demand diagrams can vary, depending on the matter of interest. For this study, the quantity of interest is VKT. In other situations, the quantity axis might be the number of vehicle trips or the number of people trips.

2.1.2 Induced traffic

This economic framework is a simple, but powerful, way to view transport-related induced demand (ie, induced traffic). It allows us to explore facets that we would expect to find in the empirical evidence, but it can guide policy.

Interlinkage between demand, price and the quantity supplied.

This simple economic framework emphasises the interlinkage between demand, price and the quantity supplied. This is important as it shows unambiguously that price cannot be lowered (eg, through a supply side intervention such as new transport infrastructure) without inducing demand. The only means to avoid inducing demand is to use complementary policies, such as mitigation (eg, taxes, charges or rationing), thus ensuring the price of the good to consumers is unaffected by the supply-side policy. In the context of road transport policy, that would include tolling, road pricing, traffic engineering, land-use restrictions or some other forms of rationing to prevent the GTC falling.

Varying perspectives to view induced traffic.

The perspective from which induced traffic can be viewed can differ. That is, the market for X on the left-hand side of Figure 2.1 can be defined in different ways. It could relate to aggregate travel demand, the demand for a mode, for an origin-destination pair, a time period, or a particular link in the network (eg, a bridge, motorway, cycle path, etc). This then means the alternative (Y) market(s) on the right-hand side will also vary. For example, in their seminal paper Duranton and Turner (2011) treat X as road traffic on the urban part of the inter-state highway network. Here, the alternative (Y) markets then reflect other road types, modes, and cities without interstate highway networks, etc. Empirical work will often consider traffic passing over screenlines,[8] such as Bucsky and Juhász (2022), who analyse traffic crossing the Danube in Budapest following changes in bridge capacity. Here the X market is traffic travelling over the Danube (over all time periods), and the alternative Y markets are everything else: modes, destinations, and housing and business migration within or to/from Budapest (eg, housing schemes, retail parks and haulage depots on the orbital motorway). Anecdotally, some transport modellers may consider that if a transport model captures aggregate demand across all modes and time periods correctly, then induced traffic only represents the generated traffic from changes in land use, which lie outside of the model.

[8] A screenline represents an imaginary line passing through several locations (eg, along a river or a city boundary).

Metric by which induced traffic is measured.

Depending on perspective, we may wish to measure induced traffic in terms of person trips, vehicle trips, vehicle kilometres or person kilometres, potentially differentiated by time of day. The Standing Advisory Committee on Trunk Road Assessment (SACTRA) (1994) were primarily interested in economic appraisal within an Origin Destination (OD) matrix-based consumer surplus calculation, and therefore focused on person trips. The recent empirical work measuring road-based induced traffic tends to focus on VKT within a year (eg, Bucsky & Juhász, 2022; Duranton & Turner, 2011). The current focus on GHG emissions points to the annual or daily VKT being the relevant measure, as GHG emissions may be broadly correlated with VKT and the time-of-day effects are unlikely to alter overall VKT significantly. However, retiming effects can have emission effects due to changes in the flow of traffic (eg, more emissions during congested periods).

Behavioural mechanisms that lead to induced traffic.

This interaction between our X market and the Y market(s) as a source of induced traffic leads us to focus on the behavioural mechanisms by which that interaction occurs – that is, how demand switches from the Y market to the X market. These mechanisms are changes in route, time of day, destination, mode, and new trips (Standing Advisory Committee on Trunk Road Assessment (SACTRA), 1994). Some of the new trips will occur because households and businesses make more trips (eg, a twice-weekly shop instead of a weekly shop). This is a change in trip frequency. Other new trips will occur due to changes in land use. The land-use changes can also be viewed as displaced (ie, development occurs adjacent to the project instead of elsewhere), or new (ie, bigger) development. The latter is related to the transport-economic growth argument. If the ‘new’ trips arise from land-use changes that are displaced, it is arguable whether these trips are actually new, as they have replaced existing trips. However, VKT may change as the ‘new’ trips may be longer or shorter than those they displaced.[9] Some displacement of economic activity within a country can also be viewed as socially positive, if it is displaced to regions prioritised for growth (eg, lagging regions).

When we think of behavioural mechanisms, we find there is some confounding in the policy literature between generated or induced trips and induced demand (traffic). Demand is measured in VKT, and generated trips are person or vehicle trips. Building on Standing Advisory Committee on Trunk Road Assessment (SACTRA) (1994), Hills (1996) clearly sets out the inter-relationship between the two and also relates them to the different behavioural responses. This is reproduced in Figure 2.2. What is clear from this diagram is that induced traffic (extra VKT) can occur through a variety of behavioural responses, including re-assignment of existing trips. An example of this confounding is contained in the MBCM:

> *Pure induced travel demand relates to entirely new trips that would not have been made without the activity or supply. For example, if an activity (or collection of activities) improves access to a shopping location, a person who in the ‘do-minimum’ scenario would make an average of one trip to the shop per week may make an average of two trips to the shop.* (Waka Kotahi NZ Transport Agency, 2020, p. 30)

At present, the MCBM only treats new trips as induced demand, a matter that NZTA may wish to review. Induced demand/traffic is much broader than this, as many different behavioural responses can lead to changes in VKT. While trip retiming can be a form of induced demand, of relevance in particular to congestion and thereby to economic appraisal and getting the benefits correct, retiming is unlikely to change daily or annual VKT. It will therefore be largely ignored from herein. It is also worth noting that these responses occur over different time intervals, with the transport-market responses occurring the quickest,

[9] Thus, changes in VKT and number of trips need not be correlated within a project due to changes in the trip length.

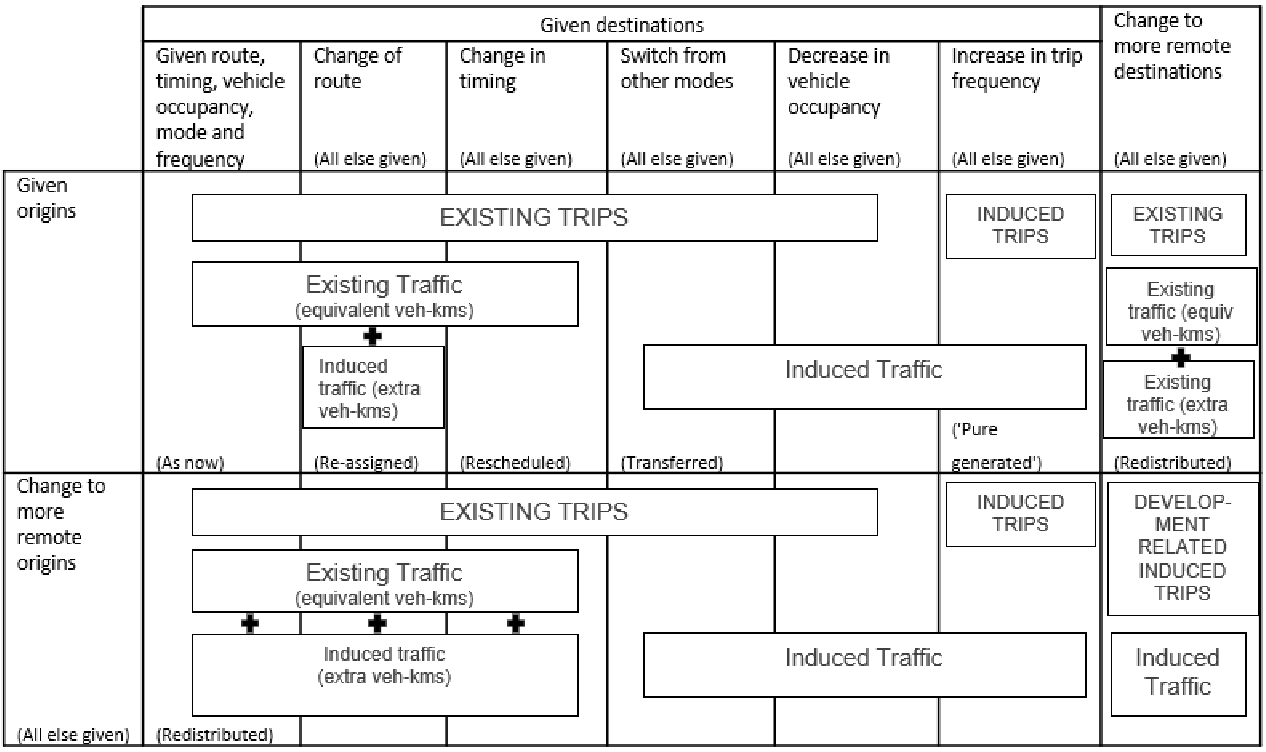
and the land-use change responses lagging behind. The time lag associated with behavioural responses is discussed further in the evidence section.

In the report, we will explicitly consider GTC reductions causing induced demand due to:

a. increases in trip frequency
b. changes in destination (such as going to destinations that are further away because of reductions in journey times brought about by new road infrastructure)
c. changes in mode choices (such as switching back to vehicle travel as a result of new road infrastructure);
d. reductions in car occupancy
e. changes in route, which increase vehicle-kms
f. changes in land use.

This does not necessarily match the results of 4-stage transport models as they typically do not incorporate changes in trip frequency as a result of changing infrastructure – few incorporate occupancy effects, and land-use effects are often treated exogenously.

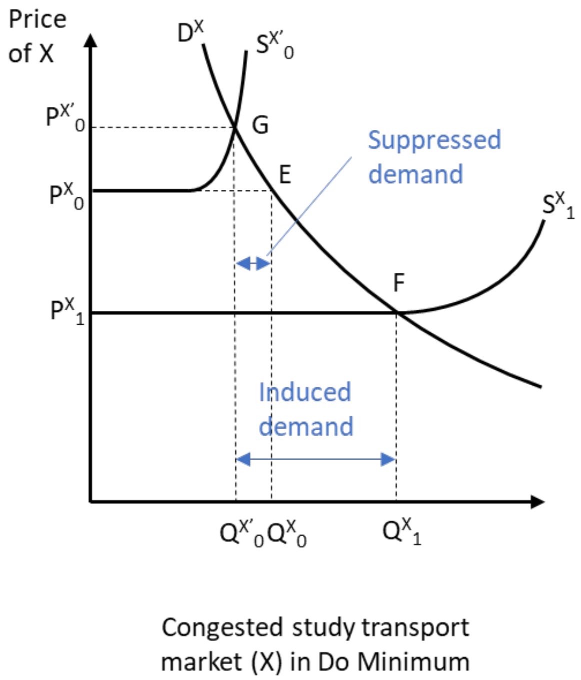
Figure 2.2 Induced traffic, induced trips, existing trips, existing traffic and behavioural responses (reprinted from Hills, 1996)



Trip suppression

This economic framework illustrates how high demand (relative to capacity) crowds out demand via price rises (increases in congestion and GTC in our case). In a transport context the price rise is driven by congestion and is evidenced in Figure 2.3 by the upward sloping supply curve $S^{X'}_0$. This graphic should be compared with the left-hand side of Figure 2.1. This leads to an equilibrium point at G with a higher price $P^{X'}{}_0$, and a lower quantity of travel demanded $Q^{X'}{}_0$. Economists call this reduction in demand 'crowding out'. Transport professionals call it 'trip suppression'. In the context of road traffic, it might also be called 'suppressed traffic'. In this example the cost reduction from new infrastructure (as illustrated in Figure 2.1) is now larger given congestion is eliminated in the 'do-something' scenario (depicted by supply curve $S^X{}_1$). This leads to a larger amount of induced traffic: it is larger by the amount of suppressed traffic that has been released.[10] The treatment and modelling of suppressed demand is seen as important when forecasting many years into the future, as invariably the capacity of the transport system cannot accommodate unrestrained travel demand caused by forecasted income and population changes.

Figure 2.3 Induced demand and trip suppression



Substitutability

The quantity of induced traffic depends not only on the size of the cost change, but the ease of substitutability between the different markets (the left-hand side and the right-hand side in Figure 2.1). For markets that are highly substitutable there will be a significant induced traffic response. Behaviourally, we observe from empirical transport modelling that changes in route choices, changes in destination, and changes in the time of day of travel are more sensitive than mode changes. Changes between modes, trip frequency and trip generation arising from land-use change are the least sensitive responses in terms of changes in trip numbers (Ortúzar & Willumsen, 2011, pp. 20-21). This framework would then lead us to expect that induced traffic on road networks will be highest where road is the dominant or only form of travel (characteristically the USA), and where the interest is on a particular road type, as per Duranton and Turner (2011). This is because where other modes exist, induced traffic effects are only limited by the congestion they impose. When other modes are present, the road may not reach capacity to the extent that PT (and

[10] The 'release' of suppressed demand will be accompanied by the extra utility availed by this extra travel, a matter considered within a CBA but not a matter of direct relevance to measuring the VKT effect.

active) alternatives act as a form of 'release valve'. Thus, elasticities that imply all new road space is filled up with traffic can only really occur in situations with poor PT alternatives.

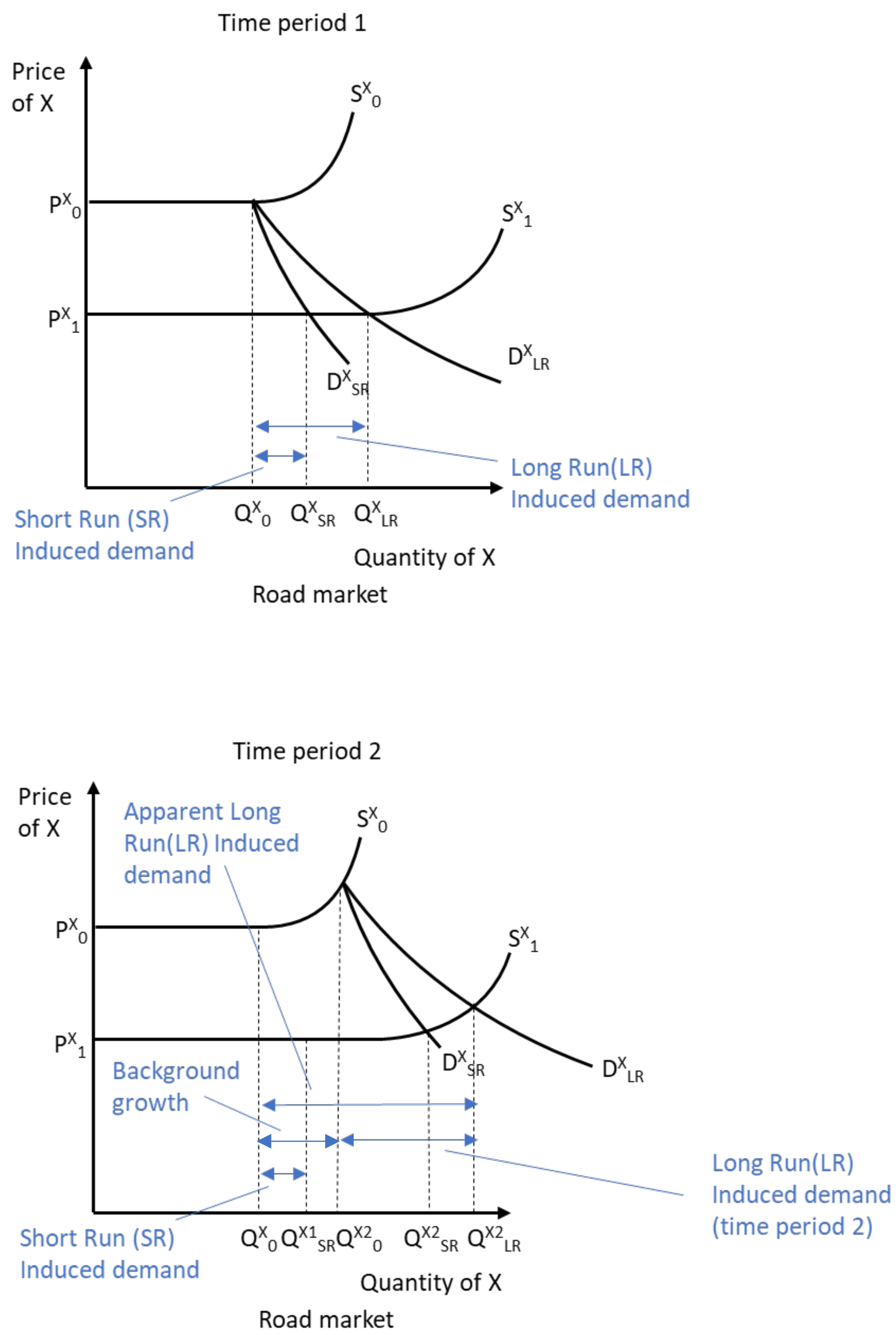
Path dependency

If the alternative markets (Y) are housing in other cities, or in different parts of a city, and a road traffic investment leads to urban sprawl within the city (Baum-Snow, 2007) or to migration to the city (Duranton & Turner, 2011; Duranton & Turner, 2012) then path dependency is likely to occur. This is due to the construction of new housing stock and business infrastructure which will likely have a very long life. If this new housing or business infrastructure is built in a location that requires high car dependence, then it will lock in induced traffic until such a time that the housing stock or new infrastructure becomes redundant, which could be a very long time.

Short-run and long-run demand, and background growth

The different behavioural responses that give rise to induced demand occur over different timeframes, which could be instant or span over several years. Changes within the transport market such as changes in route, time period and mode may occur quickly (ie, in the short run, typically taken to be within one year). Changes in housing location may take longer to occur (eg, construction of new housing and migration). This can be depicted as short run (D^{X}_{SR}) and long run (D^{X}_{LR}) demand curves, as in the top panel of Figure 2.4. The full measure of induced traffic will only occur in the long run (ie, $Q^{X}_{LR} - Q^{X}_{0}$). However, background changes due to changes in income, fuel prices, technology, etc, will occur over the time it takes the induced traffic to appear. This is depicted in the lower panel of Figure 2.4. Here, background growth leads to base levels of demand in the 'do-minimum' scenario shifting from Q^{X}_{0} to Q^{X2}_{0}. The full amount of induced traffic now only occurs at Q^{X2}_{LR}. The uplift in traffic ($Q^{X2}_{LR} - Q^{X}_{0}$) is therefore split into two components: background growth ($Q^{X}_{0} - Q^{X2}_{0}$) and the induced traffic ($Q^{X2}_{LR} - Q^{X2}_{0}$).

Figure 2.4 Short-run and long-run demand curves and background growth



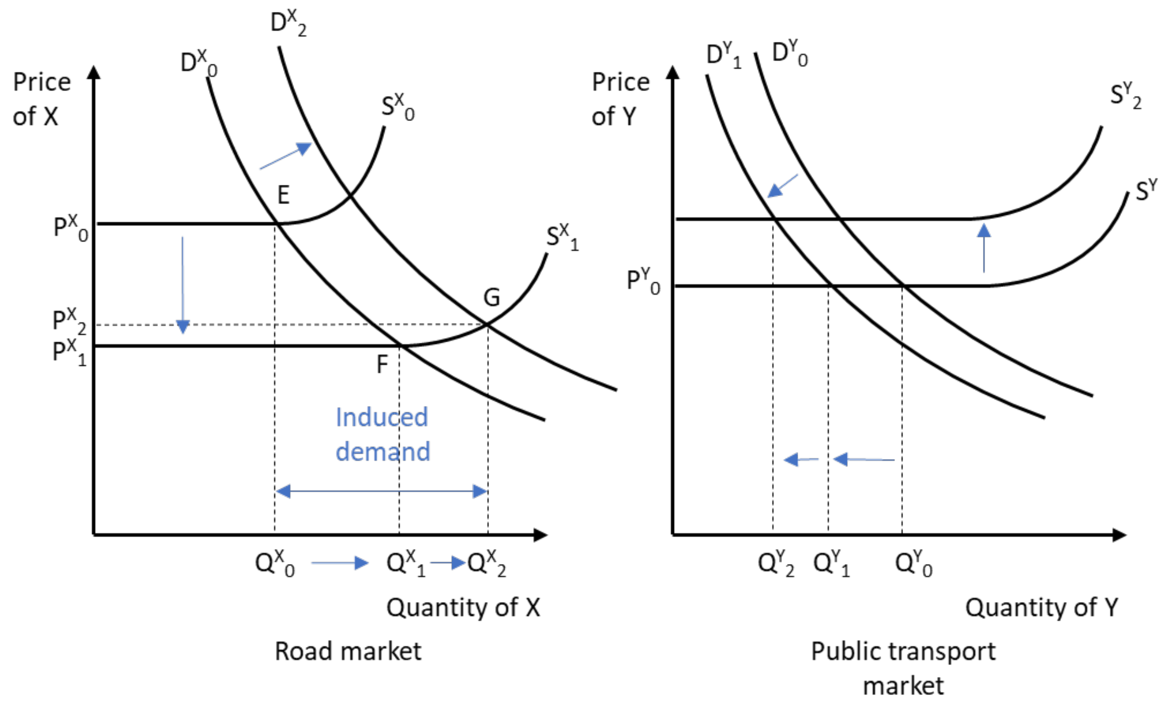
Measuring economic impacts

Economic impacts are felt not only in the market where the induced traffic occurs, but also in the markets from where traffic is displaced. An economic appraisal therefore needs to be holistic and account for social surpluses and losses in both the project transport market (where the induced demand occurs) and the other transport markets where there is a substitution of demand. This is the landscape in which the multi-modal economic appraisal frameworks sit, for example NZTA's MCBM (New Zealand Transport Agency, 2020) and in the UK, the DfT's TAG (Department for Transport, 2021b). However, to repeat, the focus of this project is the measurement of induced demand rather than the economic and social advantages or disadvantages of induced demand.

Induced traffic creates more induced traffic

One of the concerns about induced traffic is that it can lead to entrenched car-based behaviour and land uses (urban sprawl). In the long run this can erode the original transport benefits and economic gains of the investment. In certain situations all transport user gains could potentially be lost through increased levels of induced traffic, as Duranton and Turner (2011) is often taken to imply (see section 2.2.3 for a discussion on benefit measurement), or net social losses could occur, as implied by the Braess Paradox, Downs-Thomson Paradox and the Mogridge Conjecture (see section 2.2.4 where these are discussed further). The economic framework outlined earlier can accommodate these phenomena via second-round shifts in the demand and supply curves. For example, the reduction in demand in the PT market through either mode shift, or through land use change to urban sprawl, may make some PT services unviable. If these services close, then the PT supply curve will shift upwards. See curve S^Y_2 in Figure 2.5. This will then shift the demand curve for road traffic outwards to D^X_2. This creates more induced traffic with demand increasing to Q^X_2. Potentially this can increase congestion, which in Figure 2.5 is shown by a price increase to P^X_2. If government then reacts to the increased congestion on the road network with further road investment, a potential cycle of investment, induced traffic, reduced PT use or increased urban sprawl, leading to more congestion, road investment, etc, could be created. The situation can be further exacerbated if investment then shifts from PT to more road investment. Net social losses could be possible. It is to these situations that Downs (1962) referred, when he introduced his law of congestion, which is also used by other commentators. This debate continues, as commentators continue to raise the issue of the potential futility of further road building to reduce congestion and emissions (eg, Handy, 2015; Kingham, 2020; Zipper, 2021). We will return to this topic amongst other matters in the next section.

Figure 2.5 Induced demand creating more induced demand – loss of public transport service



To summarise, a demand-supply economic framework is a helpful prism through which to view induced traffic. It identifies that induced traffic is an expected feature of any reduction in GTC. It will be highest in congested areas, which is where trip suppression occurs and where substitutability is high (eg, car-dominated cities). It can be defined in different ways depending on the policy of interest. GHG emissions would typically point towards measuring induced traffic in VKT, whilst measurement of person trips or vehicle trips might be used if focused on economic appraisal matters. Person trips, rather than vehicle trips, would be needed to measure induced demand on modes other than the car. Interactions between different facets of the transport market and the extent of congestion mean that induced traffic can lead to an erosion of benefits from any investment. In extreme cases, it may also lead to path dependency, locking in car dependency for many years into the future. In extreme cases, induced traffic could potentially lead to net social losses.

Insights for the development of the tool:

*#1. A cost change is a necessary condition for induced traffic. The larger the cost change, the larger the quantity of traffic that is induced. Capacity changes (eg, new lane-kms) is **not** a necessary condition for induced traffic. (Additional) lane-kms create induced traffic only if they create cost changes. If additional lane-kms do not create a cost change, there will be no induced traffic. Implication: the tool needs to be sensitive to cost changes. The tool will likely need to reflect that different transport interventions will give different cost changes. If infrastructure type is used as an input to the tool, there is likely a need to have some indirect relationship to cost changes.*

#2. The quantity of induced traffic depends on local transport conditions. Different quantities will be induced depending on congestion, the substitutability of the new link, and the capacity of other links in the network. The tool needs to be able to accommodate different baseline conditions for the transport network.

#3. The quantity of induced traffic depends on the scope of analysis that is, traffic on the new road, total traffic in a corridor, total traffic in a city, total traffic in a region, or total traffic in New Zealand. The different perspectives give rise to different behavioural responses being included or not included within the definition of induced traffic. Implication: a definition of induced traffic needs to be agreed for use in the tool.

2.1.3 Measurement of induced demand

The above discussions have largely presumed that induced demand is readily measurable. In practice, it is not easy to measure induced demand itself, nor to measure the cause of induced demand.

First, VKT (demand) and lane-km (supply) require measurement over periods of time. Lane-km is generally recorded by the road-controlling authorities. It is reported in New Zealand for each region and district, broken down by state highways and local roads. These data are reasonably accurate although lane-kms do change in the New Zealand time series for reasons that are not obvious. The measurement of VKT is more problematic. According to the Canadian Institute of Transportation Engineers (2012), there are currently five ways to estimate VKT:

1. household activity surveys
2. odometer reporting programs
3. fuel sales
4. traffic counts
5. transport models.[11]

[11] Mobile phone data could also be used to estimate VKT, but this remains an area of research at this stage.

In New Zealand, household survey data, odometer readings and road counters (or as a substitute for the latter, estimates entered in RAMM) have been used to measure VKT. The odometer method is likely to provide the most accurate national measure but is less accurate at a regional or road level, as the region of odometer (and car fitness) inspection does not necessarily reflect the region of vehicle travel. Conversely, the road counter method more accurately measures traffic at points on the network (Canadian Institute of Transportation Engineers, 2012), which can be extrapolated to provide reasonably accurate estimates of local VKT. Note, the household survey method only records household VKT, and excludes visitors to the region, for example. Further detail on New Zealand road data is reported by McKibbin and Sewell (2022).

Second, it is relatively simple to show a correlation between VKT and lane-km, but it is much more challenging to determine causation. This is generally attempted in three ways.

1. by modelling based on standard transport relationships
2. by statistical analysis that is likely to require panel data (which allows controlling for fixed and time effects) and instrumental variables (to remove any apparent effect of VKT on lane-km), as, for example, in Duranton & Turner (2009)
3. by surveying people following the addition of a road.[12]

Each method has its shortcomings – like needing correct model specification, avoiding omitted variables, and requiring representative sampling – hence no one method provides the definitive relationship but consistent results across the three methods do encourage confidence in the findings. To be more definitive, the empirical challenge is to separate any change in VKT into that represented by a rightward shift of the demand curve from any increase in demand (ie, induced demand) caused purely by the rightward shift of the supply curve. This was illustrated in Figure 2.4.

2.1.4 Modelling the transport effect: the ‘do-something’ and the ‘do-minimum’ scenarios

Expanding on the use of transport models to measure the VKT effect of a road addition or improvement, this can be done by running a model which allows the full set of responses[13] without and with the road intervention – the first being the counterfactual or the ‘do-minimum’ (or do-min) scenario and the second, with the intervention, being the ‘do-something’ scenario. The VKT effect can then be measured by the difference between the two model runs.

Again, in theory, this is a simple process but in practice is complicated by:

a. having to construct a ‘do-min’ scenario for some point that will likely be years or even decades in the future
b. having to predict the number of trips for each zone end-point level of activity.

On this second point, traffic assignment models are good at optimising traffic flows given the number of trips starting and ending at zones, but they do require input as to the number of trip ends.

The first challenge of predicting activity levels is a general issue about uncertainty. This has been discussed elsewhere (Byett et al., 2017).[14] The second challenge of predicting trip responses is a key element of modelling induced demand.

[12] A specific problem with surveying is obtaining accurate recall of behavioural changes.

[13] It is not always the case that a full step of responses is tested in a transport model (*all* models inherently adopting some aggregated simplification of complex behavioural factors)

[14] Issues range from allowing for a known distribution of travel demands in a future year ‘do-minimum’ to modelling the ‘do-something’ vs ‘do-minimum’ difference under several (or more) uncertain scenarios.

The classic transport model consists of four stages:

1. trip generation (at a zone level)
2. trip distribution (between zones)
3. modal split (of inter-zonal trips)
4. route assignment (at a road network level).

Trip generation (stage 1) provides the number of trips starting at each zone and ending at each zone for different trip purposes, effectively giving the row and column totals for trip matrices for each purpose (but not the cells within the matrix) and, in economic terms, fixing the land use in the sense that the number of households in each zone and the amount of non-residential floor area are fixed for each zone.[15] The next three steps then iteratively estimate the optimal trip solution given trip costs and other non-cost parameters (Ortúzar & Willumsen, 2011).

An important part of the iteration process is the extent of constraints imposed on the trip matrix. It is often assumed that the transport intervention is insufficient to change the number of trips between zone pairs and hence a fixed trip matrix (FTM) is applied to both the 'do-min' and 'do-something' scenarios. Any induced demand calculated from these model runs[16] would only result from trip reassignment and (in the case of multi-modal models) mode shift (see Figure 2.2).

If the road intervention is believed to change the number of trips between each zone pair, then a variable trip matrix (VTM) approach may be adopted to reflect the scale and pattern of travel in the 'do-something' scenario. Different assumptions have been applied by modellers and the results can differ by assumption. A VTM approach can take several forms, shown as a progressive removal of constraints on a hypothetical example trip matrix below. Land use (ie, trip generation) is assumed fixed in matrices A–E. The last example below is matrix F where an analyst has returned to the trip generation stage – typically outside of the transport model – to consider more households and/or floorspace in the zones which are expected to emerge because of the transport intervention. This land-use trip generation response to changes in GTC (say, due to a new road), which can occur over a long time, has proven to be the most challenging stage to model and the most contentious when it comes to induced VKT.

- Matrix A is an FTM, in this case shown for simplicity as having unique origin (O1–O3) and destination (D1–D3) zones and trips being the number of return trips per day between each zone pair.
- Matrix B is a VTM.[17] The number of trips ending (and starting) at each zone remains fixed but the number of trips between zones can change. For example, someone can change their job or where they live, but the total number of people working or living in a zone remains unchanged, or someone can change where they shop, but the total number of people visiting a shopping centre remains the same. A VTM of this form enables a measure of the induced demand resulting from the redistribution of trips.
- Matrix C is a VTM. It is the most applied VTM approach. The number of trips at each destination end is allowed to change but the total number of trips within the matrix (ie, within the study area) is unchanged. While this type of matrix is suited to situations where there exists discretion about a destination (eg, shopping/leisure), it will not capture the movement of workplaces or homes. In other words, these are short- to medium-term responses that involve small associated transaction costs. A variation of Matrix C

[15] Some models do allow for changing trip frequency as a result of changing GTC, but such models are not common.

[16] Put aside for this project are modelled changes in travel time.

[17] Although B is sometimes referred to as an FTM.

would be to allow the number of trips originating from each origin to vary while keeping the number of destination end-trips and the total number of trips fixed.[18]

- Matrix D is a VTM. Here, both the number of trips originating and ending at each zone can vary, in accordance with trip costs, but land use and the total number of trips remains constrained (eg, no more houses, no further non-residential floor area). The effects of VKT from matrices A–D, depending on which are used, and are referred to as redistribution effects.
- Matrix E is a VTM where the frequency of trips originating from a zone has also been allowed to respond to any change in trip costs. Here again, land use is still assumed to remain fixed (eg, in terms of number of houses and floor area). Induced demand due to frequency of trip changes does occur but is not generally recognised as a major contributor to higher VKT.
- Matrix F is a VTM which also has variable land uses. The number of trips in each of the destination and origin zones are allowed to change and the total number of trips in the model area can also change. This model allows people and business to move locations because of the transport intervention, including migrating from places outside the model area. Methods used to generate the VTM with land-use change usually require a land-use change model which then, with the standard trip-generation model component, would create a new VTM. A VTM of this form enables measurement of a yet-further-expanded set of trip redistributions, and hence of induced demand. But it comes with the extra challenge, when looking at it from a national perspective, of having to measure the VKT displaced from outside the model area. For example, someone migrates from Palmerston North to Auckland and their VKT in Auckland will be estimated in the model but the counterfactual VKT that they would otherwise have incurred in Palmerston North has to be derived outside the model. Taking this logic further, if the study zone in the model were enlarged to include all relocations, then there would be little change in the total number of modelled trips – any VKT effect arising from now-longer trips would be calculated within the model. Last, the 'land-use change' envisaged is largely notional, rather than a physical relocation. The 'do-min' matrix is typically for a forecast period and includes the baseline expectations of where people will locate. The land-use change inherent in Matrix F is usually a reconsideration of these future (notional) locations, in light of the transport intervention being proposed. This reconsideration will likely also have other economic and social consequences.

Table 2.1 Examples of fixed and variable trip matrices with and without land-use change

Situation	Trip matrix				
A. Fixed number of 100 (return) trips between 3 origin zones and 3 destination zones (shown as distinct zones here). Under this assumption, modelling would not reveal any induced demand resulting from redistribution.	DM	D1	D2	D3	Total trips
	O1	100	0	0	100
	O2	0	100	0	100
	O3	0	0	100	100
	TOTAL	100	100	100	300
B. Fixed number of trips originating and starting at each zone end but now 10 trips from O1 end in D2 and 10 trips from O2 end in D2. This type of adjustment is common in modelling, is likely to have a relatively minor effect and is a doubly constrained matrix approach. It is a VTM approach.	DS	D1	D2	D3	Total trips
	O1	90	10	0	100
	O2	10	90	0	100
	O3	0	0	100	100
	TOTAL	100	100	100	300

[18] Gravity models in operation are typically constrained at one end or the other, so do not permit the number of both origin and destination trip ends to change.

<table>
<tr><th>Situation</th><th>Trip matrix</th></tr>
<tr><td>C. Variable destinations. For example, people switching to another shopping centre after road improvements. In this example, the total number of trips and the trips originating from each zone remain fixed but 10 trips to D2 are now redirected to D1. Additional VKT would result if the changed trips were now of longer length, which in turn depends on the routes taken (and can involve a further iteration of cost changes if the redistributed trips cause congestion).</td><td>
<table>
<tr><th>DS</th><th>D1</th><th>D2</th><th>D3</th><th>Total trips</th></tr>
<tr><td>O1</td><td>90</td><td>10</td><td>0</td><td>100</td></tr>
<tr><td>O2</td><td>20</td><td>80</td><td>0</td><td>100</td></tr>
<tr><td>O3</td><td>0</td><td>0</td><td>100</td><td>100</td></tr>
<tr><td>TOTAL</td><td>110</td><td>90</td><td>100</td><td>300</td></tr>
</table>
</td></tr>
<tr><td>D. Variable origins and destinations. This VTM allows the number of trips originating in each zone to change but, again, the total number of trips is unchanged. In this example, 15 trips now originate from O1 that previously originated from O3 and the trips are to D1 instead of D3.

As above, additional VKT would only result when the trip lengths are longer (after considering the route assignment and further iterations of the travel-cost effect).</td><td>
<table>
<tr><th>DS</th><th>D1</th><th>D2</th><th>D3</th><th>Total trips</th></tr>
<tr><td>O1</td><td>105</td><td>10</td><td>0</td><td>115</td></tr>
<tr><td>O2</td><td>20</td><td>80</td><td>0</td><td>100</td></tr>
<tr><td>O3</td><td>0</td><td>0</td><td>85</td><td>85</td></tr>
<tr><td>TOTAL</td><td>125</td><td>90</td><td>85</td><td>300</td></tr>
</table>
</td></tr>
<tr><td>E. Full VTM. In this case there are 10 more trips originating from O1 and going to D1, assumed to be the result of an increase in trip frequency and thus also resulting in more total trips in the study region.

Note, in all the above cases, land use has been assumed fixed. That is, the number of houses in each zone has not changed and the number of square metres of non-residential buildings has also not changed.</td><td>
<table>
<tr><th>DS</th><th>D1</th><th>D2</th><th>D3</th><th>Total trips</th></tr>
<tr><td>O1</td><td>115</td><td>10</td><td>0</td><td>125</td></tr>
<tr><td>O2</td><td>20</td><td>80</td><td>0</td><td>100</td></tr>
<tr><td>O3</td><td>0</td><td>0</td><td>85</td><td>85</td></tr>
<tr><td>TOTAL</td><td>135</td><td>90</td><td>85</td><td>310</td></tr>
</table>
</td></tr>
<tr><td>F. Variable trip matrix with a change in land use. The least constrained method is to also allow the trip matrix to include trip change that would be expected to result from changes in land use.

In this example, people might migrate to O1, which leads to 30 more expected trips between O1 and D1 (again the numbers are kept simple, but many permutations exist).

This change leads to an increase in the total number of trips within the study region (but not necessarily a total number of trips within New Zealand). Again, the national VKT effect (and hence GHG effect) is primarily due to any change in average trip length.</td><td>
<table>
<tr><th>DS</th><th>D1</th><th>D2</th><th>D3</th><th>Total trips</th></tr>
<tr><td>O1</td><td>145</td><td>10</td><td>0</td><td>155</td></tr>
<tr><td>O2</td><td>20</td><td>80</td><td>0</td><td>100</td></tr>
<tr><td>O3</td><td>0</td><td>0</td><td>85</td><td>85</td></tr>
<tr><td>TOTAL</td><td>165</td><td>90</td><td>85</td><td>340</td></tr>
</table>
</td></tr>
</table>

The two practical aspects of using a VTM approach are (a) when to know which matrix form to use and (b) how to estimate the VTM. These two questions will be taken up in section 2.4 when discussing tools available to estimate induced demand.

Before leaving the trip matrix assumptions, it is worth noting that while home-based trips account for most trips, a large portion of trips are not home-based and hence are not as readily suited to the modelling approach above. While there is modelling undertaken in many places for freight movements, it is 'often sufficient to assume that total freight traffic is fixed, but susceptible to re-routeing' (Department for Transport, 2020b). However, one trend pertinent to induced VKT that does not appear to be well-researched is the growing number of light vehicle commercial trips. At this stage, this trend and modelling shortcoming are simply noted.

The above discussion has been of the classic transport model. An alternative way to forecast the change in VKT resulting from extra lane-km, and hence typically lower travel costs, are elasticity approaches. An elasticity approach may not produce the same results as the above VTM approach, but whether one or the other is more accurate depends on the parameters, functions and inputs used in each approach (Wallis, 2007). An early-stage tool of interest to this project is more likely to be based on demand elasticities. These will be discussed in 2.3.3.

Insights for the development of the tool:

#4. An early-stage tool of interest to this project is likely to be based on demand elasticities in order to be available to a wider group of users without specific transport modelling expertise. This tool will therefore not be appropriate for a detailed assessment of large-impact projects, but will provide approximate estimates of induced travel and will guide users to a more extensive modelling approach.

2.2 Why is induced demand important?

2.2.1 Climate change

According to the (New Zealand) Ministry of Transport (2019, p. 6), it is estimated that in New Zealand transport accounts for:

- 47% of domestic CO2 emissions
- 20% of Aotearoa's total GHG emissions.[19]

Within transport:

- 90% of emissions come from road transport
- 73% of emissions are from light vehicles in urban areas.

Increasing the demand for less carbon-intensive forms of travel is critical to achieving the net zero goal and induced demand plays an important role in this.

1. Induced demand on PT and for active modes is seen as essential to meet these targets, especially when it comes to congestion relief in cities (where the emission effect is high). In fact, induced demand is seen as a critical component of active travel projects and the programme-level benefits of cycle networks (Byett et al., 2021; Laird et al., 2013; Raith et al., 2011). In these circumstances induced demand is seen as positive.
2. In contrast, induced demand by private motorised internal combustion engine traffic on the road network in a climate change context is seen as negative.

From the perspective of induced road traffic, an increase (or decrease) in greenhouse gas emissions is more closely related to a change in vehicle kilometres than a change to person or vehicle trips. If climate change is therefore the primary policy interest, then the most appropriate metric by which to measure induced road

[19] Excluding a large portion of international aviation and marine travel.

traffic is **change in internal combustion engine vehicle kilometres travelled (VKT) – at a regional or national scale**.

Such a metric includes all transport behavioural responses including changes in route (Figure 2.2). It is also consistent with most of the empirical strategies aimed at measuring induced traffic, as will be discussed in the next sub-section (Section 2.3).

2.2.2 Economic growth

One of the sources of induced road traffic is economic growth stimulated by transport investment.[20] The mechanisms by which these occur can be broadly split into three main types: investment, employment and productivity (Laird & Venables, 2017; Lakshmanan, 2011). Firstly, transport investment increases the efficiency of the transport network, which lowers input costs, and ultimately prices. Real incomes increase, and demand for goods and services increase. Businesses respond to the lower prices through increased investment and expanding output. This leads to an increased number of trips, through increased business and freight travel as well as through discretionary trips by households with higher incomes. Secondly, employment changes will arise from the expansion in output by businesses, and from increases in labour supply via reductions in commuting costs. These employment changes will be associated with changes in commuting trips. Households with higher incomes arising from new employment may also engage in higher levels of trip making. Thirdly, the reduced transport costs increase effective density[21] and raise productivity via agglomeration economies.[22] Agglomeration economies are driven through interactions between firms and other firms, and between firms and households. The more intensive the interactions, the higher the productivity gain. Larger labour markets and larger markets in general are associated with productivity gains. To realise the benefits of increased agglomeration, longer trips could well be needed, for example, to obtain the higher paid (more productive) job that was previously too far away, or to make that business connection that previously was not possible due to travel constraints. We might therefore expect the increased productivity associated with an increase in agglomeration to be associated with increased person-kilometres[23] and freight tonne-kilometres.

Investment by businesses in new premises and by households in new housing are part of the investments that can be stimulated by transport investment. The expectation is that businesses and households will invest in the locations made more attractive (and more economically productive) by the transport investment. Byett et al. (2017) used a spatial computable general equilibrium (SCGE) model to show that permitting re-location of economic activity increases the economic growth from a transport investment.

These induced land-use changes clearly will result in trips on the local network. In a local context these are new trips and would be perceived locally as induced trips. However, if they are resulting in a shift in location of a development that would have gone ahead anyway (eg, a shift in new housing will occur to cater for population growth), it is arguable whether the developments are inducing traffic at the national level. With fixed population levels and a fixed number of housing units, then it will only be through locational factors between the different potential locations for the housing that changes in vehicle kilometres could occur. For example, a housing development within a city (infill) versus one that is outside a city (greenfield) would expect to generate fewer vehicle kilometres. The greenfield site would likely generate more, as it is likely to be a more car-based form of living with higher vehicle kilometres per household, than the infill site. If the transport investment (a city bypass) tips the balance towards the greenfield site, then the difference between the vehicle kilometres each site generates would comprise the induced traffic. This is clearly a difficult metric

[20] The stimulus is likely to be high when high transport costs are suppressing travel and economic activity.

[21] Places effectively become closer together as travel times reduce.

[22] A similar process can occur through the consumption-variety effect in cities.

[23] Higher person km is not necessarily higher vehicle km if PT and active modes are used instead.

to measure, as it requires not only determining whether the transport investment has tipped the balance between the two sites, but it also requires the measurement of the hypothetical counterfactual of what would have happened in the absence of the bypass. Robust empirical evidence, however, does support the long-held view that road investment within cities is a direct contributor to urban sprawl and a more car-based form of living (Baum-Snow, 2007, 2010; Baum-Snow et al., 2017), though strong planning regimes can reduce or even eliminate that sprawl (Levkovich, Rouwendal, & van Ommeren, 2020).

In this context we can see that induced demand is a natural consequence of the economic growth generated by transport investment. If economic growth is a government priority, then in that context, induced traffic would be seen as good, rather than bad. It is for this reason that some commentators argue that induced traffic is a good thing, or not always a bad thing (eg, Polzin, 2022), and arguably a reason why governments continue to invest in road projects (eg, the UK Department for Transport's £27.4 billion investment over five years in the Strategic Road Network has a growth objective (Department for Transport, 2020a)). As regards land-use change, induced traffic will always appear on the road network in the vicinity of the development, but whether it is induced at a national level (or just displaced) is likely to depend on a variety of location-specific factors.

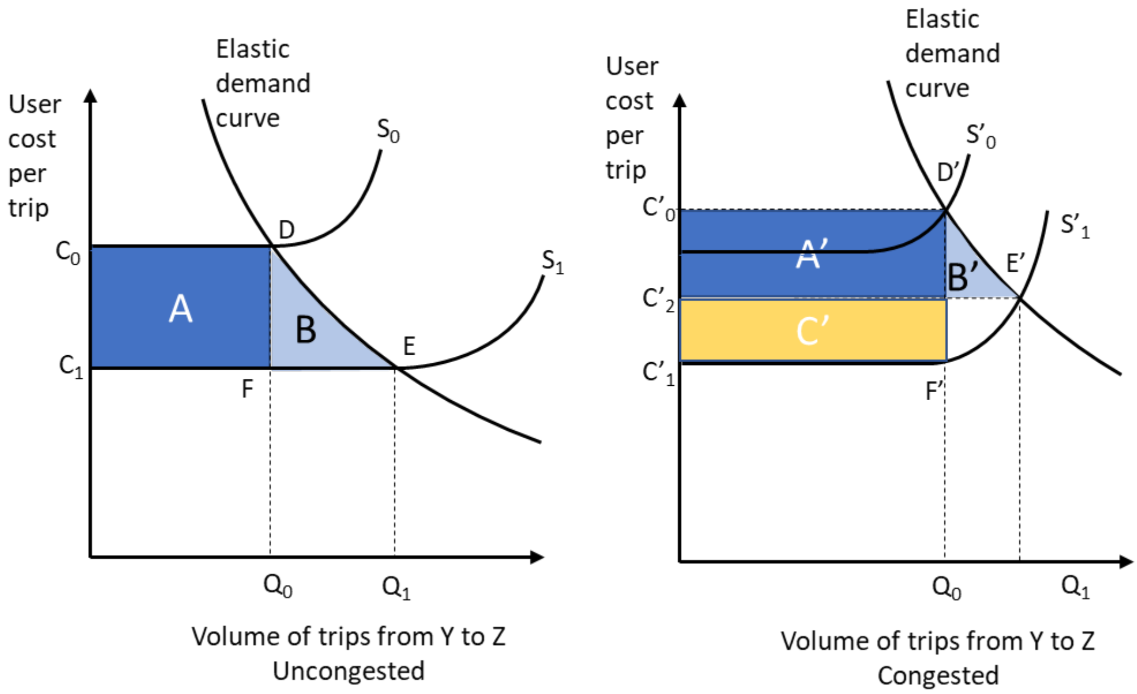
2.2.3 Getting the economic benefits correct

SACTRA (1994) and Mackie (1996) give an extensive treatment of the measurement of the internal monetised benefits with induced traffic. In this section we therefore only reproduce the key points. In a nutshell, in uncongested conditions, induced traffic creates additional benefits, but in congested conditions the extra traffic creates new congestion which erodes the benefits. In such circumstances the underestimation (or even exclusion) of induced traffic can seriously overestimate the economic benefits.

Figure 2.6 illustrates this. We have the uncongested situation in the left-hand side of the figure. Here, excluding induced traffic omits a benefit given to the new travellers denoted as Area B. Area A is the benefit to the existing traffic. Area B is not usually that large, although its omission can still bias the appraisal.

In congested conditions on the right-hand side of the figure however, the induced traffic crowds out the benefits. This is because the induced traffic raises the average cost of a trip from C'_1 to C'_2 (post intervention). Excluding the induced traffic from the appraisal leads to an overestimate in the size of both Areas A and B. Area A would be overestimated by Area C'.

Figure 2.6 Economic benefits with induced traffic: uncongested and congested conditions



It is of course also essential to look beyond the particular link, mode and time period that has been directly affected by the intervention. The behavioural mechanisms that give rise to induced traffic – changes of route, changes of origin/destination, changes of mode, changes in time period, etc – mean that surpluses and losses may occur on other links, for other origin-destination pairs, other modes or during other time periods. A full appraisal taking a national perspective needs to take these surpluses and potential losses into account. Best practice appraisal methods do take such a holistic approach.

The external costs associated with induced traffic also need to be included to get a full measure of the net economic benefit. In transport cost-benefit analysis, such costs are usually associated with safety, noise, air pollution and climate change. The appropriate values for these remain subject to some debate within the literature but are outside the scope of this study.

One of the sources of induced traffic is economic growth. From an economic appraisal perspective, if transport user benefits are correctly measured with induced traffic (see Figure 2.7) then these economic changes and land-use changes only hold value if market failures exist (Dodgson, 1973; Jara-Diaz, 1986; Mohring, 1993). The additional surpluses that these market failures create are known as wider economic benefits or wider economic impacts. Wangsness et al. (2017) identify that the most common of these in transport appraisal guidance are agglomeration, increased output in imperfectly competitive markets, and changes in labour supply. They also identify changes in unemployment (where structural unemployment exists), while movement of employment between locations with productivity differences also feature in transport appraisal guidance. Thus, advanced transport appraisal methods would estimate wider economic benefits when induced traffic is linked to increased economic activity.

2.2.4 Urban transport policy

In recent years the role of induced traffic as a mechanism that negates the economic benefit of road construction in urban areas has been debated. US evidence in particular appears to point towards induced traffic returning the road network to its original congested state (Downs, 1962; Duranton & Turner, 2011; Hymel, 2019; Noland, 2001). At face value, a return to the original pre-investment state would seem to imply a complete erosion of benefits. However, for a complete erosion of benefits to occur, or for a net social loss to occur, a certain set of conditions are required – arguably these conditions likely rarely occur.

For there to be absolutely no benefits we have to look to the substitute markets (markets Y in Figure 2.1 to Figure 2.5) as sources of the induced traffic and ensure that no benefits occur to transport users who remain[24] in those markets (eg, no reduced PT overcrowding, no reduced congestion off the motorway network or no reduced congestion on competing routes, etc). If decongestion benefits are felt in other parts of the system, the benefit of the investment will still be positive, even if induced traffic negates benefits on the road that has been upgraded.

Formally for there to be absolutely no benefits, the following conditions are required (Dodgson, 1991, cited in Mackie, 1996):

- There are alternatives which are perfect substitutes for the improved facility
- Some of these alternative facilities are not congested
- The improved facility will not attract all the traffic from these uncongested alternatives.

These are quite stringent conditions, and unlikely to be met in most road networks. Therefore, even in the case of total filling up of the new road capacity by induced traffic, we would expect some user benefits. Turning to the seminal Duranton and Turner (2011) paper, we can see two things. Firstly, traffic on major urban roads reduces slightly following investment in the inter-state highway network (elasticity of −0.05 to inter-state highway lane miles – Table 11 in Duranton and Turner, 2011). This would imply some benefits. Secondly, their analysis does not include the surrounding roads. Some benefits may therefore be experienced on the surrounding roads if traffic is routed away from these onto the relieved major urban roads or the upgraded inter-state highway roads. Furthermore, Duranton and Turner (2011) report that one of the sources of the induced traffic is migration to cities which have had inter-state highway network investment. There are two sources of benefit that might be associated with this migration. Firstly, the locations from which population migrates from will experience some decongestion benefits, and secondly the changes in land use associated with migration would be expected to be a source of benefit.

Mogridge et al. (1987) in an extension of the Downs-Thomson paradox present an even worse scenario than the zero-benefit one depicted above. If induced traffic reduces demand for PT (as in the right-hand side of Figure 2.5), then the reduction in fare revenue may lead to either a contraction in PT services or fare increases, unless the government makes up the revenue shortfall. This would shift the PT supply curve upwards, displacing more trips onto the road network, therefore eroding user benefits further. For a particular set of circumstances, Mogridge et al. showed that the final equilibrium position could be higher transport costs, following the investment, on both the road network and the PT network. That is, the induced traffic from the road investment initiated a chain of events that led to everyone being worse off. As Mackie says, this is a nightmarish scenario, but it does depend for its validity on several conditions:

> *First, public transport fares must indeed exceed marginal operator costs; in peak period urban conditions, this is questionable. Secondly, there must be no public transport user benefits when traffic is shed such as relief of overcrowding or increased chance of a seat. Thirdly the principal behavioural mechanism must be modal transfer rather than redistribution or generation. It is, therefore, an argument relating to radial movements in big cities, where public transport has a large market share, but where investing in enhanced road capacity has become something or a rarity [in the UK].* (Mackie, 1996)

[24] There is also the possibility of new users in substitute travel markets, but the same logic applies, although it gets more complicated.

This discussion identifies that even with high levels of induced traffic that return roads to pre-investment operating conditions, then the benefits are still likely to exist. It is only under certain circumstances that these benefits will be fully eroded or reversed. Notwithstanding that, it does also highlight the importance of considering the magnitude of induced traffic, and its sources when undertaking an appraisal. This is because benefits and disbenefits may occur in the markets from which the induced traffic is drawn. Clearly, as part of the appraisal process there is also a need to consider whether the predicted outcomes match onto the policy goals. Typically, policy goals centre on improved transport efficiency, economic growth and de-carbonisation. Arguably, high levels of induced traffic work against some of these goals. Critical to this appraisal is the efficacy of assessment methods to correctly model and measure induced traffic.

Insights for the development of the tool:

#5. The different policy perspectives (climate, economy, economic appraisal) give rise to different metrics with which to quantify induced traffic. Implication: we must adopt a policy perspective. The focus of this project is simply on VKT, but it is acknowledged that planners will be balancing a range of perspectives.

#6. Land-use change can be an important contributor to the level of traffic on a road. Whether it is induced depends on displacement. Without explicitly modelling the decision as to where households and businesses invest, this is likely to need to be dealt with by the user of the tool. Thus, the tool user will need to input the level of displacement (eg, quantity of housing development displaced from one part of a city to another). The different traffic characteristics between the development sites in the counterfactuals will determine the level of induced traffic. This will likely need some user input (eg, from a menu).

#7. The high induced travel-demand elasticities to lane-miles (from the USA) suggest there is a need to ensure the tool can replicate these for the relevant demand and supply conditions, to be considered reliable.

2.3 Evidence on induced demand

2.3.1 International evidence

Systematic literature reviews

There have been several substantive reviews on induced traffic over the last three decades (Dunkerley et al., 2018; Goodwin, 1996; Litman, 2022; Pells, 1989).[25] Pells (1989) cited 78 published and unpublished studies, theoretical discussions, modelling exercises and traffic counts. Goodwin (1996) summarises Pells's findings as showing:

> *[…] a wide range of results, with estimated induced traffic (defined very broadly, that is, as all extra traffic other than re-assignment) ranging from 0% to 76% of the observed increases in traffic flows. There was evidence that trip re-timing could be important, and weak evidence on the relative importance of redistribution, modal change, and generated trips (each of which could represent 2% to 10% of traffic) and land-use effects.* (Goodwin, 1996)

Goodwin (1996) himself reports evidence given to and used by the Standing Advisory Committee on Trunk Road Assessment (SACTRA) (1994). Drawing from multiple sources including costs of car use, case studies, values of travel-time savings and traffic counts from 151 road-improvement schemes and their associated relieved routes he concludes that:

> *The amount of extra traffic must be heavily dependent on the context, size and location of road schemes, but an appropriate average value is given by an elasticity of traffic volume with respect to travel time of about -0.5 in the short term, and up to -1.0 in the long term. As a*

[25] Also Currie and Delbosc (2010).

> *result, an average road improvement has induced an additional 10% of base traffic in the short term and 20% in the long term: individual schemes with induced traffic at double this level may not be very unusual, especially for peak periods. Induced traffic is particularly seen on the alternative routes that road improvements are intended to relieve.* Goodwin (1996, p. 35)

Dunkerley et al. (2018) reviewed 25 studies from 2007 to 2018. They identify two types of studies: econometric studies and case studies on traffic flows. The econometric studies report elasticities of VKT to a change in road capacity. The case studies on traffic flows report traffic flow[26] increases relative to a baseline, typically in the form of a percentage. They found a wide range of elasticities from the econometric studies, and a wide range of percentage increases from the case studies. The findings from a state level study in the USA and a national study in the Netherlands would indicate an elasticity of around 0.2 – so a 10% increase in road capacity at a national level would lead to 2% induced demand at the national level. However, induced traffic is likely to be higher for capacity improvements in urban areas or highly congested routes.

Litman (2022) cites 24 studies from 2000 to 2022. Four of them are the same as those cited by Dunkerley et al. (2018), with the others typically coming pre-2007 or post-2018. In the main, the studies that Litman cites identify large volumes of induced traffic, with long-run elasticities approaching 1.0 to increases in road capacity. As with Goodwin (1996), his view is that the level of traffic generated by a road improvement depends on the conditions. It is not capacity per se that induces demand, but the cost reduction. Increasing capacity of uncongested roads is unlikely to generate significant volumes of traffic in his view. However, expanding capacity of congested links are likely to generate considerable amounts of traffic, providing only temporary relief of congestion.

These systematic reviews give a thorough treatment of induced traffic impacts. Rather than developing another comprehensive review, we draw out some of the key aspects of the evidence base as they are pertinent to New Zealand and the development of a tool to model induced demand. In the remainder of this section, we do this by posing a set of questions, and then draw on the evidence base to answer those.

Is induced traffic real?

Our demand-supply framework presented earlier would imply that induced traffic should always follow from any reduction in the generalised cost of travel. Small changes in generalised cost would lead to small changes in induced traffic, which may be too small to observe empirically.

Turning to the empirical evidence base, it is quite clear that induced traffic happens. Average estimates for road schemes suggest projects may induce between 10% to 20% of base demand[27] (Goodwin, 1996). There is however a lot of heterogeneity, and the level of induced traffic will depend on context (Dunkerley et al., 2018; Goodwin, 1996; Litman, 2022; SACTRA, 1994).

What is the maximal level of induced traffic that may occur?

Our demand-supply framework would imply the level of induced traffic is a function of the cost reduction and the shape of the demand supply curves. Thus, we would expect that if transport projects deliver large cost savings, they could induce large increases in vehicle flows. This is what is observed. Fixed-link crossings (bridges and causeways), that replace ferry services between islands and the mainland or other islands, have the capacity to deliver large cost changes and induce a large volume of traffic. This is particularly the case if the new infrastructure is not tolled, as is the case in the Outer Hebrides, Scotland. In this island group, the bridge to Scalpay saw increases in traffic volumes by a factor of 13, that to Berneray by a factor of

[26] Care is required as traffic flow (count) studies can be conflated with VKT but there can be a potential difference between the number of trips and the (total) distance travelled. VKT is only revealed if the traffic counts cover an extensive set of network links.

[27] Where base demand was taken as either current or short-term forecast demand.

almost 8, and the causeway to Eriskay by a massive factor of 25. The latter in particular reflected the poor quality of the previous ferry and the manner that a north-south route through the island chain had been created through the construction of the causeway (Reference Economics, 2007, pp. 3-5). These islands all had very low populations of less than 300 residents at the time of the projects. The traffic uplifts to Eriskay and Berneray contain increases in through traffic, and so represent more than just changes in household behaviour. Scalpay in contrast predominantly represents an increase in Scalpay household and business activity. Some of this will be displaced from elsewhere, including a new fish processing plant, and increased tourist-related activity (eg, bed and breakfast). Thus, not all the additional traffic will be induced traffic at a regional or national level.

In a larger analysis of 38 fixed link projects in Norway, increases in traffic flows in the first year are between 10% and 600% (Welde et al., 2019). It is customary in Norway that fixed links are tolled, with the price of the toll set at 40% above the ferry fare. This and proximity to population centres, as well as the quality of the ferry service the fixed link replaced, will reflect some of the differences between the Scottish fixed links and the Norwegian ones. Within the Norwegian data there is quite a large variation in the levels of induced traffic. There is not a one-size fits all.

The Outer Hebrides and most of the Norwegian projects are in quite remote locations and population density and vehicle flows are low. In contrast, the Øresund Bridge links the cities of Copenhagen in Denmark and Malmo in Sweden. These bridge-tunnels, plus associated infrastructure at the bridgeheads, were opened in 2000. Traffic flows across the Øresund Strait have increased by a factor of three (Øresund Trends, 2012). This level of induced demand is substantial given that the Øresund Bridge is tolled, with the current toll costing €48 for a return car trip (after a multi-day discount). A large part of this induced demand (just over a third) has been commuting flows, with 96% commuting from the Malmo area into Copenhagen. Analysis of these commuters shows that Danish citizens and citizens of countries other than Sweden comprise 60% of these commuters (commuting from Sweden to Copenhagen). There is also evidence of spatial sorting of industries between Sweden and Denmark with, for example, logistics companies choosing to concentrate their plants in the Malmo area. These concentrations of industrial activity are likely to induce demand too. The composition of the induced traffic on the bridge again highlights the difficulty in unpicking net induced traffic effects at a regional level from data observed across a screenline. Very likely the Danish and overseas citizens that have located in Sweden, would instead have located in the Copenhagen suburbs, as would any new industries that serve Copenhagen from Sweden.

Ultimately, the maximal level of induced traffic that can occur is limited by capacity, with congestion crowding out growth in demand. This is illustrated in the right-hand panel of Figure 2.6. Thus, in most settings we are unlikely to see the levels of induced traffic seen with fixed-link crossings. In these contexts, the maximal level of induced traffic is the amount that takes the road (back) up to capacity. An incontrovertible body of evidence shows that US road projects in metropolitan areas exhibit a demand elasticity of approximately 1.0 to new road capacity (Cervero & Hansen, 2002; Duranton & Turner, 2011; Fulton et al., 2000; Graham et al., 2014; Hymel, 2019; Noland, 2001). That is, induced traffic fills up the spare capacity created by the urban road project. This appears to take approximately five years (Hymel, 2019).

Two recent studies have also found similar elasticities in Japanese (Hsu & Zhang, 2014) and European (Garcia-López et al., 2022) metropolitan cities. It is also important to note that elasticities greater than 1.0 can occur when road investment increases the lane capacity of existing lanes (eg, making a single carriageway road with one lane in each direction into a road with two lanes in each direction. Both Hsu and Zhang (2014) and Garcia-López et al. (2022) find elasticities greater than 1.0, with Hsu and Zhang (2014) reporting elasticities of 1.24 and 1.3 and Garcia-López et al. (2022) reporting elasticities of up to 2.0 for cities without tolling roads. Elasticities of around 2.0 are much higher than reported elsewhere. They imply that the new highways or new lanes carry at least twice as much traffic per lane-km as the average European city highway. This could be a function of the types of roads that were constructed vis-à-vis the average road in the sample (eg, only roads with high volumes of expected traffic were constructed). The average AADT (Annual Average Daily Traffic flow) on the highways in their sample was 15,900 in 1985 with an average of 1.6 lanes per km, which is suggestive that there was on average quite reasonable spare capacity on the average highway in a European city.

This latter body of empirical work utilises econometric methods to identify the role of induced traffic to changes in VKT following a road capacity increase. As with the screenline analysis (eg, Øresund Bridge) part of the induced traffic in the cities analysed stem from population change (ie, migration). The changes in VKT therefore are not net changes at a regional or national level. The projects induce them in the city under study, but there may be some offsetting decreases elsewhere. We return to this issue of population change and migration in the discussion on regional or national level elasticities in the next section and the discussion on behavioural responses later.

Will all road improvements lead to large volumes of induced traffic?

Our economic framework identifies that quantity of induced traffic will be a function of the context of the project and the existing transport network, that is, availability of alternative routes, alternative modes and congestion. It will also be a function of the mobility of the population via migration. Thus, we would not expect all projects to generate large volumes of induced traffic.

This is borne out by the evidence. Goodwin, already mentioned above, considered average road projects to generate between 10% to 20% of their screenline baseline traffic as induced traffic. This relates to pre-1996 UK evidence. Congestion levels will be higher now in the UK so that figure may need revising upwards.

Econometric studies at an area-wide level have also concluded that more moderate levels of induced traffic than the large volumes on fixed links, and seen in US metropolitan areas, can occur. Long-run observed elasticities are well below the 1.0 (that has been observed in the US urban studies referred to earlier). Road investment in Spanish regions between 1998 and 2006 has induced demand with an elasticity of between 0.27 and 0.31 (González & Marrero, 2012). At the US state level (not city level), long-run induced demand is estimated at 0.237 for all roads (Concas, 2012), with different road types inducing different levels of traffic: 0.086 for total rural lane miles, 0.267 for total urban lane miles, 0.244 for inter-state highway lane miles, and up to 0.531 for interstate highway urban roads (Rentziou et al., 2012). Similar sized elasticities have been found at the national level in the Netherlands: 0.3 (trunk roads); and 0.2 (all roads) (van der Loop et al., 2016).

US urban areas are characteristically highly congested and car-dominated. The central urban areas are penetrated by motorway-standard infrastructure which invariably is not tolled (ie, free at the point of use). Only 7% of the 16,555 miles (26,600 km) of US urban inter-state highways are tolled (Kirk, 2013, p. 3). This transport context is a key reason for the sensitivity of induced demand to increases in road capacity in US metropolitan areas. Our economic framework would lead us to expect less sensitivity where substitutability between alternatives is lower (ie, cities with useful PT systems) and where travel-cost reductions are lower (eg, the new infrastructure is tolled). The evidence supports this. In Budapest, where PT usage in the city averages 50%, changes in road capacity across the river Danube are estimated to have an elasticity of 0.5 to new road capacity (Bucsky & Juhász, 2022). These road capacity changes include the construction of an orbital motorway around the city with associated river crossings. In their large European analysis, Garcia-López et al. (2022) find that the existence of rail and metro networks almost halves their induced demand elasticity.[28] For cities with tolling on highways they find the elasticity reduces by some 85% to 0.3. Thus, whilst there is limited evidence on the impact of existing PT networks and existing tolling networks on induced demand, what is available indicates substantial reductions in the level of induced demand that may occur in cities.

[28] Although the elasticity remains above 1.0 as their 'base' elasticity is close to 2.0.

Is induced traffic ever zero?

As mentioned already, our demand-supply framework would imply that induced traffic would always occur. However, if the demand curve is inelastic (close to vertical), or the generalised transport cost changes are small, then the levels of induced traffic will be small – potentially so small that they will be difficult to observe empirically (ie, effectively zero).

In practice we see this to be borne out. For example, Highways England, the agency responsible for management and investment in the trunk and motorway network in England, found in their ex-post programme (POPE) that for 76% of their projects, the only behavioural response identified from an analysis of traffic flows across screenlines was re-routeing (Highways England, 2019). This is based on an analysis of 71 projects that were completed between 2002 and 2014 and had post-scheme data either one year (15% of ex-post analyses) or five years (85% of ex-post analyses) after project opening. Changes in traffic flow between the opening and post-opening years were therefore in the main attributed to re-routeing effects and changes in background growth. In the main these projects are 'rural' projects. They are not remote-rural projects, however. England is a densely populated country and these projects are typically located between or on the periphery of cities and towns,[29] which is where the trunk and motorway network in England is. Of course, changes in background growth arguably may be suppressed if projects are not constructed, and induced traffic would correspondingly be higher than this analysis indicates, as some commentators argue (eg, Sloman et al., 2020).

The POPE analysis is a screenline-type analysis. Using the econometric approach to studying induced traffic, and as noted above, Rentziou et al. (2012) find quite low levels of induced demand for rural roads (elasticity of 0.086). This is similar to the 0.1 elasticity found for the extension of the English motorway network between 1978 and 1988 by Williams and Lawlor (1992, cited in Goodwin, 1996).

If the project only creates small cost changes and the network is not congested, then it seems highly unlikely that the project will generate any observable levels of induced traffic. An example of such a project from the POPE ex-post programme would be the M6 Carlisle-to-Guardsmill upgrade from 9 km of all-purpose dual two-lane carriageways to a three-lane motorway. This rural motorway project generated a time saving of 31 seconds (southbound) and 47 seconds (northbound), and five years after opening, no observable effect (ie, distinct from background noise) on traffic levels could be identified (Highways England, 2015).

Is induced traffic really just displacement?

From first principles, almost all the sources of induced traffic are a consequence of displacement (or substitution) of trips from one route, mode, origin, destination, etc, to another (see Figure 2.2). However, that is quite different from saying that induced traffic is all displaced. The trips can be displaced but the travelling patterns could be quite different. It is these differences in travelling patterns between the counterfactuals that drive the net increase in travel demand (ie, the induced traffic). To understand the net effects, it is necessary to take a wide area and a holistic perspective. Therefore, it is the evidence at a national level, regional level, or a US state level, that is most indicative of the net impacts of induced demand. The evidence reviewed above indicates that elasticities to road capacity changes of between 0.1 and 0.3 are likely at these wide area levels. The higher elasticities are associated with capacity changes in high standard[30] roads, most likely subject to some congestion. These elasticities are all positive and therefore we can conclude that induced traffic is not just displacement. This means at a national level either people take more trips by road and/or longer road trips when the national road network increases.

[29] These locations are equivalent to 'peri-urban' in New Zealand (Stats NZ, 2020).

[30] These roads would be classified as Major using the New Zealand One Network Framework (ONF).

What behavioural responses drive induced traffic?

This is a difficult question to answer. If we are looking at ex-post data then the methods utilised can only describe changes in aggregate metrics: either traffic flows on links, or total changes in VKT. They cannot unpick the micro-mechanisms of changes in route, origin, destination, mode, departure time, etc. Not surprisingly, given the challenges in answering the question, there are few studies in this area. Furthermore, researchers have used different approaches to try and answer these questions. Each method has its strengths and weaknesses. None give the perfect answer, and many questions remain unanswered.

Interviews with respondents before and after project opening about their own travel behaviour are one such method. A strength of this is that it addresses household behaviour directly. But this method needs to be undertaken soon after project opening, so will only represent a (very) short-term response. Pells (1989) reviews two such studies, the Rochester Way Relief Road and the York Northern Bypass, and Wallis (2009) reviews the Amsterdam Orbital Ring Road and the Newlands Interchange in Wellington (New Zealand).[31] Whilst all these studies are dated, they do reinforce the view that the largest behavioural responses are route change and trip re-timing. Where substitution is more difficult (mode change and changing origins and destinations), fewer travellers change their behaviour, or at least the change happens slowly. These data also reinforce the ex-ante modelling evidence that responses within modes are the most sensitive (eg, changes in route, changes in time of day, and for some discretionary trips, changes in destination). They also suggest that changes between modes, and trip generation arising from land-use change, are the least sensitive responses at least in the short term (Ortúzar & Willumsen, 2011, pp. 20–21). Unfortunately, these data, whilst describing how the induced demand comes about, do not tell us which behaviour changes lead to the largest change in VKT. For example, one trip switching from PT to car may generate more VKT than twenty trips changing route – if a small change in route occurs. It all depends on the length of the trips in the before and after.

Table 2.2 Behavioural responses to new road projects (adapted from Pells, 1989; Wallis, 2009; Dunkerley et al., 2018)

	Before After Surveys			
	Rochester Relief Road (England, 1988)	York Northern Bypass (England, 1988)	Amsterdam Ring Road (Netherlands 1990)	Newlands Interchange (Wellington, 1998) Commuting trips only
Change route	96.7%	89.9%	25%	10%
Change origin/destination	3.3%	5.7%	0%	0%
Change mode	2.7%	2.6%	Possible	2%
Change time of trip	23.9%	29.7%	29%	10%
New trip	9.8%	11.9%	0%	0%

In terms of allocating VKT to different behavioural responses, there are very few studies. Rohr et al. (2012) found induced traffic from the orbital motorway around Manchester to be around 15–17%, of which 4% was due to mode shift, 9% due to destination shift and between 2%–13% due to changes in demographics. They exclude re-assignment from their analysis of induced demand, focusing instead on what SACTRA termed ‘generated traffic’, which is traffic arising from everything other than changes in route. They also found that commuting length had increased by 10% on average. Duranton and Turner (2011) estimate that the induced traffic on the new urban inter-state highway links arise as follows: up to 29% from increases in commercial

31 Not an international study, but we include it here due to the limited number of studies examining this topic.

vehicles, up to 21% from migration to the city, up to 10% from re-routeing and up to 39% from changes in household behaviour. In our induced traffic framework these 'migrating' trips are those with new remote origins and new remote destinations, that is the bottom right-hand cell of Figure 2.2.

These numbers contrast quite strongly with the those presented in Table 2.1 and where the emphasis in traffic modelling points. In terms of VKT, re-routeing only constitutes a small proportion of total induced VKT, but in terms of those who change their behaviour, it is a major element. In the absence of other studies, it is difficult to be definitive about the core responses that underlie changes in VKT. However, it is clear that a new city resident will generate proportionally much more VKT than an existing resident making a small change in route. Similarly, behaviour change by households, particularly mode switching and to new destinations will likely induce substantially more VKT per trip than an existing trip that makes some adjustments to route.

What is not clear from Duranton and Turner (2011) is the treatment of background traffic growth and displacement of both city residents and economic activity. Arguably, the increase in commercial vehicle VKT (up to 29% of induced VKT) – which in their framework has been driven by increased economic activity that has been moved to the city following road investment (Duranton & Turner, 2012) – and the city residents who have migrated to the city (up to 21% of induced VKT) may constitute pure displacement in VKT terms. That is, up to 50% of the observed VKT may net out when looked at on a larger scale (eg, at the state or national level). This makes their analysis more in line with that of other authors such as Noland (2001). Noland also estimates a VKT long-run elasticity of increases in road capacity in metropolitan areas to be approximately 1.0. His model allows him to disentangle the pure induced traffic effects from underlying demographic changes. He estimates that 28% of the additional traffic arises due to pure induced traffic, and the remaining 72% due to demographic changes. Van der Loop et al. (2016) also attempt to disentangle background changes from pure induced traffic. They find that induced traffic (at the level of the Netherlands) is 25% of the background growth in traffic.[32]

If we consider the difference between long-run and short-run elasticities as representing different behavioural responses, we can get an impression of the importance of the different behaviours on induced demand. For US metropolitan areas Noland's short-run elasticity increases from 0.6 to 1.0 in the long run. That is, only 60% of the induced traffic effect occurs in the short run. A similar proportion is found by González and Marrero (2012) for Spain. Concas (2012) reports very different short-run and long-run elasticities, with only 17% of the induced traffic effect occurring in the short run. In the econometric methods used in these studies, the short run is defined as the first year of data (which is the opening year in each of these studies). With Concas, possibly the low short-run elasticity occurs because she uses highway capital expenditure which often occurs in years prior to project opening, whilst Noland, and Gonzalo and Marroero, use available lane-miles/lane-kilometres (which will occur after project opening). If we interpret the short-term responses as being transport responses wholly contained in the transport market (eg, changes in route, mode and time and possibly some changes in destinations of discretionary trips such as retail), and long-term responses to require a change in origin or destination of the home or work place (ie, the land-use response), then this would imply that the impact of changes in land use on induced traffic are potentially quite large.

Is there evidence of these changes? Key behavioural responses include changes in household location (eg, moving out of town – the city sprawl argument), changes in employment, and firms moving location. Again, there is only limited research on this topic. For fixed links, Tveter et al. (2017) identify that settlement patterns (households and firms) change as a consequence of the fixed link construction. For the 11 fixed links studied there is a range in the size of effect seen, from limited to quite large (up to a 32% increase in population against the counter-factual).

[32] Induced traffic comprises 3% of base year traffic, whilst background growth comprises 12%.

In the US, with respect to households, Baum-Snow (2007) estimates that a new section of the limited-access interstate highway system passing through a central city reduces its population by about 18%. Estimates imply that aggregate central-city population would have grown by about 8% had the interstate highway system not been built. This is over the period from 1950 to 1990. That is, the central part of the city is 26% less populated in 1990 than it would be had the city centre highway not been built. The would-be city-centre population choose to live in the suburbs instead. Potentially, this could have occurred by businesses crowding out residents from the city centre, as the cities grew. However, Baum-Snow (2010) shows that employment locations also de-centralise, so commuting distances do not change greatly. The implied conclusion is that the city centre highways led to increased city sprawl. This, in the induced traffic framework set out earlier and in Figure 2.2, are the changes in trip origins and destinations to more remote locations. These are the land-use change effects. For China, Baum-Snow et al. (2017) show similar effects with each radial highway displacing 4% of city centre population to surrounding regions, and ring roads displace about an additional 20%, with stronger effects in the richer coastal and central regions. A city that has sprawled Is very difficult to serve by PT and becomes very car dependent. This can have negative environmental and social consequences. Additionally, city sprawl builds path dependency into car dependency, in that new housing and business infrastructure will remain utilised for a long time to come. We look at evidence on differences in VKT per household resulting from city sprawl in the next section.

It is important to recognise that these city sprawl effects are not completely independent of policy. In countries where planning policy has more constraints, city sprawl effects are much more limited. In the Netherlands, for example, there is no evidence that investment in urban highways has caused urban sprawl (Levkovich et al., 2020). Interestingly, the van der Loop et al. (2016) elasticities of induced traffic at the Netherlands-level and those estimated at a US state-level are not remarkably different.

Does ‘induced’ city sprawl create VKT?

The economic growth literature referred to earlier (see Section 2.2,2) leads to an expectation that land uses will change following a transport investment. The evidence bears this out. In their review, for example, Kasraian et al. (2016) find that both road and rail investments lead to land use change: rail is typically more associated with changes in population; road is more associated with changes in employment, as well as being more associated with dispersed development that covers a larger land area. Related to this, road (and rail) investment can also lead to increased suburbanisation as households move further out from the centre (Baum-Snow, 2007; Baum-Snow et al., 2017). Businesses can also de-centralise (Baum-Snow, 2010). The extent of the urban sprawl is, however, a function of land-use policies (Levkovich et al., 2020). If road investment leads to more dispersed land use, the question then arises as to whether this leads to higher levels of VKT, and if so by how much.[33]

Straightforward comparisons of VKT by household suggest significant differences in levels of VKT depending on household location. In the UK, people living in urban conurbations drive a third fewer miles than the average person, whilst those living in rural towns and in the urban fringe drive nearly 50% more than average (Department for Transport, 2021a). In Austria, those living in Vienna and other large cities drive 20% less than the average Austrian (Federal Ministry of Transport, Innovation and Technology, 2016, Table 4.1). Litman and Steele (2022, Table 24, p. 64) conclude from their review that, typically, households in central areas drive between 10% and 30% less than those at the urban fringe.

The difficulty with such aggregate data is that it may disguise that households are self-selecting to certain parts of a city or region depending on personal characteristics, such as household composition (families

[33] It should also be noted that fringe development (or ‘sprawl’ as some commentators may call it), and policy, including transport policy to support it, may be acting to support economic factors that provide a stronger local economy. These arguments are not explored here, as the question here is: what is the role of road investment policy in causing or at least facilitating sprawl?

versus young versus retired households), income, and also preferences for certain lifestyles. That is, VKT per household may be a function of who is part of the household, rather than where they live.

In one of the most well cited and original studies in this field, Cervero and Kockelman (1997) examined trip making characteristics in the San Francisco Bay area. Here they found an elasticity of 0.063 to intensity. Intensity is a measure of density. This they view as small. Ewing and Cervero (2010) in their meta-analysis offer the view that travel variables are generally inelastic to the built environment. Any particular variable (eg, density) has only a small impact on travel demand, but the cumulative effect of different variables can become significant. Good urban design has multiple facets, and it is the combination of variables that influences overall travel demand. Their meta-analysis finds that VKT has an elasticity of −0.04 to household/population density. Of course, if less dense urban fringe developments typically do not have a good land-use mix and are difficult to serve by PT, then VKT per household will be higher. Duranton and Turner (2018) also find that urban density in the US only has a small causal effect on driving behaviour. A 10% increase in population density leads to a 0.7% to 1% decline in driving, all else being equal. They measure ‘urban density’ as the density of residents and jobs within a 10-kilometre radius of where a driver lives. They identify that residents and employment more than 10 km from a driver’s residence do not have a measurable effect on driving behaviour. Singh et al. (2018) quantify the relative contributions to VKT of the four main influences discussed in the literature: socio-demographic differences, built environment (including density), self-selection and social and spatial dependency. They examine household travel in the New York metropolitan area and find that the built environment (including density) only explains 12% of the demand for VKT.

In conclusion, urban form does have an impact on VKT, but not as much as might be thought from a straight comparison of average household trip making characteristics in different locations. Summarising, Ahlfeldt and Pietrostefani (2019) find an elasticity to density of −0.06 in their recent meta-analysis, and Litman and Steele (2022, Table 24, p. 64) in their review of the evidence conclude that elasticities in the range of −0.05 to −0.1 are probable (in isolation of other measures). They suggest this could increase by a factor of four if combined with other built environment factors. Some of these could be correlated with density (eg, mixed land-uses, proximity to PT). One thing to note is that this empirical evidence is predominantly from the USA, and therefore relates mainly to the US context: large, high-income, car-based cities.

One contextual suggestion is that offered by Kasraian et al. (2016), that the VKT effects are an interaction between the transport infrastructure networks (TINs) and land use (LU), which together can eventually constrain VKT growth. Their contention is that once transport networks and land use reach saturation points, improving either TINs or LU will only have marginal effects on VKT. If land use is at development saturation and transport networks are not, then any further land-use policy changes are likely to lead to transport changes.[34] Conversely, it will probably be transport policy changes that lead to land-use development if the transport network is saturated and land use development is not. Alternatively, if both markets are unsaturated then the lead can come from policy changes in either market.

[34] One implication of this channel of effect is that the speed of land development can affect the rate of VKT growth.

Table 2.3 Interaction of saturation levels for transport networks and land use on causation of VKT (reprinted from Kasraian et al., 2016)

	LU *before* development saturation	LU *after* development saturation
TIN *before* accessibility saturation	**High impact** if there is demand; • TIN is likely to follow the existing LU pattern and lead further development (e.g. early railways/tramways) • TIN can lead if it has significant technological advantage or is successfully applied as a tool to encourage further growth (e.g. highways stimulating growth in undeveloped areas)	**Potential impact**; • LU is likely to lead (e.g. mass transit introduced into congested city centres)
TIN *after* accessibility saturation	**Potential impact** if LU development constraints are removed; • TIN is likely to lead (e.g. encouraging LU developments by relaxing building restrictions in accessible preserved areas/city centres, development of highly accessible brownfield sites, reclamation of land around transport nodes)	**Marginal impact** unless an occurrence of: • A substantial change of LU policies (e.g. land leasing in Chinese cities after land reform) • Supportive transport measures (e.g. restrictive parking, road/congestion pricing, fuel tax, reduced fares or increased level of service) • A combination of the above (e.g. increasing service frequencies and higher density development around transport nodes)

Furthermore, if transport projects are to induce large land-use changes then there will be some interdependency between non-transport policy makers and private sector developers (OECD/ITF, 2014). Additionally, induced land-use changes evolving over longer timeframes will bring greater uncertainties as well.

How long does it take for induced traffic to appear?

Induced traffic effects will appear immediately but are also likely to continue to play out over a long time. The ‘after’ surveys for the results reported in Table 2.1 were often conducted within four months of the project opening. So, clearly some behavioural responses can occur quickly, most likely those contained wholly within the transport market (route changing, trip re-timing, mode switching and potentially trip frequency).

The longer-term responses which involve changes in ‘relationships’ or ‘contractual’ changes are likely to be associated with changes in ‘land use’. Some of the empirical work reports short- and long-run elasticities (eg, Noland, 2001; González and Marrero, 2012). These typically are a function of the lagged econometric specification, without needing to specify the time period under consideration.[35] The short-run elasticity typically seems to be around 60% of the long-run elasticity, so the implied ‘land-use’ element can be quite significant. Other studies just consider a long timeframe (eg, Duranton and Turner take a 10-year period).

Whilst neither Noland (2001) nor González and Marrero (2012) offer a commentary on the duration of the time it takes for the induced traffic effects to appear, we can apply their models to calculate the implied time. Using the González and Marrero (2012) model and the data in their paper for Catalonia, we can calculate the implied duration of time over which the ramp-up of induced traffic occurs.[36] This is presented in Table 2.4

[35] In a model where a one-year lagged term has a coefficient λ and the non-lagged parameter (the short term) is γ, then the long-term elasticity is given by $\lambda/(1-\gamma)$ (see eg, Noland, 2001).

[36] Noland does not describe his underlying data, so we cannot ‘back out’ the implied duration from his model, but we expect it to be like González and Marrero.

Here we can see that in the first year almost 60% of the induced traffic effects have occurred, with almost 99% having occurred five full years after opening. The effects of induced traffic do not appear to be exhausted until after almost ten years. We do have to bear in mind these timeframes are a consequence of the model – in some situations it could be possible that induced traffic effects are exhausted more quickly and at other times take longer. The model results are consistent with Hymel (2019), who finds that within five years, new road capacity in US metropolitan areas has been completely absorbed and road speeds have returned to pre-investment levels.

With respect to Norwegian fixed links, Welde et al. (2019) find that the traffic forecast error keeps increasing for at least five years (their analysis does not extend beyond five years). One reason for this is that the ex-ante forecasts assume no land-use change, and if land-use change is gradual over time then the ex-ante forecasts will get progressively worse as time elapses. In this Norwegian context we can therefore interpret that land uses continue to change for a minimum of five years post-opening.

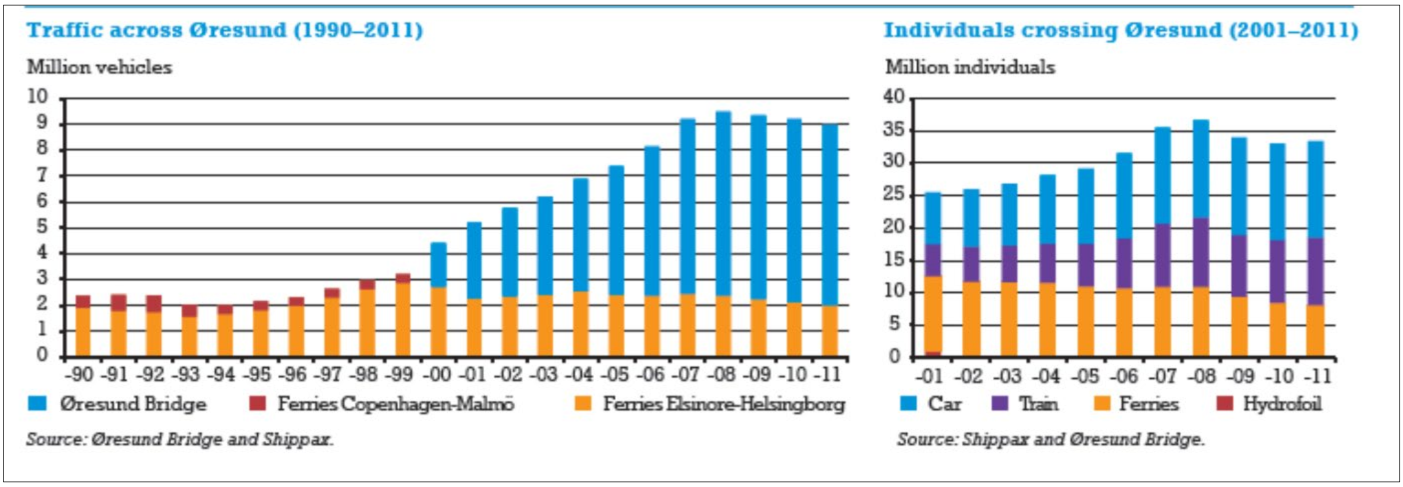
If we think about the difference between short-run behavioural responses (within the transport market) and long-run responses (involving land-use change), then these ramp-up durations are also comparable to the findings of Tveter et al. (2017). They identify that settlement patterns experience several years of inertia before they begin to change. In some cases, they are still changing and are not fully exhausted 15 years after the opening of the fixed link. For the Øresund Crossing discussed earlier, which has been associated with significant structural change in Malmo in particular, we can see that the ramp-up effects of induced traffic flows on the crossing appear exhausted eight years after opening. That does not exclude further land-use changes after eight years, but rather the impact on traffic flows over the strait become indiscernible from background noise[37] after that point (from a visual inspection at least).

[37] Which for the Øresund Crossing included the global financial crisis.

Table 2.4 Estimated cumulative proportion of induced traffic by year after opening (adapted from model of González & Marrero, 2012)

Full years after opening	Percentage change in demand	Cumulative proportion of induced traffic
0	0.00%	0.0%
1	0.13%	57.1%
2	0.18%	81.6%
3	0.20%	92.1%
4	0.21%	96.6%
5	0.22%	98.6%
6	0.22%	99.4%
7	0.22%	99.7%
8	0.22%	99.9%
9	0.22%	100.0%
10	0.22%	100.0%

Figure 2.7 Traffic and person flows across the Øresund Strait (reprinted from Øresund Trends (2012)



What policies have proven effective in reducing higher VKT on 'new and improved roads'?

Our economic framework would suggest that policies aimed at adjusting the generalised cost of road transport will be required to mitigate induced traffic. This could be directly via charges or taxes, or indirectly by making the relative cost of alternatives to the car cheaper (eg, PT investment), or through regulation (eg, of the land market).

There are only a handful of studies that we can draw off here, primarily because the international ex-post evidence base has mainly focused on quantifying the effects of induced traffic, rather than their mitigation measures. Having said that, some recent work quantifying these effects allows some interpretation of the success of mitigation measures. Firstly, consider road pricing or road tolling: on fixed links, and from the evidence presented earlier, it is apparent that road tolls significantly dampen the induced-traffic effect. Economic theory would predict this, as the cost change is significantly reduced through road tolling. We would expect other pricing measures (eg, increases in fuel taxation) to have similar impacts on induced traffic levels. Looking at cities, Garcia-López et al. (2022) estimate that the scale of induced traffic in cities with existing road tolling/pricing is 85% lower than in cities without tolling/pricing. Secondly, consider PT.

Here Garcia-López et al. (2022) find that induced-traffic effects in cities with existing rail and metro networks are approximately half the size of those in cities without such networks. Bucsky and Juhász (2022) find an elasticity of 0.5 to new road capacity in Budapest (approximately half that of US metropolitan areas). Budapest is a city where PT has a large share of total travel. Turning to whether PT projects can act as mitigation measures to the induced-traffic effects of road projects, Duranton and Turner (2011) consider that they do not. However, buses are the typical form of PT in US cities, and are also usually subject to road congestion. In contrast, metros and rail networks are not subject to road congestion, and Garcia-López et al. (2022) find that rail and metro projects reduce road VKT. Finally, consider planning policies: contrasting the findings of Levkovich et al. (2020) for the Netherlands with those of Baum-Snow (2007) for US cities, and Baum-Snow et al. (2017) for Chinese cities is enlightening. In the Netherlands where city-fringe development is tightly controlled, there is no evidence of urban sprawl caused by highways. In contrast, in the USA and China, where there are fewer controls, there is strong evidence that investment in highways in cities leads to urban sprawl.

Is the industry correctly forecasting the induced-traffic effect?

The ability for economists to correctly forecast the induced-traffic effect is limited. There is both a need to forecast the 'do-min' and the 'do-something' correctly. Ex-post analysis has typically focussed on the accuracy of the latter.

On one hand there is an argument that good quality transport modelling and appraisal gives rise to accurate transport forecasts. England's ex-post evaluation programme shows it is possible to make good forecasts of traffic flows five years post-opening (Highways England, 2019, p. 4). The evidence above would suggest that almost all induced-traffic effects would have appeared within five years, so we can conclude that it is possible to make good estimates of induced traffic. This is contingent on transport modelling guidance following good practice: wide area models that capture all re-routeing options, mode choice, and destination choice (Highways England, 2019). Using US and European data from 1,291 projects, Hoque et al. (2022) find that, on average, opening year traffic forecasts would have been correct had they been able to forecast the 2008–2009 recession. However, this disguises significant variations in traffic forecasts with the 5th and 95th percentiles about +/−37% of the median. They also found that traffic forecast accuracy has improved over time and were more accurate for higher volume roads and for studies that used transport models rather than an extrapolation of trend. Unfortunately, all too often, transport modelling does not follow good practice and significant errors in the transport forecasts occur (Bain, 2009; Cruz & Sarmento, 2020; Kelly et al., 2015; Nicolaisen & Driscoll, 2014).

There are two notable caveats to the assertion that following good transport-modelling practice will give good post-opening traffic forecasts. Firstly, expected background economic conditions need to be realised, and secondly, the projects should not involve large cost changes that cause significant structural economic changes occur. With respect to the former, Highways England (2019) in their analysis of 87 post-opening evaluations (POPE) found that most of the discrepancies in post-opening flows were due to the economic downturn during the 2008–2009 recession. Transport modellers, like most of society, did not see the 2008-2009 recession coming. How to incorporate economic uncertainty into transport project analysis remains an ongoing policy challenge.

The second caveat relates to large cost changes and potential structural changes to the economy. We will look at fixed links first. The Øresund Crossing and the Great Belt fixed link between Zeeland and Funen in Denmark both led to induced-traffic levels that exceeded forecasts. Initially the Øresund Crossing forecasts were 20% too low due to higher-than-anticipated tolls on the crossing, however, the structural change in the housing market in Malmo led to traffic flows exceeding forecasts within three years. For the Great Belt fixed link, traffic flows were 70% higher than forecast in the first year. This was attributed to higher levels of economic activity (business trips), more leisure trips and longer commutes (Welde et al., 2019). Forecasting the land-use changes that drive these high levels of induced traffic is much more difficult than predicting behavioural change within the transport market. Arguably, most of the behavioural changes of relevance to the 87 POPE projects mentioned above were contained in the transport market. This is because they are located between cities or on the periphery of towns and cities, and not in congested city centres. Errors, however, still occur. For 38 fixed link projects, Welde et al. (2019) find that the difference between predicted and realised opening year flows is low. However, the average error in the traffic growth doubled in the second year, and tripled in the third year to something quite substantial (39% more traffic than forecast on average).[38] Given that standard Norwegian appraisal takes settlement patterns as fixed (Tveter et al., 2017), it seems intuitive that the lack of land-use change modelling in the appraisal has led to a significant underestimation in induced-traffic effects.

Counter to these arguments that good quality transport modelling can give rise to accurate predictions, Sloman, Hopkinson, and Taylor (2017) find that whilst traffic flows from a random selection of nine POPE projects opening between 2002 and 2010 are on average within 7% of predicted traffic flows immediately post-opening, traffic growth on these projects exceeds background growth on eight of the nine projects examined. This excess growth led to an increase in traffic flows of between 5%–10% over three to eight years post-opening, with the largest increase being 20% higher. They attribute this growth to induced traffic, as their ancillary analysis discounts other explanations (eg, expected higher background growth rate on the upgraded road).

These higher growth rates are likely indicative of land-use change induced by the project. The question then arises as to whether this growth is displaced or not. Sloman et al. (2017) case-studied four of these POPE projects in detail, finding in all four that there was evidence of a highly car-dependent pattern of land development occurring with housing developments in the countryside, business parks and retail parks. What their analysis does not discuss is whether these were new developments or displaced developments. Given that they are housing and associated service functions (retail parks) it is likely that they are displaced. Therefore, these local traffic increases will be partially offset by reductions elsewhere in the counterfactual (do-min). Potentially, they may even completely net out (there would have been a similar car-dependent set of developments elsewhere in England had the road not been built). An alternative to the development simply displacing a development of a similar nature elsewhere, the road project could lead to a more car-dependent form of living (as with the US urban sprawl arguments). In the latter case they will not net out, and the increased ‘sprawl’ has led to an increase in VKT. Only modelling including land-use feedbacks would be able to address this question.

Turning to ‘do-nothing’ forecasts. The accuracy of these is important because if traffic levels would have been lower than forecast in the ‘do nothing’, then induced traffic levels would be higher (even with accurate post-opening forecasts). The Highways England (2019) POPE analysis indicates an overestimation of traffic flows, which they attribute to not anticipating the 2008–2009 recession. Nicolaisen and Næss (2015), using an older dataset that in the main pre-dates the 2008–2009 recession and includes 35 projects from both England and Denmark between 1970 and 2010, consider the overestimation of traffic flows as being more systematic. They only identify one project where traffic flows were below those forecast. The average overestimate in the ‘do-nothing’ is 7% (pre-opening). This does not seem particularly high, but this must be considered the starting point for traffic flows in the ‘do-nothing’. Conceptually, lower traffic flows than expected in the ‘do-nothing’ pre-opening year counterfactual could be associated with a different, more concentrated pattern of development than had been expected in the original ex-ante work. This trend may have continued over the forecast period. Thus, the level of induced traffic brought about by the scheme could have been much higher. At this moment in time, we do not have the empirical evidence to support such conjectures.

[38] On the basis that the post-opening year error was 13% above forecast flows on average.

An added complication in any modelling is the changing underlying nature of the system being modelled. These are challenges that are being faced at present (eg, more working from home and internet-based meetings).

Insights for the development of the tool:

#8. Induced traffic effects are very heterogeneous, from extremely large uplifts to very small ones. In certain environments (and in conjunction with background growth), they can completely negate all new capacity, returning traffic conditions to pre-investment levels. The change in capacity (eg, lane-kms) is not always a good indicator of the likely level of induced traffic.

#9. The elasticities to additional capacity (eg, lane-kilometres/lane-miles) are sensitive to the metric that is being considered. Thus, a US urban elasticity of 1.0, as in Duranton & Turner, is not comparable to a European urban elasticity of 2.0, as in Garcia-Lopez et al. They are also contingent on the average base conditions of each of the cities. Care will be needed to transfer such elasticities between locations.

#10. It is difficult in empirical ex-post analysis to distinguish between background growth and induced traffic. Where attempts have been made to distinguish between the two, it seems that induced traffic can be about 25% of background traffic growth.

#11. Significant displacement impacts associated with population movement imply that local-level or city-level changes in induced traffic are larger than those at a wider area level. From a GHG perspective both measures are likely to be necessary (eg, if both cities and regions/nations have GHG targets).

#12. The behavioural responses that are most important for typical economic evaluations (re-routeing and re-timing) do not appear to be large contributors to changes in total VKT. Here, the evidence points towards changes in household behaviour (mode choice) and land-use responses (destination choice, moving house, economic development) as large contributors to VKT effects. However, studies are limited and more research is needed in this area.

#13. Based on the short-run and long-run elasticities reported in the studies, first-year impacts seem to be in the order of about 60% of the total induced-traffic effect, with the remaining effects almost exhausted within the next five years, although some induced impacts have been seen to occur for many years after that.

#14. Based on differences between short-run and long-run elasticities, land-use change behaviours look to be important for induced traffic more so than they are with typical economic appraisal/CBA.

#15. Separating out displacement effects and identifying the change in VKT due to displacing economic activity and housing has not been addressed in any of the literature we have reviewed.

#16. Best-practice transport modelling is likely able to accommodate modelling of induced traffic due to transport behaviour change. However, widespread ‘best practices’ have been questioned by several authors, with numerous reviews identifying traffic forecasting errors.

#17. Modelling the feedback between transport and land-use change is challenging for projects that deliver structural change. There is also the challenge of other structural changes occurring that are not caused by the transport market, but which do affect transport.

2.3.2 New Zealand and Australian road evidence

No specific, publicly available research into the relationship between VKT and road expansion/improvement was found for New Zealand, nor for Australia. The following discussion instead presents studies and data related to VKT and modelling results with VKT implications.

New Zealand studies

General New Zealand studies into VKT patterns

If, as discussed in the previous section summarising international evidence, roading expansion is to lead to extra VKT, then the pathway is likely to be via changes in transport costs and changes in socio-economic factors. There are New Zealand and Australian studies into factors determining – or at least explaining – VKT patterns.

Research at the national level shows similar influences on VKT to those found internationally, namely a mix of economic and socio-demographic factors. No tests of the effect of lane-kms were reported in the two national studies mentioned below.

- Changes in private vehicle mileage, as estimated from household travel surveys and analysed as changes between 1998 and rolling three-year periods for the years ending 2005–2013, could be largely explained by the changes in the age and income composition of households or by changes in the size of the population, except for an 'unexplained' short-lived decline coinciding with the global financial crisis (Stroombergen et et al., 2018).[39]
- A time-series analysis of changes in quarterly national light-passenger VKT was shown to be largely explained by changes in GDP and petrol prices. Extending this study to VKT by all road vehicles, the key explanatory variables were population and petrol prices (Albuquerque & Morrison, 2022).

Earlier research at a regional level also reveals a mix of economic and socio-demographic factors. While it now includes urban density, the effect of lane-kms appears to be untested.

- A regional economic panel data model of travel demand between 2004–2014 for 12 regions has, as explanatory variables for regional VKT, a mix of regional GDP, population size, number employed, number of households, average household income, the average age and population density[40] of the cohort population, the industrial sector mix of the labour force, mode share and interregional freight flows, and people migration (Stephenson, 2016).

The linkage with a VKT-to-road expansion relationship is that a road expansion will likely reduce travel costs and could potentially change the spatial mix of people and activities that otherwise would have emerged. An insight into the complications of this potential interaction comes from a run of the Stephenson model (Stroombergen et al., 2018), whereby a higher migration of people to Auckland and Wellington was assumed (and hence a lower population elsewhere). The simulated outcome was a higher national VKT, despite the migrants (by assumption) adopting the lower VKT/household of Aucklanders. The VKT increase occurred (in the model) because the migrants from other parts of New Zealand were also assumed to have attained a higher employment status and income over Aucklanders. It was this latter effect that dominated their travel behaviour and hence VKT effect. This is not to say that such a simulated shock will indeed occur, but rather, it is a warning that there are multiple interactions at play if extra roads attract more people to cities, whether to inner cities or to the fringes of cities.

New Zealand VKT in transport models and appraisals

Information available at a project level largely consists of the modelling undertaken within the business case before a project.

[39] These results do not preclude that other factors, such as increasing urbanisation, were affecting VKT, but it does suggest the change was largely channelled through the factors included in the model, most likely income (ie, urbanisation leading to higher incomes).

[40] Measured as population per km^2 for regions, ranging from 1,217 people per km^2 (Auckland) to 94 (Upper South Island).

In theory, local modelling on induced demand should follow closely the recommendations of NZTA, which funds state highways and the joint funder of most local roads. This recommendation is reported in the box below and a discussion follows in Chapter 3 as to how widely this is applied. For now, it is noted that an early study of New Zealand practice for induced demand (Wallis, 2007) reported that New Zealand modellers were commonly employing a VTM method by, first, estimating the change in trip demand between zones using regional models or, in a few cases, elasticity methods and then, using a 3-step or 4-step transport model to estimate trip redistribution and sometimes mode shift and retiming. The estimate did not include any change in trip generation. No estimate was available at the time of the study (or since) on the effect of employing a VTM rather than the more conventional FTM.

The NZ Transport Agency Waka Kotahi (NZTA) approach

*NZTA's MBCM defines **induced demand** as such: 'Pure induced travel demand relates to entirely new trips that would not have been made without the activity or supply. For example, if an activity (or collection of activities) improves access to a shopping location, a person who in the 'do-min' scenario would make an average of one trip to the shop per week may make an average of two trips to the shop.'* (New Zealand Transport Agency, 2020, p. 30).

*And goes on to define **supressed demand** as 'effectively the opposite of induced demand. It is when people would like to undertake trips, but the travel impedance is too great for the trip to occur. It is also when people who previously made a trip decide to no longer undertake that trip because travel impedance increased (for example, congestion increases).'*

Excluded from this definition are trips within the study area that result from redistribution, reassignment, mode shift or travel-time shift.

However, given the potential for these changes in the pattern of existing trips (in a future base-case sense) to cause more VKT and hence (assuming constant ICE vehicle share) an increase in GHG emissions, the induced extra mileage associated with these trip changes is also of interest to this project.

It is also noted that interpretation of 'induced demand' is varied within the business cases and the modelling for New Zealand transport projects.

NZTA provides guidance as to when a VTM approach is to be preferred over the standard FTM approach. These situations include large roading projects in large urban areas with >100,000 population (p. 23, including other guidance) and where there are congested networks and the potential for induced/generated traffic (p. 133). Guidance on measures of congestion is also given (p. 273). The MBCM notes that the default mode for almost all regional transport models in New Zealand will be to produce variable trip matrices (p. 254).

The other issue is whether the modelling of induced demand can be accurate? It seems that local models do have the capability to predict traffic flows. A re-run of the 2006 modelling of traffic flows in Wollongong, Australia, showed that both the original model and a more recent and sophisticated model could simulate the observed traffic flows in 2016 – if they were input with the land-use patterns that existed in 2016. In other words, the accuracy of traffic forecasts was shown to be largely dependent on the accuracy of land-use assumptions (Smith, 2016). It is not known whether the models to be discussed below have been put to a similar test but there is no reason to believe that these models are any less professionally constructed and run.

Ex-ante studies

Looking at modelling approaches to major projects, the following differences between a VTM and a FTM approach have been reported in the business cases for some major road projects in recent years, offering at least some perspective on expected induced demand and diverted demand. But it is worth keeping in mind that these models did not attempt to estimate land-use changes that might have eventuated from the projects.

Table 2.5 Induced demand expected in ex-ante modelling of New Zealand road projects

Project	Where and when	Modelling	Results (and source)
Peka Peka to Otaki, Wellington	13-km 4-lane Wellington northern motorway extension (+52 lane-kms), opening late 2022	VTM (using the Wellington Transport Strategy model and a Kapiti Traffic Model)	2012 run for 2031 projection: +1% number of trips, relative to DM baseline (as measured as trip ends, including the effects of land use developed, and any mode shift expected) (Opus International Consultants Ltd, 2013a)
Mackays to Peka Peka (M2PP), Wellington	18-km 4-lane Wellington northern motorway extension (+72 lane-kms), opened February 2017	VTM (as above)	2012 run for 2026 projection: +12% vehicles and **+4–5% VKT,** relative to DM baseline. Mainly redistribution of existing short trips to new origins and destinations in the mid-section but also some mode shift away from bus/train combined trips to/from Wellington and trip re-timing. (Beca Ltd, 2012)
Transmission Gully (TG), Wellington	2-km 4-lane Wellington northern motorway extension (+108 lane-kms), Porirua to Mackays Crossing, opened March 2022	VTM (similar to above but with a different project traffic model)	2011 run for 2026, 2031, 2041 projections for region: +0.1% vehicles and **+1% VKT**. But localised increases including: +8–10% more vehicles north and south of the new road. Some induced demand comes from less-than-otherwise PT. Further land use development to be induced by the road is acknowledged and while not quantified has been estimated to be within the capacity of the road. (Sinclair Knight Merz, 2011)
Basin Bridge, Wellington	A bridge in central Wellington that has not gained approval	VTM (Wellington regional model with Saturn traffic model, trip constraints applied unknown)	2013 run for 2021 projection: <0.1% vehicles induced. Induced VKT not reported. (Opus International Consultants Ltd, 2013b)
Petone to Grenada (P2G), Wellington	New 10-km road that has not gained approval	VTM (but total number of trips fixed)	No 'pure' induced demand due to fixed total trips. But 2/3 of trips on P2G expected to come from reassignment and 1/3 from redistribution, with the latter reported as being at the upper end of the observed New Zealand range and agreed by the steering group to probably take 10–20 years to be fully realised. A sensitivity test with a potential land development that would likely be influenced by the new road was estimated to cause an extra 13% traffic at 2031 PM peak period[41] on the new road. (Ford & Rabel, 2016)
Waterview, Auckland	2.4-km SH20[42] tunnel that completes motorway ring road, opened July 2017	Variable destination modelling	2010 run for 2026 projection: 7% of vehicles results from combined redistribution, mode shift and time shift. (Beca Ltd, 2010)

[41] The PM peak period for this project was 16:30−17:30 and the AM peak was 07:30−08:30.

[42] New Zealand state highways are numbered SH1, SH2, etc.

Project	Where and when	Modelling	Results (and source)
Puhoi to Warkworth, Auckland	18.5-km 4-lane SH1 including a bypass of Warkworth, fully opened sometime 2023		Not explicitly modelled (in 2013 traffic assessment report) but assumed to add 1% per annum to traffic growth in corridor. (Bell, 2013)

Ex-post studies

Schiff et al. (2017) examined ex-post transport project evaluation in New Zealand and report 49 NZ Post Implementation Reviews undertaken from 2008-2016, undertaken one to three years after opening, and one more extensive study. The larger study was the Enhanced Post Implementation Review of the Northern Gateway road (Stroombergen & Barsanti, 2012), where a new toll way opened in January 2009, with AADT of around 12,000 to 18,000 and average weekday savings of 14.5 minutes, but the report concludes there was ‘no evidence of induced traffic’ (although the associated toll did cause traffic diversion, as discussed below).

In lieu of a lack of statistical evidence, the following observations are made about the short-term patterns of VKT following the opening of major new state highways in recent years. But, first, a warning about the data.

VKT is measured/estimated in two ways in New Zealand (Ministry of Transport, 2019). An annual Warrant of Fitness check for all vehicles provides a measure of odometer readings, and hence a measure of total VKT can be collated by the Ministry of Transport (MoT). Using the site of the testing station as an indicator of the predominant use of the vehicle also enables an estimate of regional VKT. Alternatively, vehicle counts are regularly taken on New Zealand state and local roads, including with a light/heavy vehicle split on state highways, and estimates can be derived from these counts using road lengths and transport models, which are reported by NZTA. For 2017/18, the MoT estimate for New Zealand was 48,047 million km and the NZTA estimate was 46,554 million km. There is no consistency in the differences between the measures at a regional level although some discrepancies (but not all) are readily explainable. Both sources are problematic when it comes to regressing regional (or sub-regional) VKT estimates versus lane lengths.

NZTA reports annually the road length for state highways and local roads, by districts and regions, and by road length and lane length – although the roads reported may not be open at the time they enter the database. Also reported are the length (road and lanes) of new state and local roads added each year.

The changes in VKT following the opening of major new roadways recently are tabled below. These results do not measure causation but do provide perspective on the short-term induced effects of major new roads.

Table 2.6 Extra VKT following the opening of recent New Zealand road projects[43]

Project	Where and when	Short term AADT and/or VKT patterns (NB not necessarily caused by road opening)
Mackays to Peka Peka (M2PP), Wellington (Source 1)	+72 lane-kms (+10.9% of regional state highway) opened February 2017	**+2.8% VKT** extra Wellington (ie, above average growth) in June 2017/18 (a regional VKT measure)
Cambridge, Waikato (1,2)	+64 lane-kms (+1.8% of regional SH) opened December 2015	AADT on southern end of new section +15% higher than usual in next three years (a screenline measure) **+4.8% VKT** extra Waikato (ie, above average growth) in June 2016/17 (a regional VKT measure)
Waterview, Auckland (3)	New 2.4-km tunnel SH20 opened July 2017, with an additional lane (~7.5 km) on the east of the tunnel and widening to the west. Total of around +41 km.	VKT on Auckland motorways approx. **+0.2%** in weeks after opening

Land-use change

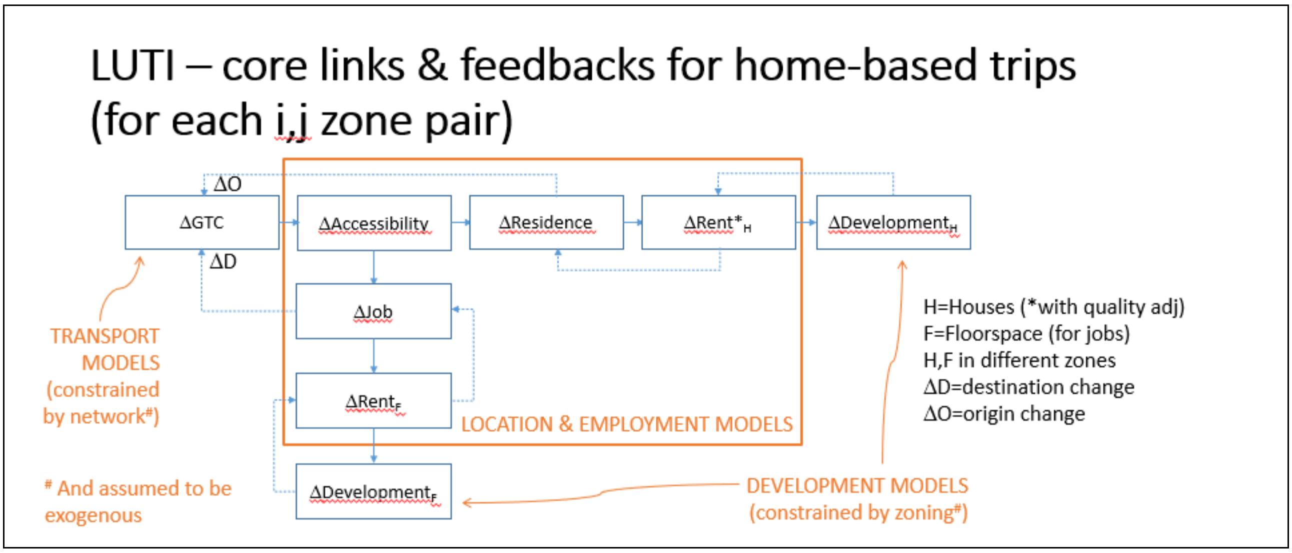
Before expanding on land-use effects, Wallis (2007) noted that 'Road provision is a necessary but not sufficient condition to attract urban fringe development: enhanced road access to/from an area will tend to increase the accessibility and hence attractiveness of a fringe area for new development' and hypothesises that any such enhancement would increase the VKT for the metropolitan area but does not provide any New Zealand evidence of this effect. He does suggest, though, that employing a land-use and transport-interaction model would increase the estimated <u>benefit</u> (not necessarily VKT) of a major transport scheme but likely no more than 5%–10%. However, this is only one opinion and remains a matter of conjecture.

There are no known ex-post studies of the land-use effects of major New Zealand road projects. Of a more general nature, Stroombergen et al., (2021) show that property rents are closely linked with accessibility and hence transport costs. Otherwise, estimates of land-use effects come from ex-ante models.

The Auckland Land Use Transport Interaction (LUTI) model gives an example of the types of feedback mechanisms that exist in land-use models to potentially measure an effect on VKT. These include accessibility affecting residential rents, which may prompt more development – subject to a zoning constraint – which in turns affects rents, the number of residents and the number of trips, and so on in a circular process. Likewise, accessibility of businesses will follow a parallel channel (Feldman et al., 2009). Note that OECD/ITF (2014) report that LUTI models track spatial redistribution of activity rather than net generative effects.

[43] Sources: (1) Beca Ltd (2012) (2) https://www.nzta.govt.nz/planning-and-investment/learning-and-resources/transport-data/data-and-tools/ (3) Hooper (2018).

Figure 2.8 Core links and feedback in a Auckland LUTI model (adapted from Feldman et al., 2009)



A similar but more general approach to land-use modelling can be gained by the use of spatial computable general equilibrium (SCGE) models, with such models providing a more extensive feedback mechanism. In particular, amongst other things, the SCGE model allows for more extensive responses to price changes, including transport costs, which results in a more flexible land-use response (Simmonds & Feldman, 2011).

One application of a SCGE was that of Byett et al. (2017). Although not specifically considering VKT effects, the population changes (ie, land-use changes) estimated for a major inter-regional travel-time reduction were a very modest employment increase, but significant redistribution of employment between zones (in this case, more jobs to Auckland than in Hamilton and Tauranga).[44]

Unfortunately, these results may be an artefact of the model assumptions, and of the project circumstances. But the results do provide perspective on the issues and also suggest that more research is required to forecast transport effects on land use.

Mitigation

The opposite of inducing and diverting traffic to a new road is the suppression and diversion of traffic away from an existing road. Increasing toll rates provide one means to achieve this suppression (see section 2.3.1 for international evidence). The following combined suppression/diversion rates were reported by (Beca Ltd, 2014) for a series of changes in New Zealand tolls, including one toll reduction. These confirm that large shifts can be quickly achieved on a road link when large changes in travel costs occur but, unfortunately, provide little direct evidence of what it takes to reduce (or increase) VKT on a regional basis.

[44] A similar small land-use effect was found with a similar Swedish model although they concluded that the size of the land use response was limited to an assumption that urban planning/zoning had been treated as fixed (Börjesson et al., 2014).

Table 2.7 Traffic-volume changes after New Zealand toll changes

Project	Where and when	Source	Results (and source)
Auckland Penlink	Charge of $0.50 toll on 4-lane, divided expressway between East Coast Road and Whangaparaoa Road	VTM modelling	Traffic volume suppressed by around 8% for each $0.50 toll increase (Beca Ltd, 2014)
Tauranga Harbour Bridge	2001 removal of $1.00 toll	AADT	Traffic volume increased across harbour, including alternative routes, by 15% within six months (Murray, 2007); considered to be equivalent to a 27% combined suppression and diversion effect (Beca Ltd, 2014)
Tauranga K route	2012 toll increase from $1.00 to $1.50	AADT	Traffic reduction of 13% in following year (relative to growth trend) (Beca Ltd, 2014)
Auckland Northern Gateway	New 2009/10 toll of $2.00	Not stated	Traffic diversion of approx. 20% (Beca Ltd, 2014)

Note: Dollar values are in NZ$

Forecasting

Before leaving this section looking at the (scant) evidence of induced demand in New Zealand, it is also worth questioning what scope exists in New Zealand for forecasting variable travel demand.

The state-of-the-art methods to predict the transport effect on land use are SCGE models or LUTI models.[45] SCGE models do exist in New Zealand[46] but they are not widely used – if at all – in transport appraisals and may not be suitable in their present structures. Only Auckland Council currently has a LUTI model (McKibbin & Sewell, 2022).

The other method to predict VTMs is with regional models of residential and industrial uses of land. These exist in New Zealand for five large centres: Auckland, Wellington, Christchurch, Palmerston North and Tauranga (Smith, 2019), and are being used to provide alternative VTM scenarios for transport models (Wallis, 2009). Elsewhere, an alternative VTM scenario must be devised in a customised fashion.

By inference, there are thus many areas in New Zealand where VTM modelling and land-use changes would require customised forecast methods.

Australian studies

In a review of induced demand for the Victorian Department of Transport, Wallis (2009) reports short-term induced demand for four major Australian projects, summarised below. It was noted that traffic increases were higher on the road links compared to the wider set of screenlines that are reported below and that changes reported were largely over three months, with longer-term changes being more gradual and difficult to distinguish from underlying trends.

[45] This puts aside the unresolved issue as to whether such models are accurate.

[46] Principal Economics (https://www.principaleconomics.com/models/cge/) and NZIER (https://www.nzier.org.nz/publications/tag/cge-modelling) have regional CGE models and a customised model was built for the Auckland-Hamilton-Tauranga region (Byett et al., 2017).

Table 2.8 Extra VKT following the opening of Australian road projects (adapted from Wallis, 2009)

Project	Where and when	Short term AADT and/or VKT patterns (NB not necessarily caused by road opening)
M4 Western Motorway, Sydney	Opened May 1992	+7% AADT (ie, above average growth) within three months, with up to 50% mode shift from rail (a screenline measure)
M5 Motorway, Sydney	Stage 1 opened 1993 Stage 2 opened 1996	+6% AADT (ie, above average growth) (a screenline measure) +7% AADT (ie, above average growth) (a screenline measure)
Harbour Tunnel/ Gore Hill Freeway, Sydney	Opened 1993 (principally)	+3% AADT (ie, above average growth), likely to be mostly due to shift from rail (a screenline measure)
Melbourne South East Arterial	Opened 2001	Net induced AADT judged to be zero, although unadjusted was +18% AADT. Relatively small-time savings occurred and CBD parking constraints existed (a screenline measure)

The mode shift from rail reported above was confirmed for Sydney's M4 by Zeibots and Petocz (2005) and for Sydney's Harbour Tunnel and Gore Hill Freeway by Mewton (2005).

There appears to be little publicly reported research into longer-term induced demand in Australia.

Insights for the development of the tool:

#18. There is very little New Zealand research on induced demand to apply so reliance will be required on the transfer of international research.

2.3.3 Demand elasticities

An alternative to full, 4-stage modelling is to estimate the change in demand – in this case VKT – to changes in factors such as lane-kms or GTC. This approach, an incremental approach, requires a database of elasticities appropriate for a range of situations. A substantial database of transport elasticities does not exist in New Zealand and often the results from offshore databases, themselves variously incomplete, are transferred as applicable to New Zealand.

The elasticities approach works from a change in quantity demanded being considered as a direct function of a causal variable. The two common applications of interest here are: the responsiveness of VKT to change in lane-km (ie, a lane-km elasticity), and (b) the responsiveness of trips to change in GTC (ie, a GTC elasticity) – of which the change in journey time component of GTC will typically be key.

There is no (known) research in New Zealand or Australia that derives local lane-km elasticities. Thus, reliance must be placed on the international research discussed in 2.3.1. To the extent that this is appropriate is an issue requiring further research – we will discuss this in Chapter 4.

There are generalised cost elasticities being applied in New Zealand. Specific elasticities, which are assumed to capture all behavioural responses including, for example, trip retiming and land-use changes, are recommended within the MBCM, are extensively discussed within a parallel research project (Torshizian et al., 2023, in preparation) and these results are summarised here (in Chapter 4.3). It is noted that a cost-elasticity approach is suited to point-to-point travel, as is the case with rail travel (Worsley, 2012), but is less suited to urban environments where interdependent road and mode networks complicate the calculation of responses and net effects.

Whatever the price elasticity applied turns out to be, the following matters are relevant for the use of elasticities within an induced VKT tool (MBCM, p. 38; Department for Transport, 2020b, p. 60; Wallis, 2007).

Insights for the development of the tool:

#19. Elasticities applied to zone-pairs require zones to be established (or assumed) and the calculated changes in the number of trips would then need to be used with average route lengths to estimate the change in VKT.

#20. The functional form for the relationship is commonly applied as a power function, which gives the percentage change in trips as a fixed (negative) proportion (which is the elasticity) of the percentage change in GTC. Any tool would require a user input or an assumption about the total base case trip-cost between the zone pair (to then calculate a percentage change).

#21. An alternative functional form is an exponential equation which replaces the percentage change with the absolute change in GTC. This introduces the question as to which function to use. DfT (p. 57) recommend the use of further choice functions if the exponential equation is to be used. Alternatively, the power function could be adjusted to have an elasticity that varies by trip length.

#22. The incremental nature of each formula implies that the number of trips can increase, as opposed to the VTM approach where the number of zone-to-zone trips may or may not be constrained – the extent and ramifications of the difference between the two methods requires further investigation.

#23. The responsiveness is likely to differ during periods of the day and this may vary by context. Any tool would require a user input or an assumption about the period during the day expected to be most sensitive to travel cost.

2.4 Tools currently available

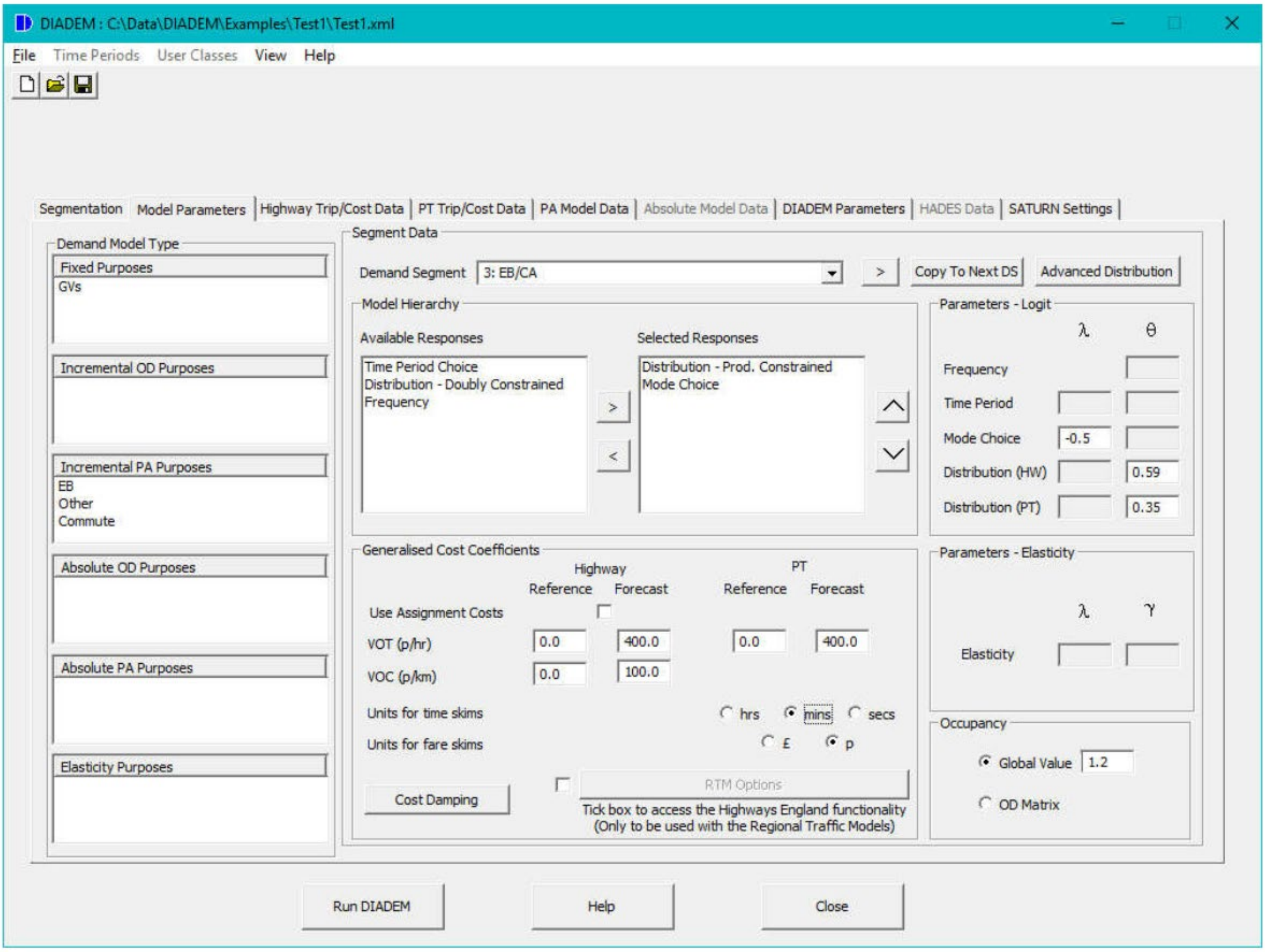
This section considers the advantages and disadvantages of the tools currently available, starting with consideration of the sophisticated UK approach and then broadening to a range of US tools, some directly addressing induced demand and others of interest for the features available to the user.

2.4.1 Diadem and the UK approach

Diadem is a commercial model that aims to lead users through the VTM process[47] recommended by Department for Transport (2020b). The tool is essentially an add-on to a transport model (designed specifically for a SATURN-based model) which requires considerable transport inputs such as details of the transport network, initial trip matrices and estimates of trip costs (Atkins, 2020). The software then uses convergence techniques to iterate with an external traffic assignment model (the SATURN step) to estimate the likely demand response to the transport policy intervention. Some perspective on the inputs required is shown in the screen shot below from the User Manual (Atkins, 2020). It should be noted that convergence to an optimal solution is not a trivial matter and will likely require some user judgement to produce a 'satisfactory' convergence.

[47] See TAG M2.1 Variable Demand Modelling.

Figure 2.9 DIADEM screenshot (reprinted from Atkins, 2020)



While this tool is too sophisticated (ie, too difficult for non-modellers to use) to be suitable for the New Zealand tool in mind, it is worth noting (below) the key steps of the Diadem/DfT method (Department for Transport, 2020b) that will have to be considered for a reasonably accurate simplified tool. These points lead directly into the insights that follow.

- Trips (and hence VKT) are estimated at a segmented level to account for many structural differences (ie, by trip purpose, zone pairs, mode, or time of day).
- Some form of distinction between travellers with and without a car available is also desirable and is expected where mode-choice is to be considered.
- DfT recommends against the use of elasticities and instead recommends full variable matrix modelling (they provide a preferred method in Appendix A if using elasticity methods).
- Estimates of trips between zone pairs include factors such as the GTC of travelling between the zones, the 'gravity' of each zone and sometimes idiosyncratic socio-economic variables (the k-factors) for the zone pair.
- There are different forms of constraints on the number of trips starting and ending in each zone that can be assumed, which have different implications for VKT estimates.
- DfT recommends realism testing.

Insights for the development of the tool:

#24. Trip segmentation may be required, including for time of day, to apply a cost elasticity approach.

#25. Methods may be required to consider car availability where mode shift is potentially a large factor.

#26. Consider any preferred elasticity method and how adjustments could be made to address pitfalls of an elasticity approach.

#27. Both GTC and local attractiveness factors may need to be considered in any VKT estimates, including any change of attractiveness.

#28. Consider methods to employ that offer flexibility about how trip ends are to be treated.

#29. Provide checks between price elasticity-derived VKT estimates and lane-km elasticity-derived VKT.

2.4.2 US tools for transport and lane projects

US VMT tools for transport projects

A suite of tools has been brought together as R-based[48] regional planning tools within the VisionEval (VE) project.[49] These tools require substantive inputs and user knowledge, but they can also quickly be brought together to test various transport policy scenarios for US states, metropolitan areas and smaller areas. The collaborative and open-source nature of the suite, plus the availability of scenario viewers, enables the scenarios being simulated to be refined in an iterative fashion, including a feature that will in time enable comparison with the results of previous simulations amongst the community of users. There are three tools within the suite that allow VMT estimation: a state-level tool, a regional tool, and a rapid policy-analysis tool (referred to as VERPAT).[50] All three tools derive estimated VMT effects from elasticities. A closer look at the VERPAT reveals that it enables differing elasticity effects by design (intersection street density), accessibility (job accessibility by auto), distance to transit (nearest transit stop), density (population density) and diversity (land-use mix). The VERPAT user has the option to override default elasticities, to adjust the total population growth and the mix of population growth for a 13-scale place typology, to adjust the growth of new transport infrastructure (by mode, relative to population growth) and to also test various travel demand policies. The tool incorporates a short-term induced demand effect from extra lane capacity, based on Cervero (2003), but does not attempt to estimate a long-term effect, stating that the ‘research has not clearly quantified effects’ (Outwater & Rentz, 2015).

A coarser and much simpler-to-use tool is the web-based tool from the National Centre for Sustainable Transportation (NCST) that applies a VKT-to-lane-miles elasticity of 1 to Californian Class 1 roads and 0.75 to Class 2 and 3, with the elasticities derived from Duranton & Turner (2011) and similar studies. The existing (ie, base case) lane miles and VMT are those provided annually from the Caltrans Transportation System Network (TSN) database, in turn a subset of a national database collated by the Federal Highway Administration (FHWA). Although the tool is available for Class 1-3 roads only, it is acknowledged that induced demand can occur with roads of other classes as well (NCST). The tool is also available elsewhere for other US states, referred to as the SHIFT calculator, which has the added feature of estimated GHG emissions (RMI).[51]

[48] R is a programming language for statistical computing and graphics.

[49] https://visioneval.org/

[50] The VERPAT is also still available as a standalone tool referred to as RPAT (AASHTO).

[51] The SHIFT calculator also is available for Colorado only https://rmi.org/colorado-induced-travel-calculator/.

The following table provides a match between the US and New Zealand classification, based on the authors' alignment of reported annual average daily traffic (AADT) vehicle volumes within each country's road classes.

Table 2.9 US and New Zealand road classification (adapted from US Department of Transportation Federal Highway Administration. (2013))

US Functional Class of roads	Typical US AADT	New Zealand One Network Road Classification	Typical New Zealand AADT
1. Interstate Freeway (Note 1)	35,000–129,000 (Urban states, see Note 2) 12,000–34,000 (Rural)	GT1. High volume	Urban > 35,000 Rural > 20,000
2. Other Freeway or Expressway (1)	13,000–55,000 (Urban) 4,000–18,500 (Rural)	GT2. National	Urban > 25,000 Rural > 15,000
		GT3. Regional	Urban > 15,000 Rural > 10,000
3. Other Principal Arterial (1)	7,000–27,000 (Urban) 2,000–8,500 (Rural)	GT4. Arterial	Urban > 5,000 Rural > 3,000
4. Minor Arterial	3,000–14,000 (Urban) 1,500–6,000 (Rural)		
5. Major Collector	1,100–6,300 (Urban) 300–2,600 (Rural)	GT5. Primary Collector	Urban > 3,000 Rural > 1,000
6. Minor Collector	150–1,110	GT6. Secondary Collector	Urban > 1,000 Rural > 1,000
7. Local road	80–700 (Urban) 15–400 (Rural)	GT7. Access Local Road	Urban < 1,000 Rural < 200
		GT8. Low volume Local Road	Urban < 200 Rural < 50

Note 1: Classes included in US Induced Demand tool.
Note 2: US Rural states are those with less than 75% of the population within urban areas, otherwise an Urban state.

Caltrans advises using the NCST as a benchmark that can then lead to travel demand modelling (California Department of Transportation, 2020).

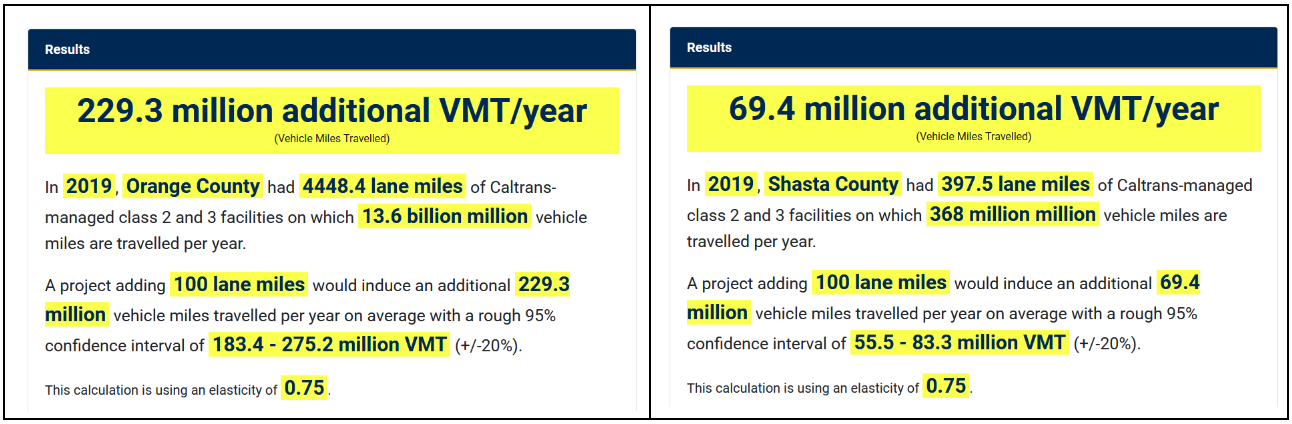
As background to the NCST tool, the Duranton & Turner (2011) study was for 228 metropolitan statistical areas (MSAs).[52] There are 384 MSAs in the USA, these are areas that have relatively high population densities at their cores and close economic ties throughout each area, which is measured by the extent of commuting to the core urban area (US Census Bureau, 2021). For example, the Albuquerque metropolitan area consists of four counties, four cities and four towns and their immediate surrounding areas, with a 2020 population of around 920,000 spread over 24,000 km^2 (37 people/km^2) and is one of four MSAs in the state of New Mexico.

The NCST tool allows estimation at an urbanised county level: for example, Orange County, of Disneyland fame, is within the large Los Angeles, Long Beach, Santa Ana Metro Area, has a population of around three million within 2,460 km^2 (1,540 people/km^2), and includes 34 cities (one of which is Yorba Linda, discussed below). Orange County, according to the NCST tool, had around 21,000 million VMT in 2019, spread approximately evenly over Classes 1, 2 and 3 (other class VMT not reported) but with a strong class bias on a per-mile basis (9.3 miles per annum VMT per Class 1 lane-mile, 6.8 miles for Class 2, and 2.1 miles for Class 3).

As an example of the tool, entering a hypothetical 100 miles of new Class 2/3 lanes for Orange County in 2019 would add an estimated 229.3 million VMT. That is (by this author's calculations), a 2.2% increase in lane miles would add 1.7% more VMT (as the 2.2% times the elasticity of 0.75 being applied to Class 2/3 roads). Note that no distinction is made between whether the new roads were Class 2 or 3 and no further contextual information for Orange County or the (hypothetical) new lanes could be input into the tool.

Another example within a smaller county shows a similar calculation for Shasta County, namely a 100-mile extra Class 2/3 road adding 25% more lanes and 19% more VMT (ie, 25% times 0.75). Shasta County has a population of around 95,000 people within 158 km^2 (590 people/km^2) and largely consists of the city of Redding, near the northern border of California. Again, no further context could be input and, out of interest, Shasta County has no Class 2 roads.

Figure 2.10 Examples of output from the NCST tool (reprinted from user inputs to California Induced Travel Calculator)[53]



[52] An MSA 'is a geographical region with a relatively high population density at its core and close economic ties throughout the area' (https://en.wikipedia.org/wiki/Metropolitan_statistical_area).

[53] https://travelcalculator.ncst.ucdavis.edu/

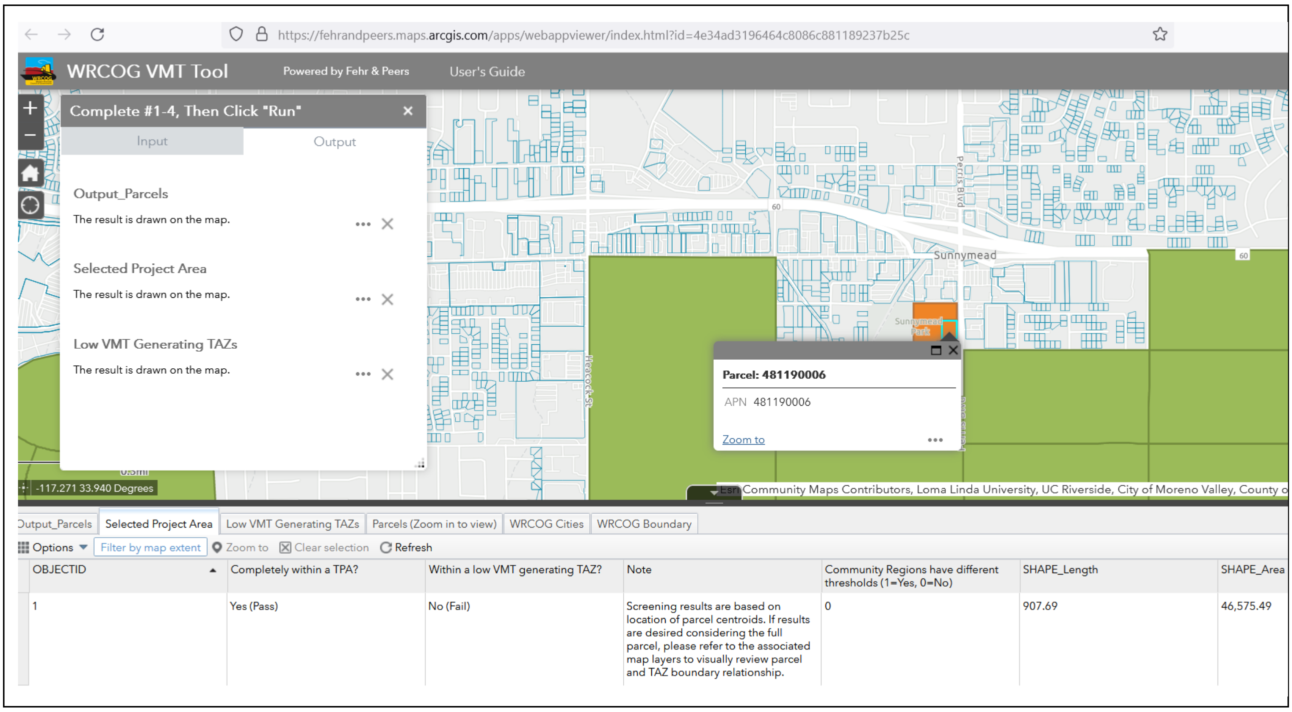
Another group of US transport tools are those focusing on travel demand management (TDM). An example is a workbook-based process to test 25 TDM measures for the Bay Area Air Quality Management District in California, leading to estimates of VMT generated, suppressed or avoided.[54]

US VMT tool for land-use projects

Returning to Orange County, Yorba Linda is a suburban city in north-eastern Orange County, approximately 37 miles southeast of Downtown Los Angeles,[55] with a population of around 70,000 people. The NCST tool is not able to estimate the additional VMT for any added lane miles in Yorba Linda, as it is below the level of a County, but the city does require developers to apply estimates of the VMT effect of rezoning for housing. For example, the analysis of a recent rezoning of 27 sites that would allow the construction of 2,410 dwelling units showed an expected below-average VMT-to-population ratio and this was judged as likely to reduce the VMT per capita ratio for the city (So, 2022).

Near Orange Country, the Western Riverside Council of Governments (WRCOG) has developed a set of guides to inform property developers of the transportation impact for proposed projects. Data on home-based VMT per capita and home-based VMT per worker were brought together from a regional transport model to form an online screening tool to identify locations where target VMT could be expected. It enables a user to select a project location and reports whether the location fits within areas known to already have VMT within the required threshold (in the example shown below, the location would not meet the VMT threshold entered, but building in the green zones would).

Figure 2.11 Example of tool to estimate VMT effect of land use change (reprinted from user inputs to WRCOG VMT Tool)[56]



There are also tools that aim to estimate GHG emissions. These include CalEEmod which steps users through a menu of causal factors, allowing the user to select a location on a map of California. The tool then

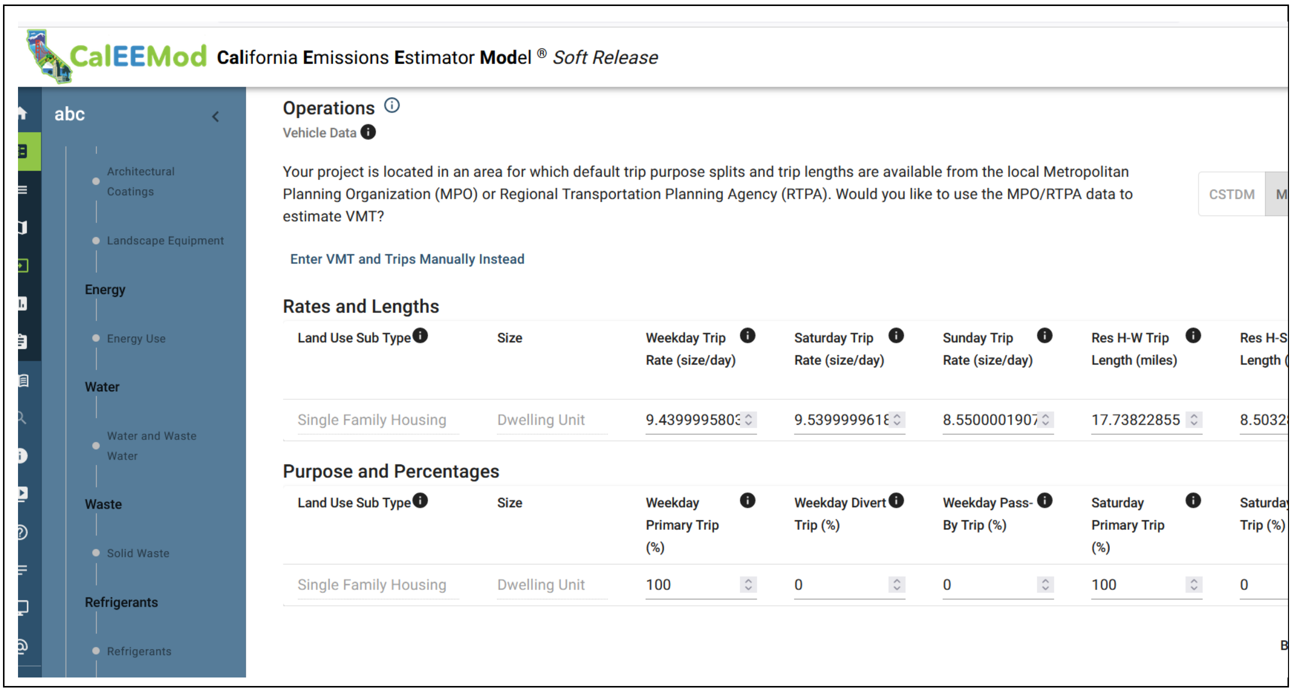
[54] https://www.ca-ilg.org/post/transportation-demand-management-tdm-tool

[55] Apparently 'Most folks take the 90 to the 91, then merge onto the Five, reaching Downtown Los Angeles in about an hour' https://www.prevu.com/blog/orange-county-towns-with-easy-commutes-to-la

[56] https ://www.fehrandpeers.com/wrcog-sb743/

suggests default values for each step, including travel variables – as shown below for a hypothetical new residential development – but also allowing overrides of defaults. Many boxes exist to explain terms and input requirements. Options exist to reconsider the project in ways that would reduce GHG emissions.

Figure 2.12 Another example of tool to estimate VMT effect of land use change (reprinted with user inputs from CalEEMod)[57]



Another GHG tool is the Caltrans SB-1 Emissions Calculator[58] which estimates the emissions reduction for an inputted change in VMT. While not predicting VMT, the tool does provide an example of a spreadsheet-based quick calculator.

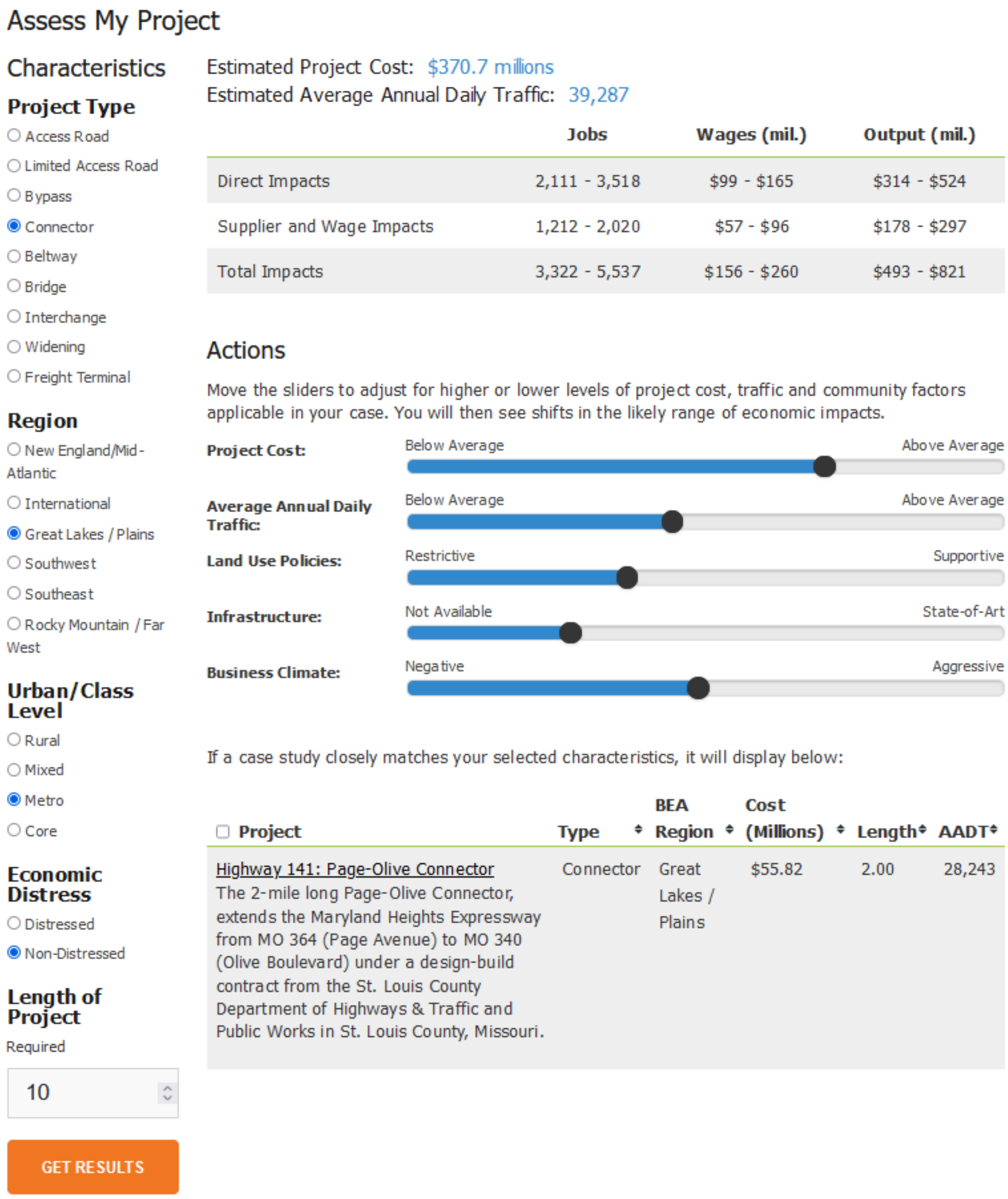
Other US tools for transport projects

The Strategic Highway Research Program, a DoT-led research program that produced the VERPAT discussed above, also developed and collated a wide range of tools, guides and case studies that target proven methods to be used for US transport projects. One tool of interest is the 'Assess My Project' web-based tool that draws from case studies to indicate economic impacts (not including VMT, unfortunately). The tool does include features that could be applied to an induced-demand tool, including suggestions of default costs and impacts in the early phases of the tool, then using sliders to adjust the context of the project under consideration and providing links to relevant case studies.

[57] https://www.caleemod.com

[58] https://dot.ca.gov/programs/transportation-planning/division-of-transportation-planning/data-analytics-services/transportation-economics

Figure 2.13 An example of tool to indicate economic impact of transport project (adapted from Assess My Project)[59]



Insights for the development of the tool:

#30. Use of defaults, sliders and case studies are likely to make the tool easier to use.

#31. The ability to chart local spatial variation in VKT provides an intuitive means to convey the potential for land-use effects on VKT.

[59] https://planningtools.transportation.org/225/assess-my-project.html

2.4.3 New Zealand VKT tool

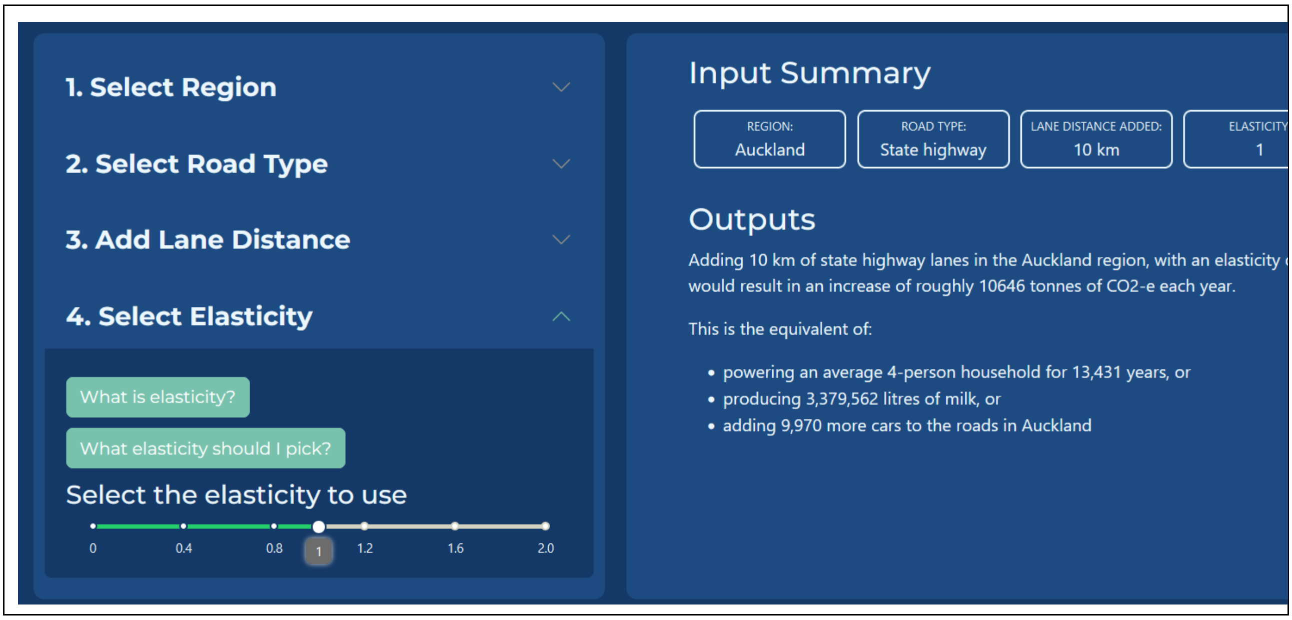
MRCagney (see figure below) have recently provided an online tool that is similar to the US NCST tool except that:

a. the user chooses the lane-km elasticity to apply

b. the induced VKT is not reported but instead converted to an estimate of extra GHG emissions

c. the base road data is segmented on a state-administered or locally administered basis by regional location.

Figure 2.14 Examples of output from the New Zealand MRCagney VKT tool[60]



60 https://induced.mrcagney.works/calculator

3 Survey of New Zealand practitioners

This chapter summarises interviews with New Zealand practitioners as to their experiences and observations about induced demand and their expectations of a tool.

There is little, if any, case study or statistical research available as evidence of induced demand in New Zealand, thus the expectation is that a heavy reliance will need to be placed on international empirical research. Interviewing New Zealand stakeholders was seen as a way to inform whether the international research was applicable in the country, to identify any New Zealand research that was available but not in the public domain (some now included in Chapter 2) and to determine the needs of a tool.

3.1 Survey method

The survey's method was to select a small group of practitioners from a range of transport modellers, transport planners and urban planners across both the public and private sector, and across the country. Potential interviewees were originally suggested by project and steering group members and other suggestions were iteratively gathered as the surveys proceeded. An invitation was emailed to the potential interviewees and a second email of questions was sent to those accepting the invitation. A (short) 15-minute semi-structured online interview then followed (in November 2022), loosely following the questions posed by email but shifting the emphasis depending on the background of the interviewee. Notes were taken of the interview, but no recordings were made and no comments below are attributed to any one person. All interviews were voluntary but a NZ$2,000 (in total) donation was made to the Child Cancer Foundation in recognition of the goodwill shown. Around 15–20 people were invited, and 12 interviews were undertaken.

The questions posed by email (although not all necessarily discussed in the interview) were as follows.

'These are the key questions of interest. It may not be possible to answer all questions and it may be appropriate to focus on 1 or more questions.

*Our interest is in '**any increase in traffic that would otherwise not be there**' for a new or improved road, putting aside whether this extra traffic is called induced demand or not. We are also primarily interested in **VKT**.*

1. At a road project or programme level, is it possible to generalise about the causation of any extra VKT? If so, what do you believe is the attribution (or at least the ranking):
   - % due to change in mode of trip
   - % due to change in timing of trip
   - % due to change in route assignment of trip
   - % due to change in distribution of trips (ie, change in where trip starts and/or ends)
   - % due to new trips?
2. At a regional level, is it possible to generalise about the causation of any extra VKT? If so, what do you believe is the attribution:
   - % due to change in mode
   - % due to change in length of existing trips
   - % due to new trips?
3. When are the factors in (1) being taken into account in New Zealand business cases?

4. Are you aware of any tool (other than the usual full transport modelling) used for early indication of expected extra traffic for a new or improved road? What would you like to see in such a tool if it were to be made available?
5. What ways are being used in New Zealand to reduce extra traffic for new or improved roads projects/programmes? What else could be done (if desirable to reduce extra traffic)?'

3.2 Survey results

Several themes emerged from the interviews. The summary below is the author's synthesis of the discussions and does not necessarily reflect the views of all interviewees.

1. Induced demand is occurring in New Zealand. There was widespread acknowledgement of induced demand but there were differing interpretations of it – only a few researched examples could be identified.
2. The factor driving induced demand is a reduction in travel cost, which most likely occurs when a traffic constraint exists and most likely to be in cities.
3. The extent of induced demand can be limited by bottlenecks that may still exist elsewhere in the network (eg, Ngauranga Gorge in Wellington, Harbour bridge in Auckland).
4. The sources of extra VKT are the usual trip diversions (mode, timing, route) plus a frequency effect that was mentioned as small. Mode shift was more a risk near the CBD, where mode share is higher (suggestive of a low level of service by New Zealand PT compared with international urban rail systems, to being alignment with conclusions reached in 2.3.1). There was also likely to be some redistribution of destinations. These combined effects were likely to occur quickly.
5. Also mentioned was that land-use changes occurred more slowly (ie, longer than 12 months) but was most likely long-lasting, which is likely to increase the average trip length. Interestingly, the international research puts emphasis on traffic diversion but the conversation with interviewees quickly turned to land-use change, mostly unprompted.
6. There was concern about the spurious accuracy of any form of tool or transport model and a warning about the uncertainties that usually exist.
7. In particular, land-use changes can be difficult to forecast. They involve much uncertainty, involve policy and project changes by non-road users who may be acting for non-transport reasons and will happen slowly. A likely land-use effect is the focus of new residential and non-residential development near one part of the city (due to new roads and other infrastructure) instead of another viable area, which remains static until growth creates an even greater need (ie, the land use effect is favouring the phasing of one location for development over another).
8. There is the risk that a path dependency is created, including around the viability and hence supply of PT, especially rail. For example, continued supply of road capacity may undermine the commercial viability of an existing or potential rail service. However, there is also the possibility that a higher population near the fringe of a city, say, induced by extra roads could in time increase the viability of a train service (ie, there is potentially a 'mass' versus 'substitute' trade-off to be considered).
9. The reminder was offered that there may be a good purpose for the extra road (resilience, safety, freight efficiency) and even the extra VKT (economic growth enabler, better match of personal preferences).
10. The MBCM VTM recommendations are not believed to be widely followed, with many benefit analyses employing a FTM, except for (some or all) larger studies. This was due to multiple factors such as limited modelling skills, costs of analysis, large information requirements and institutional habit. There are business cases where scenarios are being considered but not necessarily being taken through to a

benefit-cost ratio (BCR) analysis. There was interest expressed in knowing what is being applied as best practice overseas.

11. Situations vary so trying to use a fixed percentage attribution to causes of induced demand (eg, 20% likely from mode-shift) will be inaccurate.
12. The tool could be used as a filter and guidance to the further analysis that is appropriate eg, identify situations where induced demand is likely/unlikely: ‘give sense of scope of analysis required’. Help could be provided with definitions. One suggestion was to consider the merits of a systems dynamic model.
13. The tool would be especially relevant where ‘regional models’ do not exist.
14. The tool could facilitate communication between urban planners and transport planners, in part by applying a consistent methodology and terminology and in part by drawing on, and accumulating, an agreed evidence base – feedback was mixed as to whether interaction between the two planning groups will be more likely following Resource Management Act (RMA) reforms to come. However, use of tools was not believed to be common practice at present.
15. About mitigation, the question was raised if the road would be necessary if mitigation was to be applied. That question aside, tolls had been effective in New Zealand to avoid large levels of induced demand. It was also noted that where diversion was desired, changing the old route (usually through the urban area) to have a higher focus on place (traffic calming, active infrastructure) would reinforce the preferred behaviour. Park and ride had been used to complement PT (and hence limit increase in road trip length). Speed limits could be reduced (to reduce any new GTC advantage). More land-use intensity has been, and can be, planned, while land use near a state highway bypass can be constrained to prevent heavy dependence on the highway for local activities (eg, East Taupō Arterial).

Insights for the development of the tool:

#32. The tool will provide an opportunity to educate planners and standardise the use of terminology.

#33. The tool can provide a guide and checklist that leads to a more thorough and consistent modelling of induced demand.

#34. Discussion of long-term land-use changes will enable the consideration of potential GHG effects of land use and transport projects, and how they may interact.

4 Modelling the pathway between extra lanes and extra VKT – an exercise to find a tool engine

The preceding chapters showed that a lane-km elasticity approach has been used within (a few) existing tools to estimate the VKT effects of extra road capacity. But the research also points to many shortcomings of this approach. Alternative ways potentially available to provide an induced VKT estimate include applying a GTC elasticity approach, or to undertake transport modelling – both require a considerable database and significant user inputs. The simplicity required of an early-stage induced-demand tool means these latter two methods are unlikely to be appropriate. Hence a decision was made by the project team to also consider a composite solution that enabled the limited lane-km elasticities reported within the research literature to be adjusted to more closely match the context of a project.

Surprisingly, we were unable to find research that integrated the three approaches so a three-step investigation was followed in this project: first, a summary of the key lane-km elasticities and cost elasticities were collated (and are shown in Appendix B); modelling with a 4-stage transport model was undertaken for a selected few Christchurch projects (see Section 6.7); the arithmetic of a lane-km elasticity approach was further examined, and then an exercise of reconciling, or at least better understanding, the approaches to VKT estimation was undertaken.

This chapter starts with an overview of the four estimation approaches, including variations, and follows with a summary of the advantages and disadvantages of each option, as revealed in the literature review and from the reconciliation process. It ends with our recommendation to develop a composite approach.

The presentational form of the tool and other wider considerations are then considered in the following chapter.

4.1 Overview of four options for the Tool

The viable options we see for a spreadsheet application are listed below. Options 1–2, and their variations, are based on lane-km elasticities, option 3 entirely uses GTC elasticities and option 4 applies simplified transport (or sketch) models. We consider that options 3 and 4 are simply not feasible within this project and will be challenging to develop longer-term well enough to sufficiently cover a wide range of project locations. This is discussed further in this chapter. Options 2a and 2b vary by the extent of quantitative analysis provided to support a lane-km approach. The chapter builds up the case to aim for a tool that possibly sits between 2a and 2b.

1. Option 1a and 1b. Use lane-km elasticity, either (a) as per the MRCagney tool or (b) similar to the NCST tool.
2. Option 2a and 2b. Use a lane-km approach but build up adjustment factors to provide lane-km elasticities better aligned to the context of the project. Variation (a) would rely heavily on a qualitative selection of factors while (b) would entail more extensive quantitative elements to customise the adjustment factors, which also enables the user to explore mitigation more explicitly such as tolling.
3. Option 3. Discard the lane-km elasticities and build up a GTC elasticity approach.
4. Option 4. Develop a series of sketch models, calibrated to larger regional transport models. Such models are already held by the project team for Auckland, Wellington and Christchurch.

4.2 Lane-km elasticity approach (Options 1 and 2)

The lane-km elasticity approach estimates the change in VKT by assuming that the project fits within a set of roads that have a standard relationship between the growth in lane-km and growth in VKT. The model effectively requires only two sets of data.

- An elasticity to the change in lane-kms. This will be road type and context specific (as per the discussion in the previous chapters).
- A measurement of the stock of lane-kms and VKT by road type for a larger set of similar existing roads. This should be at the same level of disaggregation as the elasticities.

We discuss each of these in turn.

4.2.1 Lane-km elasticities

There is robust evidence regarding the situation on congested US inter-state highways, but outside of that the evidence is extremely limited. This means that any lane-km tool developed for New Zealand will leverage highly off a few international but well-established results. The key lane-km elasticities available are presented in Appendix B.

4.2.2 New Zealand lane-km and VKT data

The application of the lane-km elasticity model require data on the stock of lane-kms, collated on a similar basis to the research that derived the elasticities. The evidence base has been largely collected using national or regional lane-km and VKT data, segmented by road class and further segmented as rural or urban.

In New Zealand, road data are reported through two channels, a NZTA Transport Data webpage and a Transport Insights online portal.

Lane-km are reported annually for each region and each territory (ie, city or district), in total and according to the two classifications that currently exist in New Zealand (the outgoing ONRC and the new ONF).[61] An urban/rural split is also provided for the ONF classification, but further work will be required to map to a ONRC breakdown.

VKT data is also reported by region or territory for the two classifications, further broken down by urban or rural. Another segmentation available is local roads versus state highways, which reflect the administration authority for the road. There are inconsistences in the VKT data reported through the two websites. For example, for the Canterbury region, the NZTA Transport Data webpage reports 30,640 lane-km and VKT as 6,685 million km for 2019/20 whereas the Transport Insights portal reports totals of 29,770 and 29,800 for the former (lane-km) and 6,658 million and 6,675 million for the latter (VKT). The data were then broken down by road class. Using the ONRC classification, there were 1,457 km of arterial roads in Canterbury with 1,688 million VKT, broken down as 614 million on urban roads and 671 million on rural roads. Using the ONF classification there were 1,370 km of urban connector roads in Canterbury with 2,157 million VKT (all urban) while there were 771 km of peri-urban roads with 199 million VKT (all rural).

[61] ONF is and ONRC was the classification system applied to New Zealand roads.

Table 4.1 A cross section of New Zealand transport data available for 2019/20 (as reported on websites)[62]

Comparison of 'NZTA Transport Data' (rows in purple) with 'Transport Insights Data' (remaining rows)										
			Lane-km			VKT (millions)				
Authority	**Class**	**Area**	**Grand Total**	**Urban**	**Rural**	**Local Roads**	**State Highways**	**Grand Total**	**Urban**	**Rural**
Region		**Canterbury**	**30,640**			**3,823**	**2,863**	**6,685**		
Region	**State Highway only**	**Canterbury**	**2,846**				**2,863**	**2,863**		
Territory		**Christchurch City**	**4,436**			**2,232**	**847**	**3,079**		
	ONRC									
Region	High Volume	Canterbury	280					800	417	383
Region	National	Canterbury	931					1,177	215	961
Region	Regional	Canterbury	482					661	471	190
Region	Arterial	Canterbury	1,457					1,688	951	737
Region	Primary Collector	Canterbury	2,833					1,286	614	671
Region	Secondary Collector	Canterbury	6,532					714	349	364
Region	Access	Canterbury	8,081					251	118	133
Region	Low Volume	Canterbury	9,093					81	32	49
Region	Not Required	Canterbury	81					0	0	0
Region	Unclassified	Canterbury	0					0	0	0
Region	**TOTAL NETWORK**	**Canterbury**	**29,770**					**6,658**	**3,170**	**3,488**
	ONF									
Region	Transit Corridors	Canterbury	93	93				242	242	
Region	Urban Connectors	Canterbury	1,370	1,370				2,157	2,157	
Region	City Hubs	Canterbury	3	3				2	2	
Region	Activity Streets	Canterbury	221	221				198	198	
Region	Main Streets	Canterbury	26	26				45	45	
Region	Local Streets	Canterbury	4,023	4,023				505	505	
Region	Civic Spaces	Canterbury	13	13				2	2	
Region	**Total Urban Network**	**Canterbury**	5,748	5,748				3,152	3,152	
Region		Canterbury								
Region	Interregional Connectors	Canterbury	1,191		1,191			1,365		1,365
Region	Stopping Places	Canterbury	105		105			4		4
Region	Rural Connectors	Canterbury	6,547		6,547			1,430		1,430
Region	Peri-urban Roads	Canterbury	771		771			199		199
Region	Rural Roads	Canterbury	14,863		14,863			256		256
Region	**Total Rural Network**	**Canterbury**	23,476		23,476			3,254		3,254
Region		Canterbury								
Region	Unclassified	Canterbury	575					269		
Region	**TOTAL NETWORK**	**Canterbury**	**29,800**					**6,675**		

4.3 Transport cost elasticity approach (Option 3)

An alternative short-cut method for VKT estimation is to rely on cost elasticities, which have been estimated previously for both short- and long-run situations.

This cost elasticity approach could be used as a standalone tool or, as is more likely, as an additional component of a lane-km approach.

[62] https://www.nzta.govt.nz/planning-and-investment/learning-and-resources/transport-data/data-and-tools/ and https://portal.transportinsights.nz/onf/network-characteristics

The general relationship between lane-km elasticities and travel-cost elasticities is given by Lee (2000), repeated below, where cap=capacity=lane-km, VMT=vehicle miles travelled, p=travel cost, e_T=the travel cost elasticity and $e_{T,capacity}$=the lane-km elasticity.

Equation 1 Relationship between lane-km elasticities and travel-cost elasticities

$$e_T = \frac{\%\Delta VMT}{\%\Delta p} = \frac{\%\Delta VMT}{\%\Delta cap} \times \frac{\%\Delta cap}{\%\Delta p} = e_{T,\,capacity} \times \frac{\%\Delta cap}{\%\Delta p}$$

Research into the possibility of integrating cost elasticities into a tool proceeds here on two paths: this chapter introduces the method and the challenges with determining changes in costs, while the next chapter employs local transport modelling to look closer at the interaction of projects, travel cost reductions and transport modelling outcomes.

The data required (discussed below) implies that a tool based solely on cost elasticity equations will not be viable within this project and is also a major disadvantage of this approach in the longer term.

4.3.1 Cost elasticities

As with lane-km elasticities, a summary of international research considered relevant to New Zealand is provided in Appendix B. Notably, the evidence base for cost elasticities is considerably stronger than that for lane-km elasticities and hence it would be an advantage to include cost elasticities in a tool.

4.3.2 Applying a cost elasticity approach to an increased lane-capacity project

In simple terms, the percentage change in GTC for a particular scheme can be estimated, either crudely by the tool user or in a more sophisticated manner from speed flow curves, multiplied by the appropriate cost elasticity and the product then multiplied by the current VKT demand associated with the new road.

In practice, the approach does need additional information (compared to methods described earlier) about the trips that use the scheme, including:

- Base trip demand using the scheme/link, and identification of the origins and destinations of these trips
- Base trip GTC for the origins and destinations (identified in the step above) that would use the link, typically made up of Vehicle Travel Time (VTT) and Vehicle Operating Costs (VOC)
- The change in GTC associated with the proposed scheme – this could be based on a simple volume/delay relationship based on the road configuration (lanes, posted speed limit, classification capacity etc).

These additional data and the increased complexity of using a cost elasticity approach potentially allows for a better estimation of VKT based on specific details of the scheme that relate more directly to the economic theory rather than generic empirically based data. Other benefits include the ability to consider the effects associated a wide range of trip components (including tolls etc).

Further discussion follows below on the inputs required for travel demand (4.3.3) and cost inputs (4.3.4).

The basic steps are shown below using a new Christchurch motorway as an example.

Step 1) Base trip-demand data inputs:

- The current AADT within the scheme corridor = 32,000 vehicles/day
- The current average trip distance associated with the above demand is 27 km (which in this case was derived from a transport model)

- The current average GTC (expressed in minutes) associated with the above demand is 29 minutes (again derived from a transport model in this case)
- The average daily base VKT associated with the trip demand is 864,000 km/day (estimated in this case as 32,000 vehicles/day x 27 km/vehicle).

Step 2) Calculate change to GTC:

- The proposed scheme is likely to improve average GTC by 2 minutes (estimated in this case using volume delay curves applied to the scheme area)
- This results in a 6.9% reduction in GTC (ie, 2/29).

Step 3) Apply cost elasticity:

- The change in local corridor demand associated with the scheme is then estimated by applying a GTC elasticity (−0.5) as follows:
  - Change in VKT% = ΔGTC x cost elasticity = 6.9% x -0.5 = 3.4%
  - Change in VKT = base VKT x change in VKT% = 864,000 x 3.4% = 30,000 km (rounded).

4.3.3 Travel demand patterns for the cost elasticity model

A cost elasticity model requires a base cost from which to pivot. This will be a function of the trip length of the traffic using the corridor, with different journey purposes having different values of travel time. These data will vary by road type and area type. The ideal source for this would be a national transport model, or regional transport models and the data underpinning them. Unfortunately, such a national model does not exist in New Zealand and regional models are limited. Internationally, another source is road-side interview data on ‘template’ routes of interest.

One of the obvious ways of getting hold of the trip-length/trip-cost distribution is to do select link analysis, which can be done wherever a network model exists. A set of select link analyses for some template road types would then inform the trip cost distribution for a city. Otherwise, some matrix sectoring by road type for a set of ‘template’ corridors (eg, radial/arterial, distributor, bypass, CBD, etc) would be required. Selecting the OD trips that will pass through the ‘template’ corridor is part of a sectoring type analysis. There will be a need to deal with trips originating out of any model study area.

Clearly such a data-mining process will be very resource intensive, using multiple different models built in a variety of different software.

4.3.4 Modelling the GTC change

The cost change brought about by the intervention is critical to a cost elasticity modelling. The cost change needs to be reflective of the average cost reduction for all trips using the corridor. This is unlikely to be known by the user of an early stage induced-demand tool, as users will typically only understand the time reduction for a trip that passes along the whole length of the route and are unlikely to know the journey-time saving for a trip that only uses part of the route. The cost change will therefore need to be modelled.

This likely requires some use of speed/flow curves and data on the trip length distribution and the proportion of the trip using the route. Once again this will be context-specific and modelling work in network models will likely be needed to obtain it.

4.3.5 Wider area impacts

Wider area impacts are those where the road relieves alternative routes, which themselves induce traffic. These effects will be very context-specific. They would probably need estimating using multiple runs of transport models to develop a series of uplift factors for different contexts (different cities and road types).

4.4 Sketch modelling approach (Option 4)

A more comprehensive approach to estimating VKT effects is to employ a standard 4-stage transport model. However, this requires a model in the first place and a skilled user to then operate the model, which can be a slow and expensive process. It is possible to reduce a 4-stage model to a coarser sketch model, by calibrating an excel-based simplification of an existing 4-stage model. This has been done for Christchurch, Wellington and Auckland recently (Torshizian et al., 2023, unpublished), with key simplifications being the dropping of the network assignment stage and the agglomeration of zones to a fewer number.

These models can then be used to consider the effect of any reduction in the (average) GTC of travelling between origin and destination pairs that might result from additional lane capacity. Note, unlike a 4-stage model, the simplified model does not capture re-routing effects but will estimate redistribution effects. Typically, such models, like their parent 4-stage model, do not directly measure the effects of land-use change.

The existence of these simplified models for the three largest New Zealand cities provides an immediate opportunity to develop an induced-demand tool around them. However, this would still require a level of modelling sophistication by the user that would limit the use of the tool, plus it would be a slow and expensive process to develop similar simplified models for other cities within New Zealand, as well as leaving many locations uncatered for (due to a lack of models in all regions). These are reasons to not recommend further pursuit in this project of the integration of simplified models into an induced-demand tool – nevertheless the current models do provide an opportunity to calibrate the adjustment factors in Option 2.

4.5 Assessment of the modelling approaches

The following section provides an assessment of options 1-2, and their variations. These were investigated further within this project, to gain greater insight into their workings and implications, by first exploring the arithmetic involved in each calculation and, second, by comparing results from each method with a (small) group of Christchurch projects for which modelling results could be obtained. Below is a brief summary of the findings.

- The evidence for lane-km elasticities is weak, but New Zealand lane-km are available.
- A cost elasticity approach provides a better alignment with transport modelling but deriving underlying demand data, modelling cost changes and identifying wider area effects requires much transport modelling – unless the tool can be limited to just a handful of road types and contexts.
- The preferred option is Option 2, since it is based on adjusted lane-km elasticities and can be informed by further modelling (particularly the effects of congestion and land-use changes) and cost elasticity simulations.

4.5.1 Option 1a: User choice of lane-km elasticity to apply to regional roads within road classes ‘state highway’ or ‘local road’

A relatively simple approach is to take the available regional road statistics and let the user choose the lane-km elasticity to apply within the likely range. Thus, the tool provides access to the road statistics database and undertakes the elasticity calculation. It potentially can also contain narratives to inform the user. An example of this approach is the MRCagney NZ calculator, although the narrative component is light and it is extra GHG emissions reported, not extra VKT.

Table 4.2 Overview of Option 1a

Area of comparison	Class of roads for comparison	Lane-km to apply
Regions	State Highways	Choose between 0.0–2.0
Regions	Local Roads	Choose between 0.0–2.0

Option 1a has advantages:

- It is simple to develop and use
- The regional road statistics are readily available, now and likely in the future
- It creates the opportunity to inform users of issues and key research.

Its disadvantages are:

- The method offers little advice to the user as to the appropriate lane-km elasticity
- It does not distinguish gross VKT, being the change within the study area, from net VKT, being the national change of VKT – of core interest from a GHG emissions perspective
- The method does not consider the effect of local context
- The broad road classes employed are likely to provide variable bases, which requires customised lane-km elasticities to account for regional differences in composition.

The base effect.

Lane-km elasticities are calculated from a common base and it is then often assumed that they can be transferred to a similar base elsewhere. For example, say it is observed that 10 km of extra lanes for a group of Class-1 road lanes of 100 km length with prior VKT of 1 million km/day leads to an extra 100,000 VKT and, thus, a 1.0 lane-km elasticity. It may be reasonable to expect this elasticity to apply to a similar situation elsewhere. However, if, for some reason, the elasticity of 1.0 was applied to a mix of 100 km of roads similar to the above, plus 100 km of roads with significantly less volume – say, 200 km in total with 1.1 million VKT/day – then the effect estimated for an extra 10 km of Class 1 roads would be 5% more lanes (10/200) leading to 5% more VKT (5%x1.0), which would be 55,000 km, much less than the 100,000 one would more likely expect. In other words, applying an elasticity to a base of roads that are significantly different to the group of roads from which the elasticity was derived will bias any VKT estimate. In this case, the elasticity estimates in the literature largely derive from roads within the same class (mainly high-class roads) and separated as urban and rural networks. It is recommended that estimation proceeds on a road class and urban/rural basis.

A local example of the potential bias is to apply a tool of this nature to the Christchurch Southern Motorway extension project (CSM2). The approximate addition of 40 km of state highway lanes in Christchurch was modelled as part of this research project to likely lead to 80,000 extra VKT, largely due to short-term effects of re-routeing and redistribution of trips. The model did not include increased trip frequency or land-use change. Two bases were chosen and a 0.3 lane-km elasticity was assumed. The estimated VKT increase was 33,000 based off all regional state highway data and 94,000 based off the regional urban class GT1 data (see Table 2.9 *for more on classes). This is consistent with the regional state highway database used for the first estimate including a wider range of roads, hence using this as the base network is likely to understate an induced-demand effect.*

4.5.2 Option 1b: defined lane-km elasticity to apply to regional roads within road classes 'state highway' or 'local road'

A variation of above is to provide a more refined database of road statistics and to provide a lane-km elasticity to apply, along with a confidence interval.[63] Again, narrative can be added. An example of this approach is the NCST US calculator.

Table 4.3 Overview of Option 1b

Area of comparison	Class of roads for comparison	Lane-km to apply
Equivalent to sum of urbanised counties within MSA	Equivalent to US Class 1	1.0 with ±0.20 confidence interval
Equivalent to urbanised counties	Equivalent to US Class 2 or 3	0.75 with ±0.20 confidence interval

Option 1b has advantages:

- It is also simple to develop and use
- Again, the opportunity is created to inform the user of issues and key research
- The lane-km elasticity applied is consistent with US research and US applications
- The road statistics can align with the New Zealand ONRC, although not directly, and imprecisely, with its replacement classification system, the ONF.

Its disadvantages are:

- There is work required to establish and maintain a lane-km and VKT database that approximates the US lane-km elasticity research
- The method relies heavily on US research, which may not be applicable in New Zealand
- As above, it does not distinguish gross VKT from net VKT
- The US lane-km elasticities are based on results that included relatively strong migration into the area and minimal effect on other road classes, and hence these assumptions are implicit in their application elsewhere
- The method does not consider the effect of local context
- The confidence interval significantly understates the variation to expect for an individual project.

The variation effect.

The lane-km elasticities are highly influenced by the Duranton and Turner (2011) analysis. Their preferred estimate (column 3, Table 6) for a US interstate highway lane-km coefficient was 1.03, with a standard deviation of 0.11. In approximate terms, this implies a 95% confidence interval for the coefficient of ± 0.2; hence the number shown in Table 4.3 *here. However, the coefficient applies to what is effectively the average change to expect for groups of US counties (although some groups were a single county), with each group in turn very likely to include many projects. The variation to expect on a single project will be significantly more than the variation of the average effect, possibly over 20 times more in this case. In other words, it may be reasonable, given other assumptions, that the average lane-km elasticity of many local lane-addition projects will tend towards the coefficients given above but the VKT effect for a particular project could fall within a very large range.*

[63] A confidence interval is the range of values you expect an estimate to fall between if you repeat the calculation with a set of data drawn from the same population, often reported for 95% level of confidence.

Examples of projects with substantially higher lane-km elasticity were given in Chapter 2, some tapping into otherwise unrevealed latent travel demand. Several (small) Christchurch capacity projects were identified in modelling undertaken within this project as having a likely downward effect on VKT (ie, each project reduced VKT, largely due to easing traffic bottlenecks that were otherwise leading to 'rat-running' on uncongested alternative routes).

It is possible some variation inherent in the projects underlying the Duranton and Turner research, and that of others, could be identified as due to fixed effects. A search for such factors is taken up in the Option 2a.

4.5.3 Option 2a: defined lane-km elasticity to apply to regional roads within road classes

A further variation of the lane-km tool is to consider known factors that are likely to scale the VKT effect either upwards or downwards, provide default coefficients for these factors under a range of contexts, and then allow the user to select a context and possibly overwrite the default coefficient. Elaboration of the likely key factors is provided in the text boxes below. Further innovations are to add differentiation (a) between short-run and long-run effects, (b) between local and national effects and (c) between urban and rural effects. As previously, narrative guidance can also be provided. Such a tool would appear to not exist at present – a possible warning of the challenges inherent in the approach.

Table 4.4 Overview of Option 2

Area of comparison	Class of roads for comparison	Lane-km to apply
Regions	ONRC GT1 to GT8 urban only	The 1.0 elasticity above rescaled according to factors and differentiated as short-run or long-run net effects and a long-run gross effect. Factors to include: Road class, PT alternatives, link AADT, congestion, land use, migration; tolling
Regions	ONRC GT1 to GT8 rural only	As above

Option 2 has advantages:

- The method is still relatively simple to develop and use, although it does require more research by developers and (slightly) more input from the user than Option 1
- The opportunity is created to inform the user of issues and key research
- The lane-km elasticity would be consistent with wider international research than just the US
- The data can be aligned to the New Zealand ONF classifications
- The method distinguishes gross VKT and net VKT
- Allowance for key local context can be made, albeit this will only be partial (variation is still to be expected)
- The approach allows user override of default assumptions, to allow for more knowledge held by the user or simply for sensitivity tests.

Its disadvantages are:

- There is likely to be substantial ongoing research required to establish and maintain default elasticities and factors
- The research evidence for these factors is limited
- The calculation is still unlikely to capture the full range of contexts that will apply
- The method by default assumes relatively strong displacement and minimal effect on other road classes.

The congestion effect.

The international induced-demand research is closely tied to the 'fundamental law of congestion'. In its simplest form, it can be shown mathematically that the addition of extra lanes will lead to a lane-km elasticity of 1.0, if all roads adjust to the previous level of capacity usage. This applies to additions within any road class – repeating, if they return to previous capacity usage. Much of the research has been of road systems that are at or near congested levels, which provide the conditions likely to produce the result above.

However, the 'filling up of capacity' will not always occur. In particular, if usage of current capacity is currently moderate or low then additional capacity will in many cases not be filled. Variations of this effect are (a) the additional lanes do not get used to the current capacity levels of similar roads, and/or (b) the extra capacity created on alternative routes by rerouteing to the new road is not replaced. In these situations, the lane-km elasticity to apply will be less than that for a congested road.

The Christchurch projects mentioned in the 'Variation effect' are examples of (b).

Conversely, if the existing road is congested and currently at or close to capacity, but the new road can operate well below capacity (ie, with no significant congestion), then the lane-km elasticity will exceed 1.0. This is because the induced traffic on the new road will not be curtailed by congestion.

Further research is required to calibrate a congestion factor to the New Zealand road network.

The within-road classes variation effect.

A similar mathematical effect to the 'Variation effect' above is due to different traffic volumes along roads within the study region of the same class. The elasticity effect is a measure of the average effect. Assuming no other fixed effects and negligible natural variation, adding extra lanes to a class of road with constant AADT on all sections of roads within the class will produce the average effect. However, AADT is rarely constant within a road class (let alone the other two assumptions). More likely, the AADT of the extra lanes will be above or below the class average in the study region. If it is higher, the law of congestion would imply a lane-km elasticity for the class of roads above 1.0; conversely the lane-km elasticity would be lower if AADT is below the average traffic volume for the road class.

A look at the AADT for a (small) set of roads within Christchurch revealed a wide range of AADT within a road class. The effect on the lane-km elasticity was not investigated by example but remains a topic for further research.

The land-use effect.

With respect to the law of congestion, land use is not necessarily a factor that increases or decreases the reversion to congestion but rather can be one of the causes of the extra travel demand. In uncongested networks, land-use change has the potential to increase the VKT response to additional road capacity. It is a matter of debate as to what extent any extra roads cause land -use change but it is often found in research that VKT effects of extra lanes and/or of travel-cost reductions are greater over the long run, and the difference between long-run and short-run effects is often at least partially attributed to land-use changes. The research literature shows the ratio of the long-run to short-run lane-km and cost elasticities ranges between 1.5–2.0.

The project team has identified that a land-use factor is likely to be a fixed effect of relevance but has yet to finalise the composition of the land-use factor to apply within a tool, that is, the specific effect of density and location (as discussed in Appendix B). It is expected that such a factor will tie back to the ratio reported above. This can be tested and calibrated with simplified model runs for Auckland, Wellington and Christchurch.

4.5.4 Option 2b: cost elasticity equations used to inform lane-km to apply

A further variation on the previous options for the induced demand tool is to incorporate cost elasticity calculations into the tool, or at least to use a cost elasticity approach to inform some of the factor effects identified in Option 2a.

Table 4.5 Overview of Option 2b

Area of comparison	Class of roads for comparison	Lane-km to apply
Regions	ONRC GT1 to GT8 urban only	As in Option 2a but with cost elasticity equations used to create factor coefficients
Regions	ONRC GT1 to GT8 rural only	As above

As well as having the same advantages as Option 2a, Option 2b has advantages:

- It provides more contextual factor coefficients, produced in a manner consistent with transport modelling and economic theory
- The method enables a wide range of trip components to be considered directly, including the mitigation effects of a toll on the new lanes
- It provides access to substantial cost elasticity research in New Zealand, that validate (or not) the lane-km elasticities that have been derived from a smaller evidence base.

Its disadvantages are:

- Considerable research is likely required to establish cost-elasticity approaches and the data required
- The relationship between GTC and induced traffic can be highly variable and dependent on specific situations (eg, relating to the number of viable alternative routes)
- It may require the use of a transport model to estimate the GTC change, in which case the modelling can also determine the change in VKT directly.

The tolling effect and a cost-elasticity approach.

A cost elasticity would take the current distribution of trips for a corridor and estimate the extra VKT to expect based on the reduced GTC created by the new lane capacity. This requires reasonable estimates of (a) the distribution of trips at any one point or for any road class within a region and (b) the GTC cost change incurred for all these travel demands. These demand data preclude a full cost elasticity tool being developed within this project, but it is expected that some situations can be addressed with a cost-elasticity equation, for example, where trip distributions data is available (as in the major cities) and/or where trip distributions are likely to be reasonably predictable (such as on rural roads).

The added advantage of building up an understanding of the GTC effect for a project is that a toll can be directly included within the GTC to estimate its mitigation effect. It is to be investigated whether a GTC approach can be applied to situations that are likely to attract a toll in New Zealand and as to whether such an approach would provide significantly different induced-demand estimates to a cruder approach based on a high level of tolling reducing the VKT effect by 85% (as reported in Appendix B).

5 Other tool specification and testing

The previous chapter explored the functional aspects of options for an induced-demand tool and concluded with a preference for Option 2, preferably the 2b variation.

This chapter considers wider requirements of the tool and whether the Option 2 variations can also meet these wider objectives.

This then leads to a consideration of the constraints, including initially within this project, followed by a longer-term consideration of what would be preferred, why, and what would be viable for a tool to be developed.

5.1 Objective of tool and potential users

The objectives for the tool and the types of users and uses are listed in the tables below.

Table 5.1 Suggested objectives of VKT tool

Objective	Reason
Educate users about induced demand	Much confusion exists as to what induced demand is and what its causes are. There is also widespread confusion between causation and correlation. The tool provides an opportunity to improve understanding of the causes of induced demand.
Work towards **best practice** within New Zealand	Systematic consideration of induced demand does not appear to be currently applied in New Zealand.
Provide an early indication of the **order of magnitude** of induced demand to expect	To provide users with information that will guide the scope of further analysis required.

It is acknowledged that the tool could be targeted at urban planners, as outlined below. However, initial discussions did not reveal latent demand by urban planners so more emphasis is being placed on the development of the tool primarily for transport modellers and planners, who are more likely to use such a tool in situations such as the development of a programme business case and/or for cross-checking other modelling results.

Table 5.2 Suggested potential users of VKT tool

Potential users	For
Urban planners	Providing a consistent terminology and understanding of induced demand Providing the scale of induced demand effect, and reasons, to expect Providing a guide to next steps Providing an insight into the scale of mitigation effects
Transport modellers	Providing a guide to next steps, including use of VTM and possibly LUTI or SCGE models
Transport planners	As for urban planners Plus providing a checklist of factors to consider

5.2 Desirable features of the tool

The desirable attributes of the tool are listed below, and are derived from a review of current tools and guides, as well as interviews with local stakeholders. While desirable, it may not be possible to provide these attributes and it will not be possible to deliver all within the scope of this research project. Nonetheless, the list of attributes can guide the specification of the tool and indicate future enhancements to be considered. A list of constraints then follows in the next section.

Table 5.3 Suggested desirable features of a VKT tool

Attribute of tool	Implication for tool design (where possible)
Mimics full transport modelling (ie, gives similar result, steps can be readily aligned)	Follows similar structure to traffic model*
Is based on best practice	Involves VTM and not just FTM*
Educates users	Needs lots of notes & diagrams, including glossary (including possibly supply and demand diagrams for each cause)
Can be applied in all New Zealand locations	Includes regional (and maybe finer) data*
Considers major influences	Includes road categories (ONF) to capture functional use and traffic volume. Include standard transport model steps.
Can consider lower/higher GTC elasticities for length of trip, purpose of trip, social/economic/demographic groups	Includes ability to adjust standard elasticity
Shows before and after mitigation	Includes basic travel demand management (TDM) features (may in time become a TDM tool?)
Considers potential land-use effects	Distinguishes between short-run and long-run effects
Conveys the sense of uncertainty inherent in the output derived	Shows steps involved, assumptions being made and concludes with a wide range
Integrates with current NZTA/RCA institutional arrangements and definitions	Matches with ONF and MBCM
Is easy to use for novice users	Provides default settings which can be overridden as more information is gathered. Preferably web-based (but with excel download of results)
Warns of the cumulative effect of many small additions to lane-km (which individually may be minor).	Includes warning when filtering out likely small individual project effects. Recommends consideration of individual project within programme or package of interrelated projects.

* Requires regular calibration

5.3 Potential constraints on tool development

The following section lists potential features of the tool that would be advantageous, based on the previous chapters, and considers whether these features are viable within this project – if at all.

Table 5.4 Probable constraints of an initial VKT tool

Scope	Comment on constraints
(a) Possibility of building a tool similar to DIADEM or VERPAT that entails traffic modelling?	Complex, so unable to build in timeframe of project and unlikely to meet needs of non-modelling users
(b) Possibility of establishing a database of trip distribution for sub-regional zones, either based on household trip surveys or current transport models or TomTom data?	Likely best starting point is to adopt recent Beca disaggregation (of odometer data) by TLA. NZ Household Travel Survey potentially not yet reliable (major changes to sampling and survey methods post-2015)
(c) Possibility of providing an interactive online map of (a) or (b)	Not possible within current project scope but likely to be valuable as an additional step
(d) Possibility of providing an interactive online tool with features like 'Assess My Project'	As above, current build within a workbook could be treated as a proof of concept that could be integrated more widely as considered of value.
(e) Possibility of using GTC elasticities in the tool derived from New Zealand evidence	Heavy reliance will be required on international evidence
(f) Possibility of using lane-km elasticities in the tool derived from New Zealand evidence	No such evidence exists but the project team will attempt to estimate from current models
(g) Possibility of including background travel growth for regions within the tool as default	Is possible

5.4 Steps within the tool

The judgement of the project team, taking into account the challenges obtaining a reasonably unbiased prediction of a VKT effect, the data requirements of alternative methods, the likely needs and (lack of) modelling skills of the user, and the aim to assist users in their consideration of VKT effects, is that Option 2 is the most viable and useful method to develop for this project.

The aim would be to take the basic lane-km method and then:

a. at least categorise the expected VKT effect as low, medium, high or similar, although some care is required with this wording
b. filter out early in the tool situations that will likely produce minimal or negative induced demand
c. identify the lane-km added and provide an indicative range of induced VKT (which will be wide)
d. identify the GTC saving likely and apply GTC elasticities
e. adjust lane-km elasticities for key factors to provide a comparison to the range provided by (c), and an indication of where in this range the effect of this project would likely lie
f. differentiate between short-run effects and long-run effects (and possibly include note about >10-year effects such as long-term land-use changes or mode dependency)
g. include the option to show the probable VKT effect of mitigation measures
h. suggest default values where possible
i. provide notes on each step
j. provide guidance on further analysis required.

6 The tool

A tool was developed that consisted of five steps, with not all steps required to be undertaken. It must be stressed that the results from the tool are indicative only, especially the effects pertaining to any changes in land use that might be induced by a road project. Nonetheless, the tool is intended to provide an insightful and methodical process to provide an order of magnitude estimate of VKT effects and the risks involved, and offers the opportunity to consider mitigation effects.

6.1 Step 1: estimate VKT based on minimum lane-km information

The first step is to calculate an initial VKT effect by applying international lane-km elasticities to New Zealand. The initial result is not intended as 'the forecast' but rather as (a) a starting point for further adjustments and (b) an initial filter to warn where induced demand is likely to be minor.

The following judgements and data gathering were undertaken to provide the base results for this step:

- Gather New Zealand road statistics by road class including:
  - June 2019/2020 data, due to this period preceding the COVID-19 disruptions
  - ONF classification, as data will be available for this (relatively) new classification in the future, with some aggregation of classes where there are few roads
  - Further disaggregation by administrator, as NZTA-administered roads carry higher traffic volumes than the same classes administer by Territorial Local Authorities
  - Regional groupings, as sub-regional groupings increased the base networks and decreased data conflicts that exist between actual and reported road location.
- Lane-km elasticities from the international literature were summarised and the project team made judgement calls to map US elasticities to New Zealand road classes, based primarily on the average AADT.

The user is asked to provide the region, road class and extra lanes added. The tool will apply the standard lane-km elasticity approach to give an initial estimate, labelled 'estimate A'.

At this stage, the tool also tests for the existence of roads of the class selected within the region and also whether the AADT of the road class is sufficiently high enough to result in induced demand.

The tool also provides a warning that this initial estimate is insufficient and proceeds to further adjustments.

6.2 Step 2: estimate VKT based on travel cost changes

The objective of step 2 is to provide a crude estimate of the likely change in GTC, to then apply a cost elasticity approach and, last, to suggest an alternative lane-km elasticity to be used in the steps that follow. That is, the cost elasticity step refines the lane-km elasticity that is then further adjusted in steps 3 and 4.

The logic applied in this step is illustrated in Figure 6.1.Two cases are considered: the addition of extra lanes to an existing road, or the addition of a new road.

In both cases, the tool uses the basic input information from Step 1 (effectively road classification and the length and number of lanes added) combined with the below additional inputs.

- Annual Average Daily Traffic (AADT). If unknown, then the average value AADT for the road type and region selected in Step 1 will be used. The GTC, and the outputs to Step 2, are usually very sensitive to AADT, so it is recommended that a value is entered (even if just to explore the sensitivity).

- Posted speed limits of both the existing road and the proposed road (used to select flow delay curves used for calculating the travel time component of GTC).
- An option to change the road classification type for the proposed road is also provided.
- Within urban centres, the general location of the road within the city. This is used to establish the average trip distance and average speed from lookup tables (which informs both the travel time and vehicle operating cost components of the full trip).
- Tolls (in dollars) can be added to either the existing or proposed roads, or both. These can also be used to represent any other elements of GTC not already included.

The GTC is calculated for an average user of the existing road over the average trip length from the inputs above. Elements included in the GTC are Travel Time Cost (TTC), Vehicle Operation Costs (VOC) and Other (tolls).

- TTC is calculated using volume delay relationships in sheet 'aCASTCI'. These (for now) are based on the Christchurch CAST SATURN Model. Specific volume delay curves are selected based on user inputs 'road type', 'number of 'lanes' and 'posted speeds'. Ideally an allowance for intersection delay would also be included, but this has not been done yet.
- VOC is based on congested speed (calculated as part of TTC) and distance, using values (including Value of Time for selected road type) from NZTA's Monetised Benefits and Costs Manual.
- Tolls are a direct user input. This input needs to be used with care, noting the simplistic nature of the model that does not stratify road users – with the cost representing the average of all users.

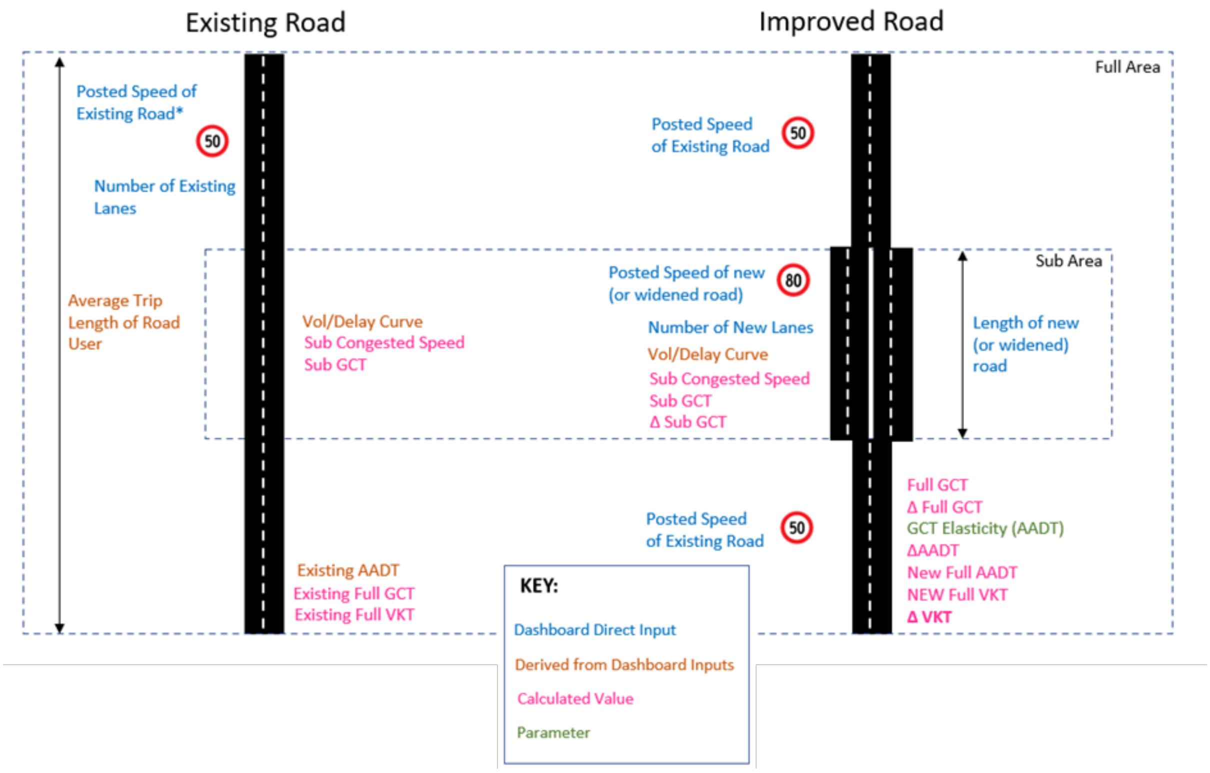
Based on the specified length of improvements (user input in Step 1), a subsection of the existing road has a revised calculated GTC based on the inputs for the proposed road. Outside of this subsection, the existing road GTC is used for the balance of the trip.

The change in GTC between the existing and proposed road can then be calculated.

Generalised Cost elasticities (currently sourced from Table A14 of the MBCM) are then used to estimate the change in demand (AADT) for the road. The change in demand then affects the GTC, so several iterations are required before the proposed road AADT and GTC converge.

The change in AADT can then be applied to the average trip length to get the estimated change in VKT.

Figure 6.1 Logic applied in cost-elasticity approach



Finally, the estimated VKT effect from the cost elasticity approach is used to imply a likely lane-km elasticity for the current situation.

6.3 Step 3: combine steps 1 and 2 and adjust for other known factors

Steps 1 and 2 lead to two estimates of the lane-km elasticity to apply. By default, the tool recommends the lane-km elasticity derived in step 2, as this considers any differences in traffic volumes on the new lanes and also the expected change in GTC, but the user is invited to override this recommendation. This override function is envisaged as being useful to an informed user where other information not included within the tool can be taken into account and is otherwise offered as an opportunity to undertake sensitivity analysis.

The other objectives in step 3 are to adjust the lane-km elasticity for the PT and land-use effects noted in the research literature.

The PT effect noted was that the lane-km elasticity was more moderate in the presence of strong PT systems, especially rail. This relationship was only crudely quantified, so the following judgements were made by the project team as to rules to apply to make an adjustment for the existence of strong PT systems, noting that New Zealand's existing PT systems are likely to fit in the 'low' category. From this perspective, this tool feature is largely academic but does (a) remind the user of this interaction with PT and (b) provides an opportunity for mitigation testing.

The land use effect is more challenging. The attribution of road projects to land use changes has not been clearly established (let alone the direction of causation). However, simply ignoring these potential effects is equivalent to treating the land effect as zero and is not helpful in understanding the potential for induced demand arriving from residential development choices. The judgement was made by the research project team to apply a rule that (a) considers local development effects and (b) can be traced back to reported literature. Note, the rule developed is offered as a pragmatic indicator, probably best approached as an indicator of the direction and magnitude of risk – the risk of extra VKT, in this case. The rule was tested against a sample of situations and provided results that the project team judged to be reasonable. To repeat, the rule is not directly derived from an evidence base but is considered consistent with wider evidence on land-use effects and produces results judged to be reasonable in the cases viewed. Given the tentative nature of this estimation process, the effect on the land use calculation is explicitly identified in the final VKT estimate.

An override function on the lane-km elasticity implied by the tool is provided for the same reasons as the previous override.

6.4 Step 4: adjust for diverted traffic

As above, a relatively simple rule was applied to the diversion effect in the tool. Again, the research literature identifies that traffic induced on a road class or through a specific corridor is likely to be partially – but not fully – offset by traffic reduction elsewhere. Based on the limited research available, a rule of 50% diversion was applied as a default adjustment. One adjustment was further made to this diversion factor: the extra VKT arising from land-use change is calculated as a net VKT such as, for example, the average distance travelled by a resident in a suburb on the fringe of a city, minus the average distance travelled by an average city dweller. Hence, the diversion factor is adjusted to exclude any further adjustment to this land-use effect.

An example will illustrate the methodology applied:

- If the induced VKT figure from step 3, termed the ‘local effect’, was 100,000 km and did not include any land-use effects then the diversion factor of 50% would apply and the net induced traffic effect would be estimated to be an extra 50,000 km, termed the ‘national effect’.
- If step 3 produced a local VKT effect of 139,000 km, including 39,000 km arising from induced land-use changes, then a diversion factor of 36% would apply, with the national induced VKT estimate now being 89,000 (being the 50,000 above, plus the land-use effect of 39,000).

The results from step 4 are presented as an implied long-term national lane-km elasticity. An override function on the diversion factor is provided for similar reasons to the previous overrides on the lane-km elasticity.

6.5 Step 5: present results

The results are presented in step 5, along with a summary of key steps taken in the tool as a check that the user had made the selections they intended to.

The results are presented, first, as point estimates of the local and national long-term induced demand effect, along with the component due to the land-use rule (and user selections) applied.

Two extra features desired of the tool were to also show the range of probable VKT outcomes and to classify the effect as ‘low’, ‘medium’ or ‘high’. There are problems with both features. First, there is no consistent model applied through each step in the tool that would enable estimation of a standard deviation or confidence interval. In particular, a series of pragmatic judgements were made, which will have introduced an unknown (but hopefully small) bias. Second, rating a small VKT effect as ‘low’ risks undermining the cumulative effect of repeated small changes, while terming a VKT effect as ‘high’ when it is likely to be less than 0.5% of New Zealand’s VKT (and inducing an even smaller proportion of New Zealand’s GHG emissions) can be misleading. The suggested compromise is to show the estimated VKT effect within three ranges:

a. an effect similar to that of a large motorway expansion in Auckland – termed ‘top of range’ (for want of a better term)

b. an effect similar to that of a large motorway expansion in Christchurch, termed 'mid-range'

c. lower effects, termed 'bottom of range'.

6.6 Example of tool application

The following is an example of the output for a known project, namely the recently completed CSM2 improvement to the Christchurch southern motorway. The estimated induced VKT in New Zealand of the project to add 40 km to the existing NZTA-administered motorway in the Canterbury region, which will likely reduce GTC by 52% on the affected trips (ie, the OD pairs within the OD matrix), is around 215,000 km per day, including a tentative 100,000 km due to higher residential development near the fringe-city project that might not have happened elsewhere across the city. The local effect is likely to be 388,000 km or 288,000 km excluding the land-use effect.

Figure 6.2 Tool output for CSM2 project (see also Worked Example in tool)

Combined lane-km elasticity and cost elasticity tool to indicate induced traffic

Click in orange shaded cells. Select from dropdown menus or provide input. See Notes to right of dropbox for more information.
The tool builds up an estimate (from A to D) of the long-term VKT effect for NZ in 5 steps (click + to left to expand each step).
It is recommended that time is taken to cosnider each step.
This tool should be viewed as an indicative estimate, to be confirmed by transport modelling.

USER INPUTS	INFORMATION REQUIRED	NOTES (including via links)
Step 1. Estimate VKT change based on (minimal) lane-km information		
Takes road statistics for user-selected region and road class (#1), plus user-provided project data (#2), plus tool-provided lane-km elasticities (#3), to give initial unadjusted estimate of change in VKT (A) using international research on lane-km elasticities		
Project and tool run identifier:	CSM2 - Add 40 lane-km to Christchurch Southern Motorway (that connects to fast growing Rolleston)	Note: Glossary
#1 Selecet existing roads to be used as base for comparison:		*Change selections to update regional road data (shown to right)*
NZ Region:	Canterbury	Note: Regions
Waka Kotahi or TLA administered roads:	Waka Kotahi	Note: Admin
NZ Road Classification (ONF):	Transit Corridors	Note: ONF
#2 Input project data to determine length of new road lanes:		*Tick confirms valid entries in boxes below*
Length of new or widened road (km):	10	
Number of existing lanes (the BEFORE):	0	*Enter 0 if new road*
Lane number after adding new lanes (the AFTER):	4	
END of step 1 inputs		Note: Lanes
Click + to left to expand step		
Step 2. Estimate VKT based on travel cost changes		
If step 2 selected (#4), then takes more user-provided project data (#5), plus tool-provided speed-flow curves(#6) , plus user-provided tolls (#7), plus MBCM-reported cost elasticities (#8), to give a second estimate of change in VKT (B), using a cost elasticities (NB this step can be skipped)		
#4 Select if to enable step 2 (or disable)	Enable	
Click on + to left to expand step		
Step 3. Choose between A and B (or other), then adjust for other known factors		
Uses a lane-km elasticity, either from A or implied by B or a user-provided override (#9), then adjusts for user-selected PT and land use factors (#10), and then allows provides another opportunity for a user-provided override (#11) (NB this step can be skipped)		
Click on + to left to expand step		
Step 4. Adjust for diverted traffic		
Applies a simple conversion factor, with the user ability to override (#12), to isolate extra national VKT		
Click on + to left to expand step		
Step 5. Present results		
Provide the adjusted VKT estimates and summary	*Check as intended*	
% change in GTC	-52%	*You applied Step 2*
Elasticity overrides applied	FALSE	*You chose default elasticities*
Land use effects applied	TRUE	*You applied land use effects*
Diversion overrides applied	FALSE	*You chose default diversion*
Extra lane-kms (km)	40	

	Induced VKT per day
	Within locality
C. Earlier estimates adjusted for cost and other factors to give local VKT point estimate of:	388,000
	At NZ level
D. After further adjusting for diverted traffic, the net VKT point estimate for NZ is:	215,000
Of which, the (less certain) land use effect is:	100,000
Induced demand rating (tentative):	**Mid range. VKT 50-250k**
Note, typically around 50-60% of the VKT effect will occur within 1-3 years (ie, in the short-term)	Note: Short-term

WARNING: the point estimates provided for a single project sit within wide probable ranges, say as wide as ± 80%

Further transport modelling is recommended where induced demand is considered important

The tool is an output of Waka Kotahi NZ Transport Agency research project TAR21/22: Assessing induced traffic demand in New Zealand

6.7 Sense checking

The above example, plus four others, were used to compare the tool results to results from modelling runs for the same project with the Regional Christchurch Transport Model (CTM).

The five real world projects that have been tested are as below.

- Ferry Road 4 laning (yet to be constructed) – adding 1.3 km of additional lanes on a radial major arterial road near the city centre.
- Northcote Road 4 laning (yet to be constructed) – adding 0.6 km of additional lanes on an orbital major arterial road in mid-Christchurch.
- Harewood Road 2 laning (yet to be constructed) – removing 0.8 km of additional lanes (to accommodate a cycleway) on a radial arterial road in mid-Christchurch. This project tests for a negative change in VKT.
- Christchurch Southern Motorway Stage 2 (CSM2) (constructed in 2020), the example shown above and repeated here in more detail but excluding the land use effect – a new 10 km motorway connection between outer Christchurch and Rolleston (in Selwyn District).
- Christchurch Northern Corridor (CNC) (constructed in 2021) – a new 10 km motorway connection within Christchurch connecting the Northern Motorway to Waimakariri District.

While the CTM can provide estimates of VKT, it was found that results were unsuitable for comparisons with the tool for the following reasons.

- Model noise – despite convergence to less than 0.1%, this difference equates to approximately 3,000 VKT per day.
- Fixed trip generation – the CTM (like most regional models) maintains constant trip generation based on demographic inputs but allows distribution of trips between origins and destinations to vary in response to network changes. While increased traffic (and therefore VKT) was estimated on improved routes, the model reduced VKT in other areas (including those remote from the area of interest) due to the balancing required to satisfy the constraint that overall trip generation cannot change.
- Traffic assignment – changes in VKT related to traffic assignment are difficult to untangle due to cascading effects combined with the noise issue described above. For example, where additional capacity is provided, trips can be drawn from other routes, which in turn draws other traffic to the newly relived routes, etc, each with VKT implications that extend over a wide area (beyond the corridor of interest).

Therefore, comparisons with CTM have been limited to the implied changes in AADT for each scheme. Generally, it was found that Step 2 of the Induced Traffic Tool estimates an increase in AADT of similar magnitude indicated by the CTM.

The comparisons also confirmed the findings in Section 6.7, where the GCT calculated in Step 2 of the Tool results in a much higher VKT increase than Step 1 (lane-km) where base roads are congested (eg, Ferry Road and Northcote Road). And also where the GCT calculated in Step 2 of the tool results in a much lower VKT increase than Step 1 (lane-km), where base roads are not congested (eg, Harewood Road).

For the two motorway projects (CSM2 and CNC), it was found that the GTC method (Step 2) yielded similar results to the lane-km method (Step 1). This suggests that the lane-km method is reasonably reliable for these types of large-scale motorway projects.

A summary[64] of the model inputs and outputs used to make the comparisons above is provided on the following page.

[64] The outputs of the tool may vary slightly compared with results currently produced by the tool due to subsequent refinements of the tool.

Figure 6.3 Comparison made by current authors of tool runs versus CTM model runs for same five Christchurch projects

Regional Model (CTM) Outputs		Ferry Road 4L	Northcote Rd	Harewood Rd	CSM2	CNC
Outputs	Model Base AADT	27,000	26,000	11,000	33,000	30,000
	Model New AADT	29,000	27,000	10,600	44,000	35,000
	Change in AADT	2,000	1,000	- 400	11,000	5,000
	Change in AADT (%)	7%	4%	-4%	33%	17%

Induced Traffic Tool Step 2		Ferry Road 4L	Northcote Rd	Harewood Rd	CSM2	CNC
Outputs	Additional AADT	2,687	1,288	-63	12,253	9,377
	Change in AADT (%)	10%	5%	-1%	37%	31%
	Change in GC	-14%	-7%	1%	-52%	-44%
	Step 1 VKT	6,212	2,914	-3,855	287,412	287,412
	Step 2 VKT	21,630	10,367	-510	284,863	217,916
	Step 5 VKT	20,000	10,000	0	280,000	210,000
Inputs						
Step 1	NZ Region:					
	NZ Region:	Canterbury	Canterbury	Canterbury	Canterbury	Canterbury
	Waka Kotahi or TLA administered roads:	Local LTA	Local LTA	Local LTA	Waka Kotahi	Waka Kotahi
	NZ Road Classification (ONF):	Urban Connectors	Urban Connectors	Urban Connectors	Transit Corridors	Transit Corridors
	Length of new (or widened) road (km):	1.29	0.605	0.8	10	10
	Number of existing lanes:	2	2	4	0	0
	Number with new lanes:	4	4	2	4	4
	Added Lane km					
Step 2	Enable	Enable	Enable		Enable	Enable
	AADT of nearest alternate road (if known)*:	27,000	26,000	11,000	33,000	30,000
	AADT (for road) used for calculation:	27,000	26,000	11,000	33,000	30,000
	Length of nearest alternative route (km)*:	1.29	0.605	0.8	11	11
	Posted speed limit nearest alternative roads (kph)*:	50	50	50	80	60
	Number of lanes on nearest alternative route*:	2	2	2	2	2
	Posted speed limit of new (or improved) road (kph):	50	50	50	100	100
	New lanes location within city:	Christchurch Inner	Christchurch Mid	Christchurch Mid	Christchurch Outer	Christchurch Outer
	Implied change in distance (km):	0	0	0	-1	-1
	Tolling on new (or widened) road ($):	0	0	0	0	0
Step3	PT mode share (rail, metro, segregated bus):	Low	Low	Low	Low	Low
	Counterfactual development density:	Mid - within city but not CB	Mid - within city but not CB	Mid - within city but not CB	Mid - within city but not CB	Mid - within city but not CBD
	New development density:	Mid - within city but not CB	Mid - within city but not CB	Mid - within city but not CB	Mid - within city but not CB	Mid - within city but not CBD
	Development quality (from induced traffic perspective):	Not strong	Not strong	Not strong	Not strong	Not strong

6.8 Tool sensitivities and performance

Several permutations of inputs were also run through the tool to (a) test the working of the tool and (b) to test the reasonableness of the results, as judged by the project team, for hypothetical projects beyond the five Christchurch projects above.

The key observations were as follows.

1. The lane-km model gives results that are a direct function of the average AADT of that road type in the region in question. Thus, we see variations by road types in different regions that result from different average AADT for a regional road type. Some of this variation is displayed in Figure 6.4 to Figure 6.7 (from authors' own analysis), where we can see that for two additional lane-kms, the lane-km model estimates between an additional 32,000 VKT/day on an Auckland transit corridor and 34 VKT/day on a Chatham Islands rural connector. This has some sense about it as we would expect congestion costs to be highest on the roads with the highest AADT flows and the cost reductions to be largest on these roads. Additionally, the level of generated traffic will be proportional to the AADT, all else being equal.

Figure 6.4 Induced traffic by road type in Auckland (for an additional 2 lane-kms) using the lane-km model (local VKT/day)

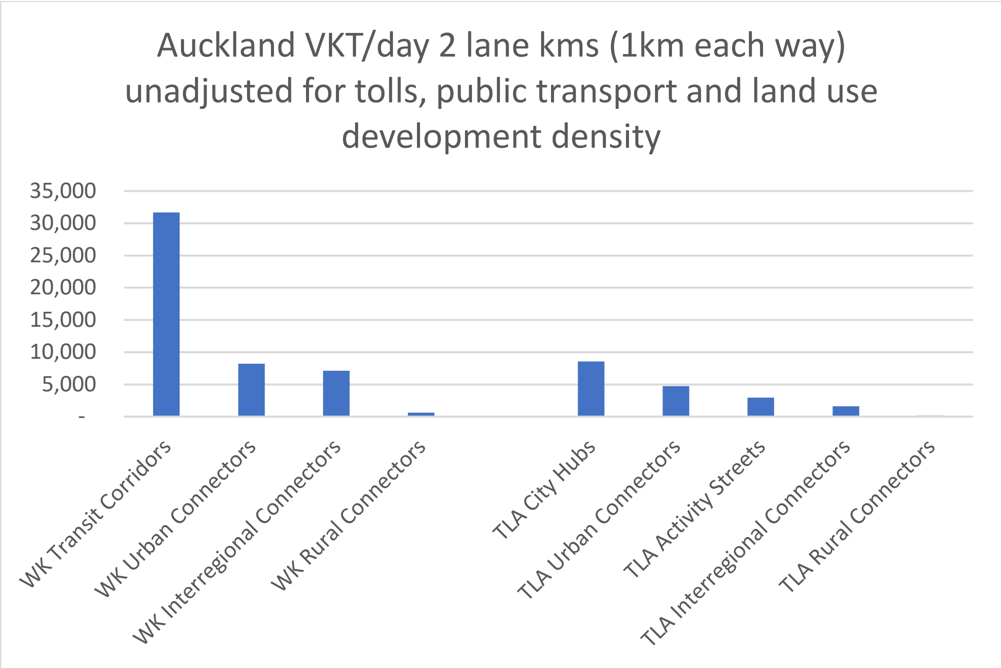


Figure 6.5 Induced traffic by region for urban transit corridors (for an additional 2 lane-kms) using the lane-km model (local VKT/day)

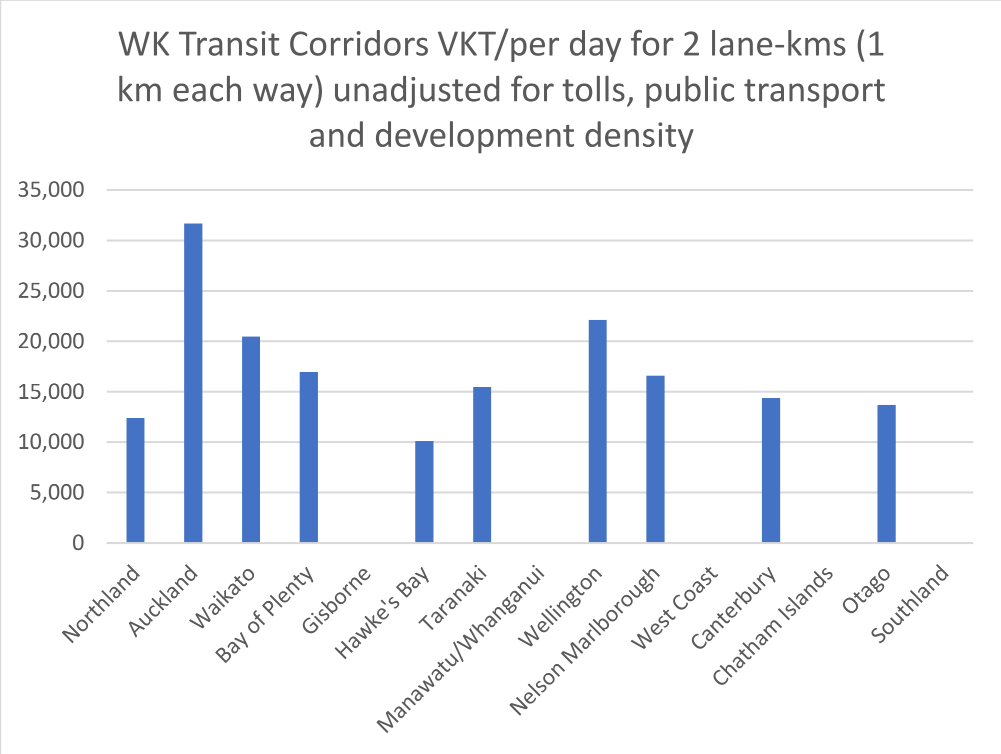


Figure 6.6 Induced traffic by region for NZTA inter-regional connectors (for an additional 2 lane-kms) using the lane-km model (local VKT/day)

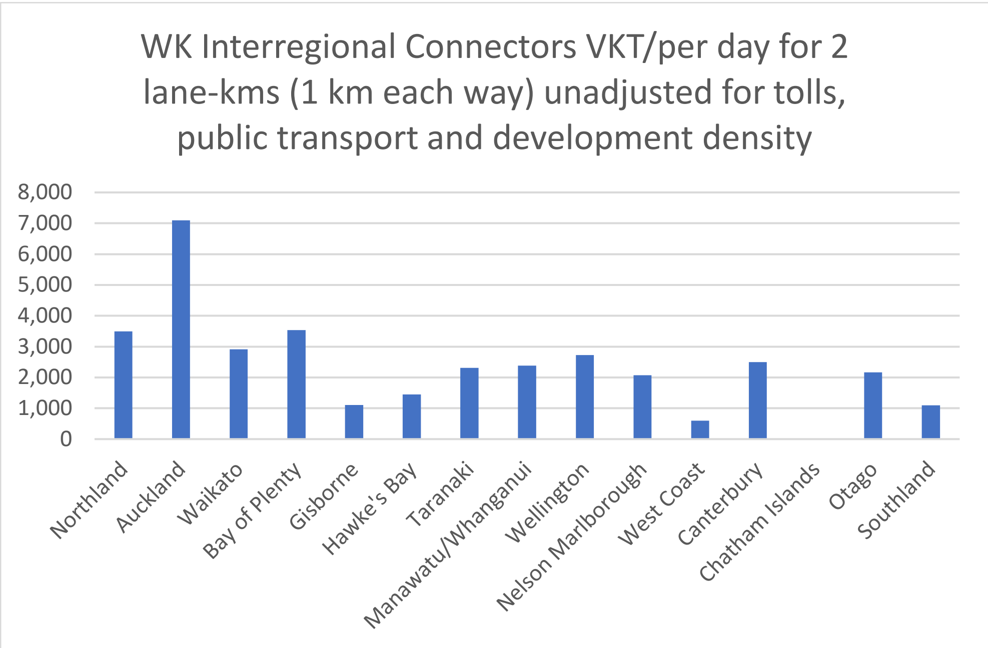
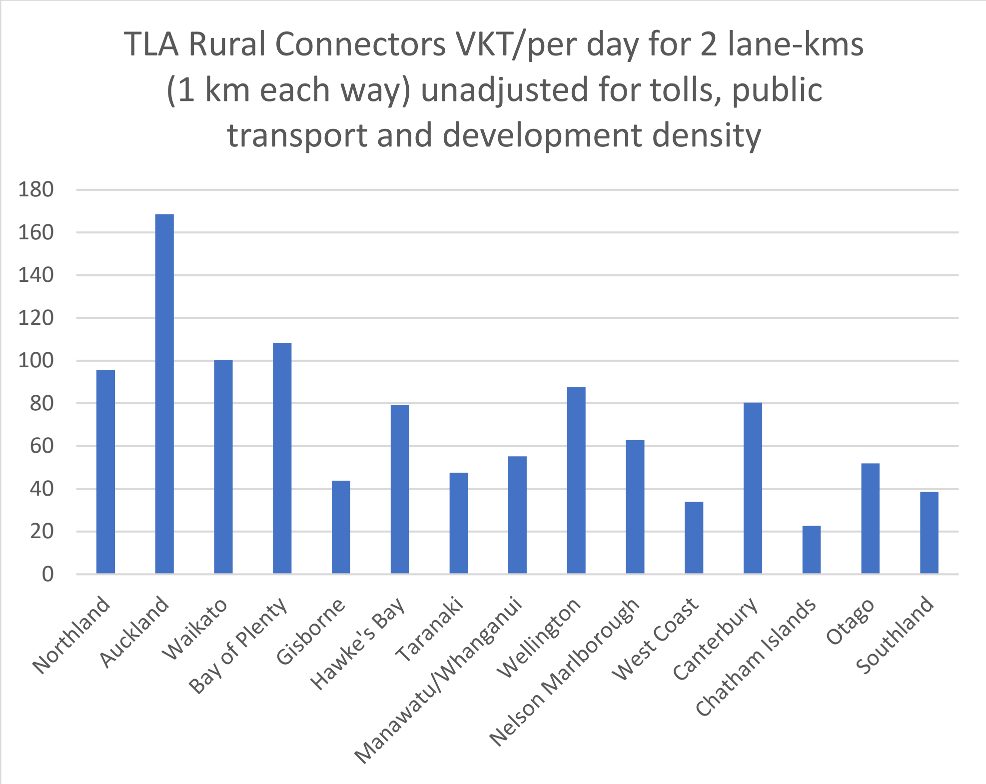


Figure 6.7 Induced traffic by region for TLA rural connectors (for an additional 2 lane-kms) using the lane-km model (local VKT/day)



2. It is likely that the lane-km model overestimates induced VKT on the **average** urban road in a region. The lane-km elasticities have been imported from the USA where most urban roads are highly congested. New Zealand road conditions do not seem to replicate those, aside from in Auckland on the urban motorways (transit corridors). For average AADT flows we can see that it is only on Auckland Urban Transit Corridors that we get similar predictions between the lane-km model and the GTC model (Figure 6.8). Closer analysis of ‘average’ volume-to-capacity ratios on roads outside of Auckland indicate that the average road is congested, but not overly so (Figure 6.9).

Figure 6.8 Comparison between lane-km and GTC approaches for average AADT flows by region (transit corridors) (local VKT/day)

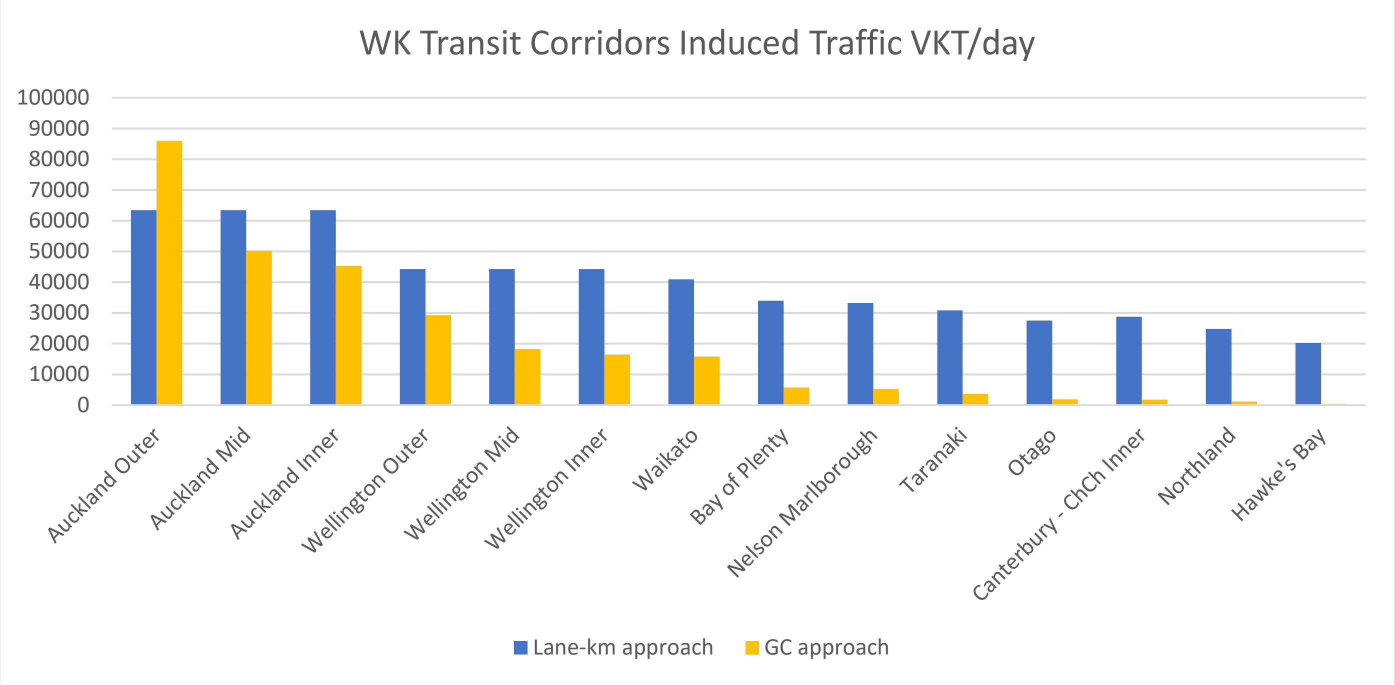
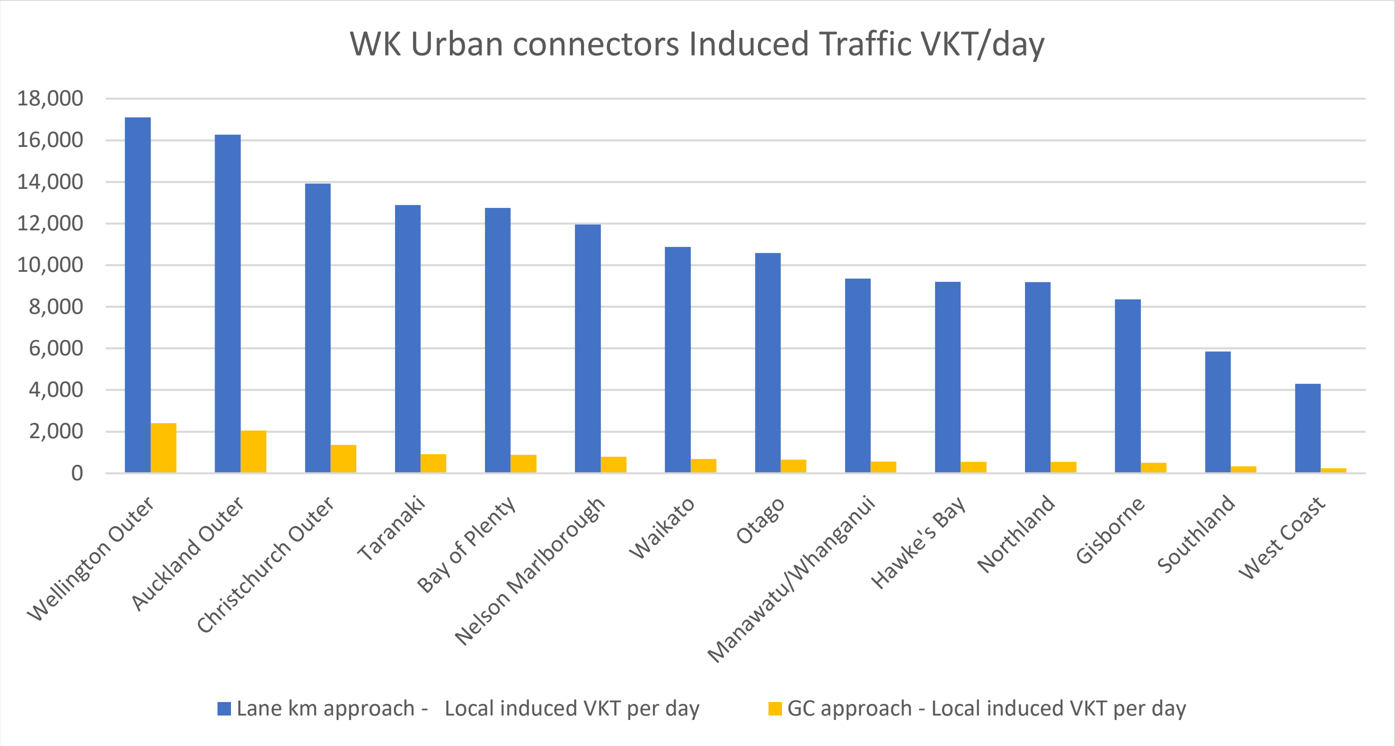


Figure 6.9 Comparison between lane-km and GTC approaches for average AADT flows by region (NZTA urban connectors) (local VKT/day)

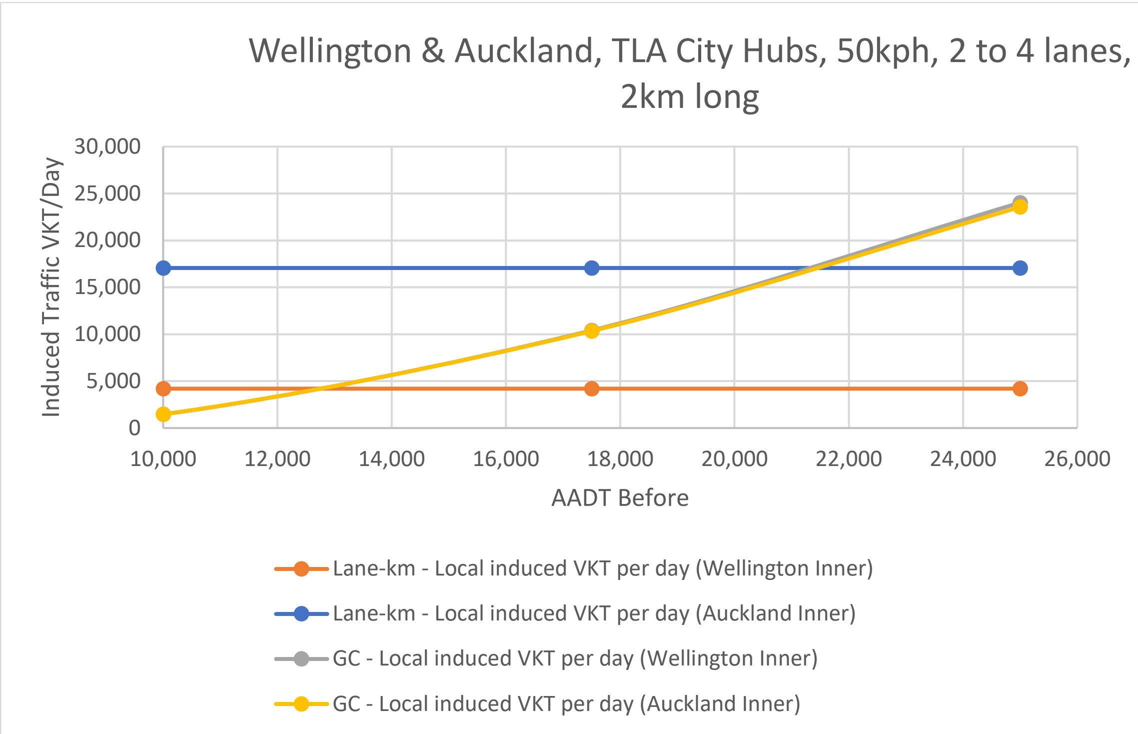


3. Whilst the lane-km model gives inter-regional variation, it does not pick up the variation within a region. Some road types within a region have very different traffic levels, despite the same ONF classification.

This would not be a problem were it not for that fact that, typically, road investments tend to focus on problem areas, which invariably are those where delays (ie, congestion) are worst. In other words, investments will most likely occur on roads that have above average AADT.

This and some of the earlier points are nicely illustrated in Figure 6.10. Here we can see that the level of induced traffic predicted by the lane-km approach for a city hub in either Auckland or Wellington differs between the cities, but is insensitive to the actual flows (and congestion) on that road. This gives two very different predictions of induced traffic between the cities. However, the generalised cost model gives very similar predictions for both cities (the difference between the predictions arises from a slight difference in average trip length between the cities), with the predicted level of induced traffic dependent on the base level of AADT flows. We can also see from this figure that the GTC model can predict more traffic than the lane-km approach for higher congestion levels than the city 'average'. In this particular case it is predicting more traffic in Wellington when the volume/capacity ratio exceeds around 0.5, and in Auckland around 0.85 (volume-to-capacity ratios are not shown in the figure).

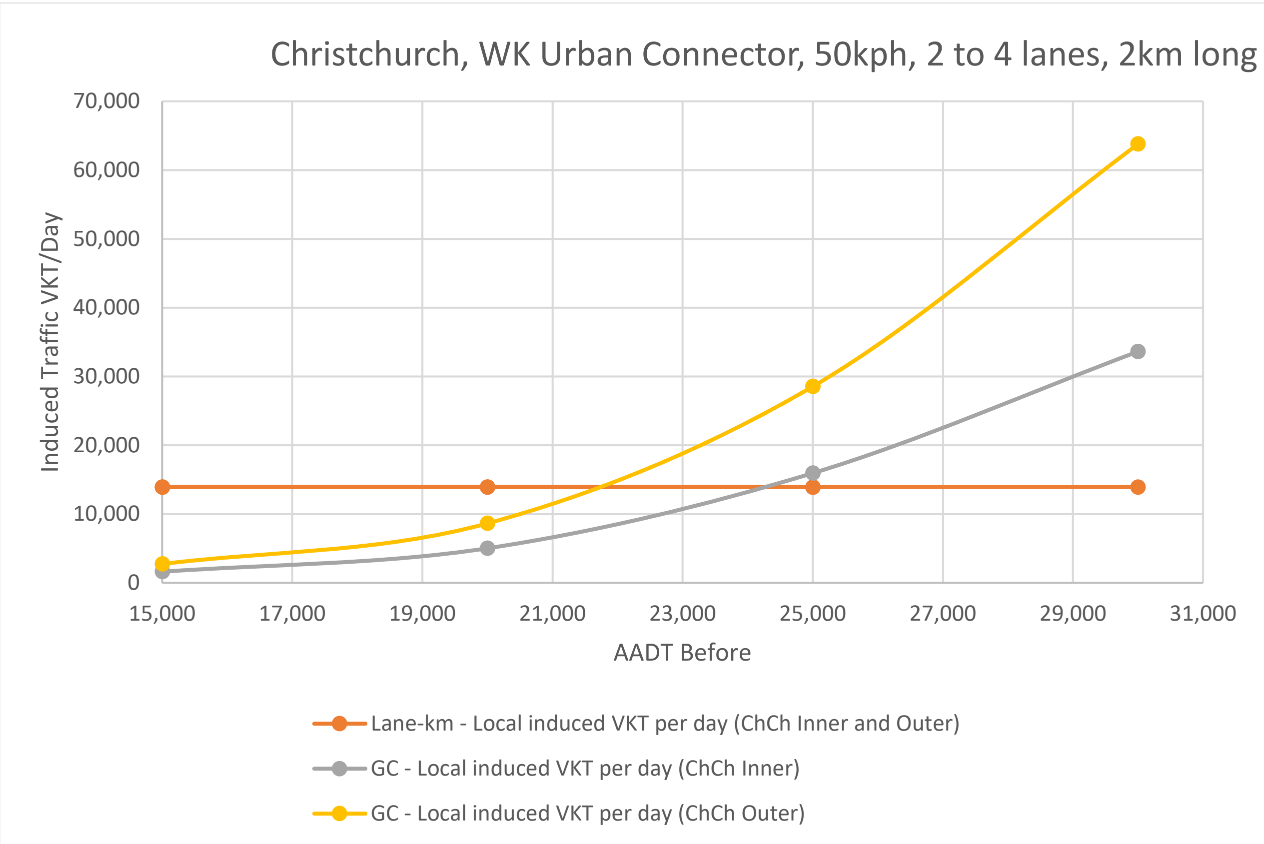
Figure 6.10 Comparison between lane-km approach and generalised cost model by AADT flows for TLA city hubs (local VKT/day)



4. The level of induced traffic is not only sensitive to the cost reduction, but also trip types. As trip lengths vary between different city areas, with trips in the outer areas longer on average, then the level of induced traffic also varies, as can be seen in Figure 6.11 and Figure 6.12. This variation in location is not significant at low volume/capacity ratios but becomes quite marked at high volume/capacity ratios. This clearly has a policy implication, as investment in city-centre road infrastructure is likely to induce less VKT than in roads in the outer suburbs. This also links into the discussion on increased vehicle usage for fringe developments compared to mid- and inner-city developments.

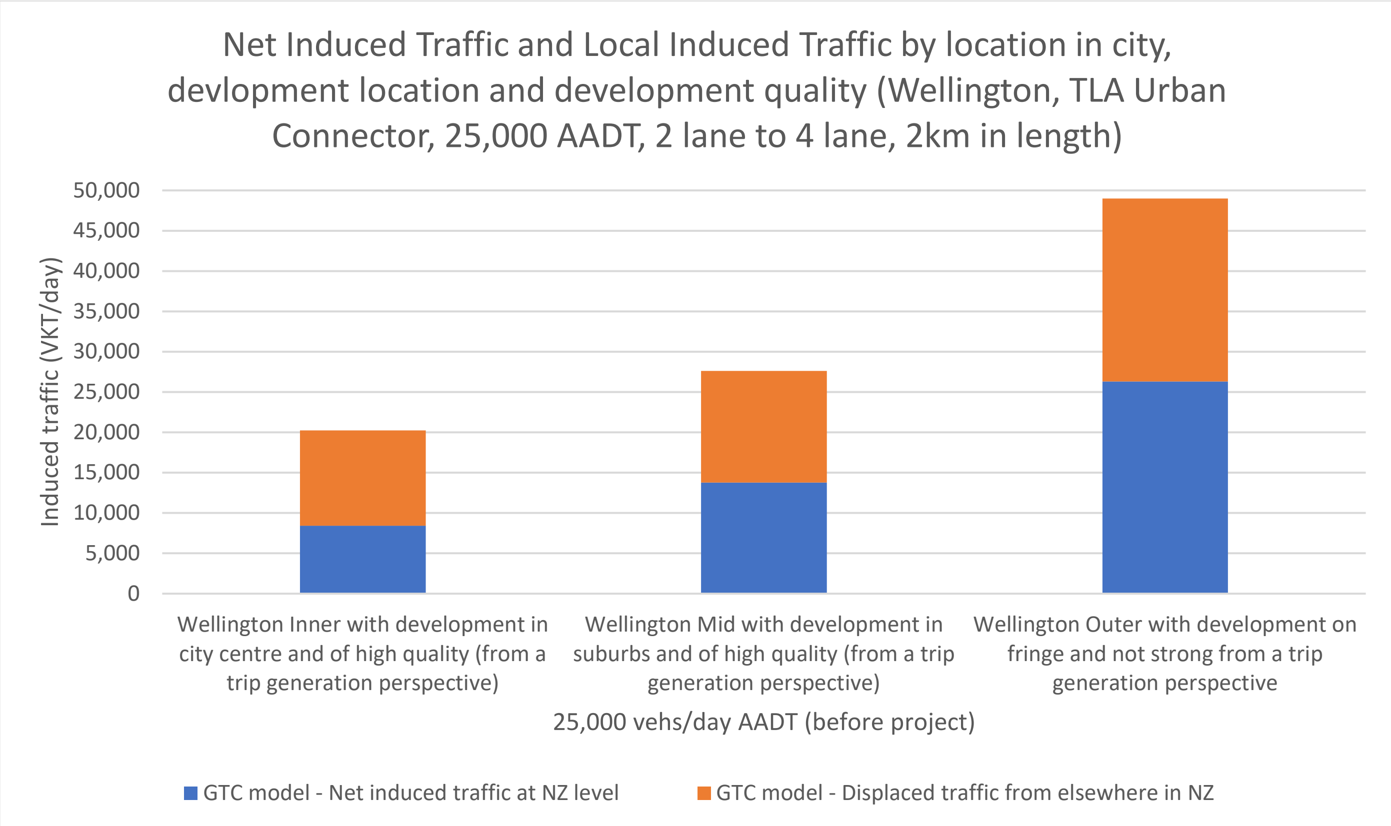
Figure 6.11 Comparison between inner- and outer-city projects with the lane-km approach and generalised cost model by AADT flows for Auckland Transit Corridor (local VKT/day)

Figure 6.12 Comparison between inner- and outer-city projects with the lane-km approach and generalised cost model by AADT flows for Christchurch NZTA Urban Connectors (local VKT/day)



5. Land-use change and the movement of economic activity (and residential locations) both have a strong impact on the net level of induced traffic, which also varies with the location of development in a city. From the empirical evidence, the starting point is that 50% of the locally induced demand is displaced (or diverted) from elsewhere. It is also assumed that it is drawn from a like-for-like location. This represents the middle column in Figure 6.13. Changing the location of the project to Inner Wellington and focusing high-quality, permitted development around the city centre reduces not only the total amount of induced traffic, but also reduces the proportion of that traffic that is net induced at the national level. That is, the proportion of net induced traffic at a national level reduces proportionately more than the amount of locally induced traffic does. Conversely moving the project to the outer part of Wellington and permitting fringe development of lower quality (from a trip generation sense), substantially increases the amount of induced traffic, and also increases the proportion of the local traffic that is induced at the national level. The modelling in this example suggests changing the location of the project – the development location and its quality may increase the amount of net induced traffic at the national level by a factor of three (compare the size of the blue rectangle in the first and third columns). This is for a similar road, TLA urban connector, with the same level of AADT (25,000).

Figure 6.13 Net induced traffic and local induced traffic example (Wellington, TLA Urban Connector)



6.9 Key risks applying the current tool

The following risks with use of the tool are noted below.

1. The logic of the lane-km section of the model rests heavily on the additional lanes being similar to the existing roads with the same classification. There is the risk that the roads within a regional class can vary from the new lanes of interest and hence the estimated VKT effect will be biased, either upward or downward. This risk is compounded with any changes over time to road classifications.

2. Likewise, the tool relies on AADT estimates and these estimates may be inaccurate, being either outdated or based on judgements rather than actual counts.
3. Within the GTC elasticity steps, there is the risk that the generic speed-flow curves may not be appropriate for the new lanes under consideration. Also, it is possible to use combinations of inputs that are unrealistic (eg, an AADT that grossly exceeds the capacity of the road). In these cases, we have provided warnings where possible.
4. The GTC model functionality to include a new road (eg, a bypass), rather than the widening of an existing road, is simplistic in that it assumes that the new road costs are comparable with an alternative 'generic' route of similar function and distance, and which has its capacity constrained by the (alternative route) user-specified speed and lane configuration. Methods that calculate the cost on the new and nearest alternative roads and then distribute existing and induced traffic over both routes precisely were considered, but found to be too complex for the current spreadsheet-based tool.
5. The GTC model also focuses on the corridor of interest and therefore does not fully account for potential secondary 'knock-on' VKT effects over the wider network. Adjusting for this in a simple tool is difficult due to such a wide range of context-specific factors.
6. Both estimation methods – lane-km and cost – use elasticities inferred from international research and a few local studies. Further research may reveal these elasticities to be inaccurate and, even if correct, the elasticities apply to a large set of projects. The results for any one project can differ widely. From this perspective, the tool is more suited to programme appraisal rather than project appraisal.
7. The scale of combined transport and land-use effect is indicative only.

These are all reasons to undertake more extensive modelling and investigation if induced demand is a sensitive issue for the project in mind.

It is also important to note that the version of the tool provided for delivery has been developed in Microsoft Excel and evolved over the project duration as new ideas were tested and then either discarded, retained or modified further. As a result, some of the calculations and layout can appear 'clunky' or inefficient at times. There is the potential to streamline many of the calculations (especially those associated with the GTC step). We have purposely avoided using VBA,[65] even though this would have been more efficient and tidier, due to the issues this can cause with the internal security checks of different organisations. The tool has been alpha and beta tested, but in line with its proof-of-concept nature, not all permutations have been tested.

The tool in its current state should therefore be considered as a fully transparent prototype or proof of concept, which can potentially be tested, refined and implemented in other various ways (such as a custom web-based application), as NZTA sees fit.

[65] Visual Basic for Applications – which enables Visual Basic scripting within Microsoft Office applications.

7 Conclusion and recommendations

The outcome of the research project is summarised below and recommendations for further steps are made.

7.1 Summary

The project set out to find evidence – and the causes – of induced road traffic in New Zealand and to develop a tool to predict the likely magnitude of induced traffic and the likely effect of mitigation methods.

A review of local and international literature and a (brief) survey of local stakeholders revealed limited evidence of induced traffic demand in New Zealand but offered good reasons to believe induced demand was happening. In particular, road projects that lead to large reductions in GTC are expected to lead to higher demand, such as those that reduce congestion and more generally shorten or quicken trips, especially where more travel from the city fringe is facilitated.

A small number of tools are available to estimate induced traffic demand but these tools were judged to be too restrictive in terms of road classes considered, and failed to consider contextual matters such as the magnitude of GTC savings.

A tool was developed by the research project team that built on the lane-km elasticity approach at the core of the few induced traffic tools available. The Excel-based tool entails five steps that a relatively novice user is likely to be able to apply, with user notes, background notes, and guides providing assistance.

The first step is an application of the lane-km elasticity approach, using New Zealand regional road data for 2019/20. This acts as:

a. a filter to exclude mooted projects of likely minimal induced VKT effect, such as small GTC savings or low volume roads

b. as a starting point for a more complete consideration of the factors that have strong influence on any VKT effect.

The second step considers the travel-cost reduction likely to be created by the project and offers a customised lane-km elasticity to build into steps 3 and 4. These two steps then further adjust the lane-km elasticity: first, for PT and land-use influences, and second, for capturing the effect of traffic diversion (the diversion could be from other road classes in the region and potentially from other roads in other regions, should people choose to migrate to the project city). The fifth and last step presents a point estimate of the induced traffic demand for the project which, it must be stressed, sits within a wide range of probable outcomes. It provides a context for the VKT effect relative to a large Auckland motorway project, a large Christchurch motorway project and any smaller projects.

Each step can be traced back to international research and/or NZTA's MBCM, but the broad nature of the assumptions required to make the calculations imply that the estimated result is indicative. The process of forming the estimate has several intentions:

1. to provide the user with insights into the key influences, the sensitivities to influences, and the potential for mitigation
2. to provide a perspective on the magnitude of potential VKT effects
3. to inform project refinement ahead of more extensive transport modelling.

We have illustrated some of the differences between policy options that the tool can help identify.

7.2 Recommendations

The tool developed is an innovative attempt to align international and local research on lane-km elasticities, travel-cost elasticities and land-density elasticities with local road data and user-contextual inputs. It is likely that improvements will emerge as the data improves, the lines of research develop, and as users explore the current tool. Thus, further iterations of the tool are to be expected. In the short term, testing on projects of interest will likely reveal any immediate shortcomings, which could be corrected or improved before general release.

In the longer term, the processes that will likely lead to changes revolve around maintenance and further improvements.

Under maintenance, processes will be required to:

- Update the annual road data, while possibly not required annually, it would likely add value if done every 3–5 years
- Capture any improvements to road data, such as more accurate and prompt reporting, and any refinements to ONF classification of specific roads
- Register and correct any workbook issues that might arise
- Monitor and include updates to lane-km, travel cost and density elasticities and other MBCM parameters
- Collate the results when the tool, especially when more detailed modelling outcomes is also undertaken, to provide case studies for education and for subsequent refinement of the tool parameters.

Further improvements are likely to include:

- Extending the GTC model component to rural roads, which would require data on trip-length variation by road type and region
- Refining the GTC calculation, including the provision of speed flow curves for more New Zealand roads and allowing for intersection delay
- Adding an option in the tool for users to input average trip length
- Improving functionality for modelling new roads (eg, bypasses), compared to widening of existing roads
- More precisely categorising the level of PT service and its influence on the induced-traffic effect
- Better defining and estimating the road project attribution to land-use changes, and in turn the effect of these land-use changes on VKT
- Better defining and estimating diversion effects.

That said, the tool as it stands is expected to provide a reasonable insight into the induced-traffic issues faced for road projects as they are mooted.

Beyond use of the tool, it is recommended that NZTA provides a broader definition of induced demand in the MCBM.

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Appendix A: Summary of insights for the tool

This is a collation of numbered insights from within the report.

*#1. A cost change is a necessary condition for induced traffic. The larger the cost change the larger the quantity of traffic that is induced. Capacity changes (eg, new lane-km) is **not** a necessary condition for induced traffic. (Additional) lane-km create induced traffic only if they create cost changes. If additional lane-km do not create a cost change, there will be no induced traffic. Implication: the tool needs to be sensitive to cost changes. The tool will likely need to reflect that different transport interventions will give different cost changes. If infrastructure type is used as an input to the tool, there is likely a need to have some indirect relationship to cost changes.*

#2. The quantity of induced traffic depends on local transport conditions. Different quantities will be induced depending on congestion, substitutability of the new link and capacity of other links in the network. The tool needs to be able to accommodate different baseline transport network conditions.

#3. The quantity of induced traffic depends on the scope of analysis eg, traffic on the new road, total traffic in a corridor, total traffic in a city, total traffic in a region, total traffic in New Zealand. The different perspectives give rise to different behavioural responses being included or not included within the definition of induced traffic. Implication: a definition of induced traffic needs to be agreed for use in the tool.

#4. An early-stage tool of interest to this project is likely to be based on demand elasticities in order to be available to a wider group of users without specific transport modelling expertise; this tool will therefore not be appropriate for detailed assessment of large-impact projects, but will provide approximate estimates of induced travel and will guide users to a more extensive modelling approach.

#5. The different policy perspectives (climate, economy, economic appraisal) give rise to different metrics by which to quantify induced traffic. Implication: we must adopt a policy perspective. The focus of this project is simply on VKT, but it is acknowledged that planners will be balancing a range of perspectives.

#6. Land use change can be an important contributor to the level of traffic on a road. Whether it is induced depends on displacement. Without explicitly modelling the decision as to where households and businesses invest, this is likely to need to be dealt with by the user of the tool. Thus, the tool user will need to input level of displacement (eg, quantity of housing development displaced from one part of a city to another). The different traffic characteristics between the development sites in the counterfactuals will determine level of induced traffic. This will likely need some user input (eg, from a menu).

#7. The high induced travel demand elasticities to lane miles (from US) suggest there is a need to ensure the tool can replicate these for the relevant demand and supply conditions, to be considered reliable.

#8. Induced traffic effects are very heterogeneous, from extremely large uplifts to very small ones. In certain environments (and in conjunction with background growth) they can completely negate all new capacity, returning traffic conditions to pre-investment levels. The change in capacity (eg, lane-kms) is not always a good indicator for the likely level of induced traffic.

#9. The elasticities to additional capacity (eg, lane-kilometres/lane-miles) are sensitive to the metric that is being considered. Thus, a Duranton & Turner US urban elasticity of 1.0 is not comparable to a Garcia-Lopez et al. European urban elasticity of 2.0. They are also contingent on the average base conditions of each of the cities. Care will be needed to transfer such elasticities between locations.

#10. It is difficult in empirical ex-post analysis to distinguish between background growth and induced traffic. Where attempts have been made to distinguish between the two, it seems that induced traffic can be about 25% of background traffic growth.

#11. Significant displacement impacts associated with population movement imply that local or city level changes in induced traffic are larger than those at a wider area level. From a GHG perspective both measures are likely to be necessary (eg, if cities have GHG targets and regions/nations have GHG targets).

#12. The behavioural responses that are most important for typical economic evaluations (re-routeing & re-timing) do not appear to be large contributors to changes in total VKT. Here the evidence points towards changes in household behaviour (mode choice) and land use responses (destination choice, moving house, economic development) as large contributors to VKT effects. However, studies are limited and more research is needed in this area.

#13. Based on the short and long run elasticities reported in the studies, first year impacts seem to be in the order of about 60% of the total induced traffic effect, with the remaining effects almost exhausted within the next five years, albeit that some induced impacts have been seen to occur for many years after that.

#14. Based on differences between short run and long run elasticities, land use change behaviours look to be important for induced traffic more so than they are with typical economic appraisal/CBA.

#15. Separating out displacement effects and identifying the change in VKT due to displacing economic activity and housing has not been addressed in any of the literature we have reviewed.

#16. Best practice transport modelling is likely to be able to accommodate modelling of induced traffic due to transport behaviour change. However, widespread 'best practices' have been questioned by several authors, with numerous reviews identifying traffic forecasting errors.

#17. Modelling the feedback between transport and land use change is challenging for projects that deliver structural change. There is also the challenge of other structural changes occurring that are not caused by the transport market but which do affect transport.

#18. There is very little New Zealand research on induced demand to apply so reliance will be required on the transfer of international research.

#19. Elasticities applied to zone-pairs require zones to be established (or assumed) and the calculated changes in the number of trips would then need to be used with average route lengths to estimate the change in VKT.

#20. The functional form for the relationship is commonly applied as a <u>power function</u>, which gives the percentage change in trips as a fixed (negative) proportion (which is the elasticity) of the <u>percentage change</u> in GTC - any tool would require a user input or an assumption about the total base case trip cost between the zone pair (to then calculate a percentage change).

#21. An alternative functional form is an exponential equation which replaces the percentage change with the absolute change in GTC. This introduces the question as to which function to use? DfT (p57) recommend use of further choice functions if the exponential equation is to be used. Alternatively, the power function could be adjusted to have an elasticity that varied by trip length.

#22. The incremental nature of each formula implies that the number of trips can increase, as opposed to the VTM approach whereby the number of zone-to-zone trips may or may not be constrained – the extent and ramifications of this difference between the two methods requires further investigation.

#23. The responsiveness is likely to differ during periods of the day and this may vary by context - any tool would require a user input or an assumption about the period during the day expected to be most sensitive to travel cost.

#24. Trip segmentation may be required, including for time of day, to apply a cost elasticity approach.

#25. Methods may be required to consider car availability where mode shift is potentially a large factor.

#26. Consider any preferred elasticity method and how adjustments could be made to address pitfalls of an elasticity approach.

#27. Both GTC and local attractiveness factors may need to be considered in any VKT estimates, including any change of attractiveness.

#28. Consider methods to employ that offer flexibility about how trips ends are to be treated.

#29. Provide checks between price elasticity derived VKT estimates and lane-km elasticity derived VKT.

#30. Use of defaults, sliders and case studies are likely to make the tool easier to use.

#31. The ability to chart local spatial variation in VKT provides an intuitive means to convey the potential for land use effects on VKT.

#32. The tool will provide an opportunity to educate planners and standardise use of terminology.

#33. The tool can provide a guide and checklist that leads to a more thorough and consistent modelling of induced demand.

#34. Discussion of long-term land use changes will enable consideration of potential GHG effects of land use and transport projects, and how they may interact.

Appendix B: Summary of elasticities

Using both a lane-km and cost-elasticity approach to estimate the extra VKT to expect from additional road capacity requires applying a set of elasticities. These elasticities should have a solid evidence base and be applicable to New Zealand projects. A summary of recommended elasticities follows.

B.1 Lane-km elasticities

The lane-km elasticity evidence is segmented by road type. It shows a lower effect nationally (termed 'net' in the table below) than would be the case locally (termed 'gross' in the table below), due to the movement of people between regions. It also shows a lower effect in the short-run than the long-run, largely for similar people-movement reasons. The evidence is strong for heavily congested motorways, but limited for other road types, while showing that strong PT and tolls can reduce the VKT effect. The following table and notes summarise the key lane-km elasticities.

Table B.1 Summary of core international lane-km long-run elasticity evidence[66]

Context	Net of migration	Gross of migration
Urban trunk/motorway at capacity	0.5	1.0
Urban other	0.3	0.6
Rural highways	0.2	0.4
Rural other	0.1	0.2
Short term response is	60% of full response in congested conditions	

Severely congested urban 'trunk/motorway' roads operating at capacity

For these types of conditions, the evidence points to a long-run elasticity of 1.0 (Fulton et al., 2000; Noland, 2001; Cervero and Hansen, 2002; Duranton and Turner, 2012; Graham et al., 2014; Hymel, 2019), which includes people migrating into the area and hence overstates the national VKT effect. Duranton and Turner (2011) estimate the breakdown of the source for this extra VKT (for these road types) to be: 29% from commercial vehicles, 21% from household migration, 10% from re-routeing, and 39% from changes in other household behaviour.

These results imply a long-run net elasticity of around 0.5, possibly slighter higher, depending on which sources are considered a transfer of VKT, rather than a national increase in VKT. A similar conclusion is reached from the results produced by Rentziou et al. (2012), where the net impact is 50%. However, this assumes all economic activity is displaced, whereas in reality there will have been some increase in economic activity. A lower conclusion is derived from Noland's 2002 work, where 72% of VKT change was attributed to demographic changes, implying a net land-km elasticity of 0.28.

The following assumptions are recommended for a New Zealand tool for this road class and situation:

- Net of migration elasticity in the range of 0.3–0.5

[66] Source: Authors' conclusions from international evidence.

- Gross of migration elasticity (in locality following land-use change) is 1.0.

Other roads

Here, there is very limited evidence. Rentziou et al. (2012) estimate a rural road lane-km elasticity of 0.086 and 0.267 for urban roads. As this is at the US state-level, this would be interpreted as net of migration elasticity. Van der Loop for the Netherlands found an elasticity of 0.4 for trunk roads, which reduces to 0.2 when taking traffic diversion from other roads into account. These are interpreted as net-of-migration elasticities at state or national level.

The following net-of-migration elasticities therefore seem justifiable: rural highways, 0.2; rural other, 0.1; and urban other: 0.3. It is recommended that the default position is to use a gross-to-net ratio similar to that of Duranton and Turner (2011), which was 2.

Short run/long run

Change in travel behaviour alone typically occurs within one year, and almost certainly within two years. A combined land-use and travel behaviour change takes longer:

- In heavily congested locations, land-use change is exhausted after five years (roads return to capacity) – in these conditions, the short-run response is 60% of the full response
- In uncongested locations, land-use change may take many years to reach exhaustion (10 years or even 15 years).

The 0.6 short-run to long-run ratio is recommended as a default position.

Mitigating/exacerbating factors

Other factors have been identified as affecting a VKT response. It is recommended that the following central tendencies be considered for inclusion in a tool.

- Road pricing: Elasticity is 85% lower with road pricing (Garcia-Lopez et al., 2020; note only one study).
- PT: Elasticity is 50% lower with good rail PT (Garcia-Lopez et al., 2020; Bucsky and Juhasz (2022), two studies).

B.2 Density elasticities

Another set of elasticities that will be insightful for an induced demand tool are those pertaining to land-use changes. The research literature estimating the effects of land-use changes (in terms of changes in population density) has evolved.

However, it should also be acknowledged that the interdependency of land-use change and transport infrastructure is a challenging area to evaluate. The figures below should therefore be thought of as central tendencies, rather than precise causal effects.

The following table also provides default figures to apply when adjusting a lane-km elasticity for different land-use situations. These results reflect an interaction between built-design and population density.

VKT/person tends to increase as population density falls. Litman and Steele (2022) suggest an elasticity of −0.05 to −0.1 in isolation of other measures (ie, good built design), which could increase by a factor of 4 if combined with other built-environment measures (ie, poor built design), giving a full range of elasticities from −0.05 to −0.4. Based on population densities commensurate with the variation observed in Auckland, we therefore get uplift factors on top of the lane-km elasticities of between 0% and 90% depending on whether the urban development is high density with good design, or low density with poor design. See Table B.2 for more detail.

Table B.2 Changes in trip numbers by density and built design[67]

	Good built design		Poor built design	
Elasticity	**−0.05**	**−0.1**	**−0.2**	**−0.4**
Density (persons/km²)				
500	8.4%	17.5%	38.0%	90.4%
1000	4.7%	9.6%	20.1%	44.3%
1500	2.6%	5.2%	10.8%	22.7%
2000	1.1%	2.3%	4.6%	9.3%
2500	0%	0%	0%	0%

B.2.1 Cost elasticities

The use of price elasticities of demand (denoted η) are widely used to assess the demand response to expect from price changes. The applicability of this approach to transport interventions in New Zealand is summarised by Wallis (2004), which this section draws from heavily.

The demand of relevance to this project is the change in VKT across the network affected by the project, while the price effect is a combination of travel-time changes and potentially trip-distance changes (hence affecting vehicle operating costs) for the many trips that will occur across the same network. In other words, there are multiple supply/demand curves and multiple cost changes to consider. At this stage, it is useful to think in terms of a weighted average travel-cost reduction for the area affected by the project in the following discussion of cost elasticities. The travel cost changes to expect from any mooted project will be taken up in the next chapter.

While there is likely to be a wide range of demand responses to each origin-destination cost change, there is a large body of research that points to central tendencies in the response to variables, such as fuel price and travel time. It is these central tendencies, and the contextual situations that lead to different central tendencies, that this appendix seeks to reveal, with applicability to New Zealand.

Cost-component elasticities

Wallis (2004) provided a summary of the component elasticities that are most applicable to New Zealand (and Australia) for light vehicles. In this summary, the response measured is VKT (as opposed to the number of trips), the short-run was taken to be less than 12 months, and the long-run was likely to eventuate within 5 years. The central fuel-price elasticities were amended slightly in a recent update by Torshizian et al. (2023 unpublished). Table B.3 summarises the component elasticities, combining the 2004 and 2023 conclusions.

[67] Source: Authors' conclusions from international evidence.

Table B.3 VKT travel-cost elasticities applicable to New Zealand (adapted from Wallis, 2004, Table 2; Torshizian et al., 2023, unpublished)

Variable cost component	Measured by	Short run elasticity	Long-run elasticity
Fuel price (1)	$/litre	−0.12 (−0.10 to −0.20)	−0.24 (−0.20 to −0.30)
Travel time (2)	minutes/trip	−0.30 (−0.15 to −0.50)	−0.60 (−0.60 to −0.80)
Parking cost (3)	$/trip	−0.30 (−0.10 to −0.60)	N/A
Toll charges	$/trip	−0.15 (−0.05 to −0.40)	N/A

Notes: N/A not available (1) A fuel cost elasticity would also include a fuel efficiency factor (2) In Vehicle Time (IVT) only but could potentially be amended to include Out of Vehicle Time and Trip Time Reliability (3) relates to CBD commute only.

These elasticities are broadly similar to those estimated internationally for each component.

Goodwin et al. summarised fuel elasticities as follows:

> *[the] overall picture implied is … if the real price of fuel rises by 10% and stays at that level, the result is a dynamic process of adjustment such that … the volume of traffic will fall by roundly 1% within about a year, building up to a reduction of about 3% in the longer run (about 5 years or so).* (Goodwin et al., 2004)

The UK DfT has picked up this conclusion and strongly recommends a long-run car-fuel cost-elasticity (which may differ slightly from a fuel-price elasticity) of −0.25 to −0.35, across all trip purposes (Department for Transport, 2020b). In a 2014 review, Dunkerley et al. (2018) concluded that, in the UK, ‘it was reasonable to assume the fuel-cost (price) elasticity falls within a fairly narrow range of −0.1 to −0.5, but will vary by distance, area type, trip purpose etc’. They also reported that fuel-cost elasticities are not necessarily transferable across countries and that a range of −0.1 to −0.2 is expected with the Dutch National Model. To demonstrate examples of potential segmentation – and the difference in results – Table B.4 reports the results from a recent Great Britain meta-study (Wardman, 2022), as well as recommendations for European countries with more than 450 cars per-capita, which resulted from modelling and a literature review – primarily of UK and Dutch studies (De Jong & Gunn, 2001).

The TRACE project did recommend differential elasticities for the current PT mode share for countries with low per-capita car ownership, but these have not been reported here as New Zealand has high car ownership.

Kennedy and Wallis (2007) estimate a lower fuel elasticity for New Zealand and also report that other studies find the elasticity in New Zealand and Australia to have been less than in Europe and the US.

Table B.4 Long-run car VKT fuel-cost elasticities applicable in Great Britain (adapted from Wardman, 2022, Table 7; Hague Consulting Group, 1999, Table 11; Department for Transport, 2020b, p. 48)

Trip purpose	Inter-Urban Wardman (2022)	Urban Wardman (2022a)	Not specified TRACE (1999)	Not specified DfT (2020b)
Commute	−0.31	−0.47	−0.20	−0.3
Employers Business	−0.11	−0.10	−0.22	−0.1
Education			−0.32	−0.3
Leisure (Wardman) / Other (TRACE)	−0.63	−0.33	−0.44	−0.4

Wardman (2022) and the TRACE project also provide a summary of journey-time elasticities, repeated here in the table below along with DfT current recommendations, although both reviews are based off fewer studies than the fuel-cost studies reviewed above. As well as summary statistics from their literature review, Hague Consulting Group (1999) report long-term travel-time elasticities ranging from −0.15 (home-based work) to −2.00 (commuting) used in the Netherlands national model and note that the results they reviewed were consistent with the earlier SACTRA (1999) conclusion that long-run travel-time elasticity is a factor of two or more times the fuel-price elasticity. The Department for Transport (2020b, Table 6.2) study recommends more inelastic default journey-time elasticities but acknowledges a wide range is possible by recommending the implied limit for journey-time elasticity being −2.0.

Wallis (2004) found no studies of the New Zealand journey-time elasticity but reports that the few Australian studies estimated short-run journey-time elasticities that were similar to those found internationally, and hence recommended the range reported in (above) as appropriate for New Zealand. Wallis also noted a wide variation in disaggregated journey time elasticities in the international literature, therefore did not recommend any disaggregated elasticities for New Zealand.

Table B.5 Long-run car VKT journey-time elasticities applicable in Great Britain (adapted from Wardman, 2022, Table 6; Department for Transport (DfT), 2020b, Table A.1; Hague Consulting Group, 1999, Table 22)

Trip purpose	Inter-urban Wardman (2022b)	Urban Wardman (2022b)	Not specified Low modal competition DfT (2020b)	Not specified High modal competition DfT (2020b)	Not specified TRACE (1999)
Commute	−0.79	−0.98	−0.14	−0.22	−0.96
Employers business	−0.60	−0.75	−0.35	−0.60	−0.12
Education					−0.78
Leisure (Wardman) / other (TRACE)	−0.80	−0.99	−0.20	−0.35	−0.83

The New Zealand parking-price elasticity largely derives from Australian and international studies which are summarised by Hamer et al. (2009), rather than any New Zealand evidence. A wider discussion of the response to parking charges is provided by Torshizian et al. (2023, unpublished).

For our purposes, the elasticity is irrelevant in many situations as parking charges do not apply for most trips (or is otherwise a low charge). Parking fees are common in the CBDs of many New Zealand cities and towns but are low in many cases. Elsewhere parking charges are not widely applied. This presents two problems for the component elasticity approach: (a) a sharp rise in low or zero fees creates a disproportionate or undefined percentage change in the parking price, which does not suit elasticity analysis; and (b) the varied existence of alternative parking opportunities will create a wide range of elasticities to be applied to existing non-trivial parking-price situations.

A more relevant question is: what would the expected VKT response be if the GTC of travel were to increase by, say, NZ$1 as a result of a new or extra parking charge? This addresses (a) above, but still leaves open the issue of (b). EPA (1998) refers to some US transport models applying a factor of 1.5–2.0 to parking costs relative to other vehicle operating costs, but does not reference this comment (it is not clear what this includes). This is a matter for further investigation within a GTC framework.

Similar issues exist with tolling: tolls are not widely used in New Zealand and, when used, a range of alternative routes exist. The toll elasticity in Table 9.3 is strongly influenced a Singaporean study (Menon and Hemming Group, 2000). Other factors of relevance noted in the research include off-peak being around 1.5 times more responsive to peak travel, and the short-run effect being around two-thirds of the long-run response (Torshizian et al., 2023 unpublished).

These issues with parking and tolling elasticities can be reduced by using a generalised travel cost.

Generalised cost elasticities

An insightful and convenient way to apply the above elasticities is to combine the trip costs to give a GTC and then apply one elasticity to any change in GTC. For this project, this has the advantage of providing a simple mechanism to consider the trade-off between travel time, and higher parking or toll charges.

Before proceeding to discuss typical GTC elasticities, though, it is worth pointing out their disadvantages: (a) the GTC elasticity is not stable if the relativity of component costs is not constant over time; and (b) the magnitude of the GTC elasticity is sensitive to the costs included as the base components, with the magnitude of the (negative) elasticity being larger when more costs are included. Wardman and Toner (2020) are amongst those who question the widespread use of GTC.

The variable components of GTC that are of interest to this research project are:

a. the travel time of the trips
b. the fuel portion of the vehicle operating costs
c. parking costs at either trip end
d. any tolls or road charges incurred between trip ends.

Using a value of time (VOT), it is possible to express the sum of these costs in dollars or minutes. The elasticity derived would be considered a variable (or marginal) GTC elasticity.[68]

NZTA recommends generally using low modal competition GTC elasticities of −0.4 to −0.7 for long-run effects. Torshizian et al. (2023 unpublished) recently concluded that −0.3 was appropriate as a general light-vehicle GC elasticity. An earlier recommendation (Wallis, 2004) was for −1.00 as a New Zealand long-run elasticity when the variable costs (a)–(d) above constituted GTCs. Internationally, SACTRA (1994) estimated the GTC elasticity to be within the range −0.5 to −1.0. Lee (2000) derived a range of −0.57 to −5.1 from probable component elasticities and concludes a GTC elasticity within the range −1.0 to −2.0 as most plausible, noting the sensitivity to the composition of GTC.

[68] Fuller GTCs might include access time to/from the car (DfT,2020) or typically fixed vehicle costs such as maintenance, accidents/insurances and ownership/depreciation (Lee, 2000).

Table B.6 Long-run GTC elasticities (adapted from Waka Kotahi NZ Transport Agency, 2020, Table A14; Wallis, 2004)

Trip period	New Zealand Wallis (2004)		Principally Urban New Zealand Low modal competition MBCM	Principally Urban New Zealand High modal competition MBCM
Peak			−0.4	−0.6
Off-peak			−0.7	−1.0
Total	−1.0			

Long run and short run

The above elasticities have focused on long-run responses. Typically, the long-run response has occurred within five years (Lee, 2000; Wardman, 2022) although, as discussed in Chapter 2, longer lags can occur.

The long-run price elasticities are consistently reported higher than the short-run responses. The most common explanation for these higher long-run elasticities is that given more time, travellers will have more options for reducing their travel expenditures. People can often quickly change the timing, route and mode of a trip, and in some cases their trip frequency and destination (eg, for leisure, but not usually for work or school). However, it can take longer to reorganise vehicle, home, work and other situations to redistribute travel across different origin and destination zones, including the possibility of shifting to another home location.

While this explanation seems reasonable, there is surprisingly little reported empirical evidence to quantify these effects.

As to the magnitude of the delayed response, Dong, Davidson, Southworth, and Reuscher (2012) summarise the international empirical literature on the relative responsiveness as the long-run response to travel-cost changes as being 2–4 times the short-run response. A wide selection of elasticities appears to fit within this generalisation, although possibly the lower end of this range needs to be extended to accommodate New Zealand fuel-elasticity results. Examples of conclusions about the ratio of long- to short-run elasticities reached elsewhere include:

- 3 times for fuel-price effects on VMT (Goodwin et al., 2004), (Graham & Glaister, 2004) and 2.5 times for vehicle ownership (Goodwin et al., 2004)
- 1.3 times for New Zealand elasticity to fuel price (Kennedy & Wallis, 2007)
- 2 times for UK travel time effects (SACTRA, 1994, p. 46)
- 2 times for US GTC effects (Lee, 2000)
- 1.5 times for Norwegian tolls (Odeck & Bråthen, 2008)
- And – while not directly car related but of general interest – 2-3 times for transit demand (Litman, 2021).

One further factor requires consideration when it comes to travel-time elasticities. Travel-time savings are different to fuel-price changes in two fundamental ways. First, while the immediate travel-time reduction can be reasonably estimated, subject to the trip distribution challenges to be discussed below, the future travel-time reduction will typically be more, but uncertain, in congestion situations, being based on an unknown counterfactual (which is not the observed demand in the future). Second, the travel-time savings typically apply to a subset of trips in an area, possibly a small subset, which is likely to create larger redistribution and land-use effects than an equivalent average cost change generated by a fuel-price change. That said, there is little evidence that points to the long-run/short-run journey-time elasticity ratio being relatively more than the similar ratio for fuel prices. In other words, the response mechanism may possibly be different, but on balance it would appear that the net effect in VKT terms is similar. This is an important conclusion as it provides justification to use the ratio of long-run to short-run effects to measure land-use changes (among other changes) associated with new road capacity.

Urban and rural

The evidence on urban versus rural cost elasticities is mixed.

The New Zealand response to fuel prices points to less elasticity for rural travel, even though trips are on average longer. Kennedy & Wallis (2007) looked at the New Zealand petrol price effect on fuel consumption between 1974–2006 and on light vehicle VKT between 2002–2006 and concluded that the VKT elasticity to petrol prices (in 2002–2006) was higher and quicker for inter-peak travel, lower and slower for the urban peak, and generally low for rural traffic. This result is consistent with international research. Wadud, Graham, and Noland (2009) showed in a time-series regression that US households in rural communities had a fuel-price consumption elasticity that was 30%–45% lower than the those of urban households. Santos and Catchesides (2005) find lower fuel-price mileage elasticity for rural households in the UK. However, not all travel on rural roads is by rural households.

An opposite effect is reported by Goodwin (1992) for rural roads, finding a more elastic long-run VKT response to travel time rurally (η=-1.33) than in urban networks (η=-0.57).

One possible explanation is that there can be large time and distance reductions in some rural projects, should, for example, a bridge substantially shortens a journey, which is likely to have large traffic responses (see discussion of fixed links in Chapter 2) whereas urban projects tend to increase capacity. These road improvements can be expected to have different effects to general fuel-price changes.

Appendix C: Notes included in the tool

Notes that have been included within the tool are repeated here.

Methods

In a nutshell

There are three key methods that can be used to estimate the VKT to expect from a new or improved road.

1. A **lane-km elasticity** approach, whereby extra VKT increases as a ratio of the proportion by which the lane-km increases for the road class of the project road.
2. A **cost elasticity** approach, whereby extra VKT increases as a ratio of the proportion of general travel-cost reduction that the project road will enable.
3. Various **transport models** that balance the change in relative costs of travel and travel patterns over the model area.

This tool provides an initial application of (1) and (2). Method 3 is also recommended where more accuracy is required for induced VKT.

More detail

The link between a cost elasticity approach and a lane-km elasticity approach is shown below (Lee, 2000), where h=elasticity. That is, the cost elasticity (h_{GTC}) is equal to the lane-km elasticity (h_{LKM}) times the ratio of the percentage change in lane-km (%ΔLKM) and the percentage change in GTC (%ΔGTC):

$$h_{GTC} = \frac{\%\Delta VKT}{\%\Delta GTC} = \frac{\%\Delta VKT}{\%\Delta LKM} \times \frac{\%\Delta LKM}{\%\Delta GTC} = h_{LKM} \times \frac{\%\Delta LKM}{\%\Delta GTC}$$

See references below for more detail:

Lee, D. B. (2000). Appendix C demand elasticities for highway travel. https://rosap.ntl.bts.gov/view/dot/9724

Method 1

In a nutshell

(1) The **lane-km elasticity** has grown out of statistical research (including case studies) that has revealed a relationship between the addition of new lanes to a local road network and any additional VKT. A commonly quoted study is the Duranton and Turner (2011) analysis of Class 1 roads in US metropolitan areas where a lane-km elasticity of demand 1.0 to new road capacity was revealed. Other studies for other road classes and other locations have revealed a similar relationship but with a range of elasticities, including over 1.0.

The initial lane-km elasticities applied in this tool are those provided in Byett et al. (2023, Table 9.1, see link in tool).

Below are some noteworthy observations.

- In mathematical terms, a lane-km elasticity of 1.0 is equivalent to the extra lane-km being 'filled up' to the same capacity of the existing lanes within that road class, and within that study area, as well as no change to capacity utilisation within the existing road lanes of that class. Hence, it can be thought of as demand rising to match the extra supply. In practice, the dynamics may differ.
- The lane-km elasticity is not always 1.0 and is sensitive to the class definition applied to the new and existing roads.

- This lane-km approach does not measure the effect on traffic volumes on other road classes and on roads outside of the study area. Often, there is likely to be some traffic diversion from other road classes and also from other areas (including longer term via internal migration). See note on diversion.
- Effects are likely to be lower in the short term. See note on short-term vs long-term.

See references below for more detail:

Duranton, G., & Turner, M. A. (2011). The Fundamental Law of Road Congestion: Evidence from US Cities. The American Economic Review, 101(6), 2616–2652. https://doi.org/10.1257/aer.101.6.2616

Region

In a nutshell

The tool uses 14 regions as defined by Statistics NZ and as mapped by Local Government New Zealand. The 15th region, Chatham Islands, has been excluded.

The regions become the base road network for the lane-km elasticity approach.

Regions, as opposed to districts or metropolitan areas, were chosen as the base for this tool as:

- regional data was available (district data was also available but metropolitan areas were not)
- the recording of road data to regions is more accurate than the recording of road data to a district
- road projects are less likely to cross regional boundaries than district boundaries.

However, the use of road data over what can be large and diverse regions does increase the variation of road use within a road class, which makes a like-for-like comparison in the lane-km approach difficult.

Data issues

- The sum of the component of regional road data sometimes does not equal the regional total also reported, however, these discrepancies appear to be immaterial.
- Some roads are classified within an adjacent district.
- Road data for 2019/20 are used as current within the tool, since data for 2020/21 and 2021/22 include the effects of COVID-19 restrictions.

Admin

In a nutshell

NZTA administers the state highways in New Zealand while Land Territorial Authorities (the local councils) administer most roads within cities and districts. There are a few roads administered by the Department of Conservation but these are access roads to parks and have been excluded from the tool.

Road data is collated in a Road Assessment and Maintenance Management (RAMM) database. These figures are available on several websites (link shown within tool).

Data of relevance to this tool include:

- lane-kms by region and district, in total, and for NZTA administered (ie, State Highways) roads only – locally administered road data have been inferred from these two figures
- VKT by region and district, in total, and for NZTA administered roads only – an average AADT across all roads of the same class within each region has been calculated by comparing the lane-km data above.

Data issues

- Road statistics are often estimated, which creates uncertainty about accuracy.

- Major roads do have counters automatically measuring traffic but these data are not always reported punctually.
- New Zealand driving patterns, as elsewhere, were significantly different from 2020–2022, during the COVID-19 lockdowns. Hence, the 2019-2020 figures are used for base calculations here.

ONF

In a nutshell

The One Network Framework (ONF) is the road classification system currently used by New Zealand road authorities.

There are 12 road classes, defined according to their 'movement' (M1-M5) and 'place' (P1-P5) functions. Seven classes are for urban roads and five for rural roads, where the urban/rural split is according to adjacent land-use.

The ONF supersedes the One National Road Classification (ONRC) system, which is still widely reported at present.

ONF data was chosen to ensure data availability in the future.

The ONF road classes were further aggregated into nine classes (four for NZTA roads and five for local roads), grouping road classes with small lane-km into those with similar AADT.

A link to the mapping of the road classes to the administrators and administrator groups is provided in the tool.

Also provided is a link to an approximate mapping to US road classes.

Data issues

- ONF classification of roads is subject to revision, especially within the early years of ONF.

Lanes

In a nutshell

Road data is reported on a per-road length basis and on a per-lane length basis.

For example, a 10-km road of two lanes in each direction (ie, four lanes in total) would consist of 40 km of lanes. If the road had an AADT of 1,000 vehicles per day, then the lane AADT would be 1000/4 = 250 AADT per lane.

GTC

In a nutshell

In simple terms, the GTC for any origin-destination pair of zones is the weighted sum of the time and operating costs of travelling between the two zones. The GTC of travel through a corridor which includes the road project under consideration is the weighted average GTC of all the origin-destination travel that passes through the corridor. Estimation of this cost requires several steps:

- Weighted average distance of travel
- Weighted average time of travel
- Weighted average value of travel time (the tool uses the value of time provided within the MBCM)
- Weighted average vehicle operating costs

- Weighted average charging applied for tolls and parking.

In practice, the approach does need additional information (compared to methods described earlier) about the trips that use the scheme, including:

- Base trip demand using the scheme/link, and identification of the origins and destinations of these trips
- Base trip GTC for the origins and destinations (identified in the step above) that would use the link, typically made up of vehicle travel-time (VTT) and vehicle-operating costs (VOC)
- The change in GTC associated with the proposed scheme – this could be based on a simple volume/delay relationship based on the road configuration (lanes, posted speed limit, classification capacity, etc).

These additional data and the increased complexity of using a cost-elasticity approach potentially allows for a better estimation of VKT based on specific details of the scheme that relate more directly to the economic theory rather than generic empirically based data. Other benefits include the ability to consider the effects associated with a wide range of trip components (including tolls, etc).

For more information on this issue, see also Method 2 Cost Elasticity Approach.

Within City

In a nutshell

The distances of trips passing through corridors in the inner, middle and fringe parts of the city generally reduce as the corridor nears the centre of the city.

The tool uses the weighted-average trip length as reported in the MBCM for Auckland, Wellington and Christchurch. See link in tool.

Distance

In a nutshell

The distance of trips between various origins and destinations may be reduced by the new project (eg, building a bridge over a river alleviates the need to drive around or across existing bridges). The reduced distance will affect (a) the travel time of the trip and (b) the vehicle operating costs of the trip, which both feed into a reduced GC of travel (and hence likely more induced demand). The tool allows for a shorter average trip distance to be included in the GC calculation.

Tolls

In a nutshell

Tolls provide a way to achieve the opposite of induced demand, namely traffic suppression. In GC terms, the dollar value of the toll is a direct reduction in any other GC saving due to improved or new roads. In this tool, a toll can be included as a change in the GC of travel, either due to the current situation or as a test of mitigation methods.

More detail

The following combined suppression/diversion rates were reported by Beca Ltd (2014) for a series of changes in New Zealand tolls, including one toll reduction. These confirm that large shifts can be quickly achieved on a road link when large changes in travel costs occur but, unfortunately, provide little direct evidence of what it takes to reduce (or increase) VKT on a regional basis.

Traffic volume changes after New Zealand toll changes (copy of Table 2.7)

Project	Where and when	Source	Results (and source)
Auckland Penlink	Charge of $0.50 toll on 4-lane, divided expressway between East Coast Road and Whangaparaoa Road	VTM modelling	Traffic volume suppressed by around 8% for each $0.50 toll increase (Beca Ltd, 2014)
Tauranga Harbour Bridge	2001 removal of $1.00 toll	AADT	Traffic volume increased across harbour, including alternative routes, by 15% within 6 months (Beca Ltd, 2007); considered to be equivalent to a 27% combined suppression and diversion effect (Beca Ltd, 2014)
Tauranga K route	2012 toll increase from $1.00 to $1.50	AADT	Traffic reduction of 13% in following year – relative to growth trend (Beca Ltd, 2014)
Auckland Northern Gateway	New 2009/10 toll of $2.00	Not stated	Traffic diversion of approx. 20% (Beca Ltd, 2014)

PT

In a nutshell

A simple (downward) adjustment is made to the lane-km elasticity where PT offers a strong alternative to private travel. This adjustment is unlikely to apply in any New Zealand city at present but is offered as an opportunity to test mitigation methods.

The adjustment made is to halve the previously estimated lane-km elasticity if ‘high’ PT mode share exists and, as an interim step, reduce the previously estimated lane-km elasticity by 25% for ‘medium’ PT mode share. This is a crude approach and does require further investigation. For now, it is recommended that ‘high’ and ‘medium’ PT mode share thresholds of 50% and 25% are appropriate.

More detail

The supply-demand economic framework leads to expecting less new-capacity sensitivity where substitutability between alternatives is lower (ie, cities with useful PT systems). The evidence supports this. In Budapest, where PT usage in the city averages 50%, changes in road capacity across the river Danube are estimated to have an elasticity of 0.5 to new road capacity (Bucsky & Juhász, 2022). These road-capacity changes include the construction of an orbital motorway around the city with associated river crossings. In their large European analysis, Garcia-López et al. (2022) find that the existence of rail and metro networks almost halves their induced demand elasticity. Thus, whilst there is limited evidence on the impact of existing PT networks on induced demand, what is available indicates substantial reductions in the level of induced demand that may occur in cities.

See references below for more detail:

Bucsky, P., & Juhász, M. (2022). Long-term evidence on induced traffic: A case study on the relationship between road traffic and capacity of Budapest bridges. Transportation Research Part A: Policy and Practice, 157, 244–257. https://doi.org/10.1016/j.tra.2022.01.018

Garcia-Lopez, M.-A., Pasidis, I., & Viladecans-Marsal, E. (2020). Congestion In Highways When Tolls And Railroads Matter: Evidence From European Cities (No. 2020/11; IEB Working Paper). Barcelona Institute of Economics. https://ieb.ub.edu/wp-content/uploads/2020/11/Doc2020-11.pdf

Land use

In a nutshell

The attribution of land-use change to road projects remains a challenge. There is research to show that land-use planning and transport planning jointly affect the location of people within a city. Rather than ignore the land-use effect of transport, since it creates an additional challenge, the approach taken here is to upscale or downscale the lane-km elasticity according to a rule that traces back to density elasticities for travel demand. Hence, the resulting VKT effect should be viewed as indicative rather than as a forecast. The permutations of the rule most likely to be applied are a 39% upscaling of the VKT effect if the road project facilitates fringe-city development (likely where planning is not strong), and a 14% downscaling for facilitating inner city residential development, both relative to the extra population otherwise being spread across the city.

More

The economic growth literature leads to an expectation that land uses will change following a transport investment. The evidence bears this out. In their review, for example, Kasraian et al. (2016) find that both road and rail investments lead to land-use change: rail is typically more associated with changes in population; road is more associated with changes in employment, as well as with dispersed development covering a larger land area. Related to this, road (and rail) investment can also lead to increased suburbanisation as households move further out from the centre (Baum-Snow, 2007; Baum-Snow et al., 2017). Businesses can also de-centralise (Baum-Snow, 2010). The extent of urban sprawl is, however, a function of land-use policies (Levkovich et al., 2020). If road investment leads to more dispersed land use, the question then arises as to whether this leads to higher levels of VKT, and if so by how much.

By way of summary, urban form does have an impact on VKT, but not as much as might be thought from a straight comparison of average household trip-making characteristics in different locations. Summarising, Ahlfeldt and Pietrostefani (2019) find an elasticity to density of −0.06 in their recent meta-analysis, and Litman and Steele (2022 Table 24 p64) in their review of the evidence conclude that elasticities in the range of −0.05 to −0.1 are probable (in isolation of other measures). They suggest this could increase by a factor of four if combined with other built environment factors. Some of these could be correlated with density (eg, mixed land uses, proximity to PT). One thing to note is that this empirical evidence is predominantly from the USA, and therefore relates mainly to that context: large, high-income, car-based cities.

Override

In a nutshell

An override facility is provided at two points in the tool.

Override #1. Two initial estimates of the gross long-term VKT effect of the project are provided. The default position assumed is that the lane-km elasticity implied by the cost-elasticity calculation – taking into account congestion and specific AADT – will provide the best estimate of the lane-km elasticity to form the basis of the induced demand estimate.

Two other adjustments are possible at this step.

- The expected AADT of the road project may be very different to the average AADT of the regional base for the road class chosen. It may be appropriate at this stage to change the base road-class used for the lane-km elasticity, for example, if the AADT of the project is much higher than the average AADT for the regional class of roads, then maybe a higher road class (in terms of average AADT) is more appropriate. This may bring the two estimates of induced VKT closer together, in which case, choosing either the assumed lane-km elasticity or the implied lane-km elasticity may be apt.

- There may be high uncertainty about the expected AADT, congestion and induced demand effects and an average of the two (assumed and implied) lane-km elasticities is considered more appropriate.

Users can provide a user-selected lane-km at Step 3. This would then be further adjusted for PT, land-use and diversion factors. Alternatively, leaving the override #1 input box as blank will use the default lane-km elasticity.

Override #2. The initial lane-km estimate (either default or provided by the user) will be adjusted in Step 3 to provide an adjusted lane-km elasticity. At this stage, the user is also offered the opportunity to override the elasticity provided. Again, a blank in the override #2 box will lead to the default elasticity estimate to be carried through to Step 4.

The latter feature is likely to be useful for consideration of what-if scenarios.

Short term

In a nutshell

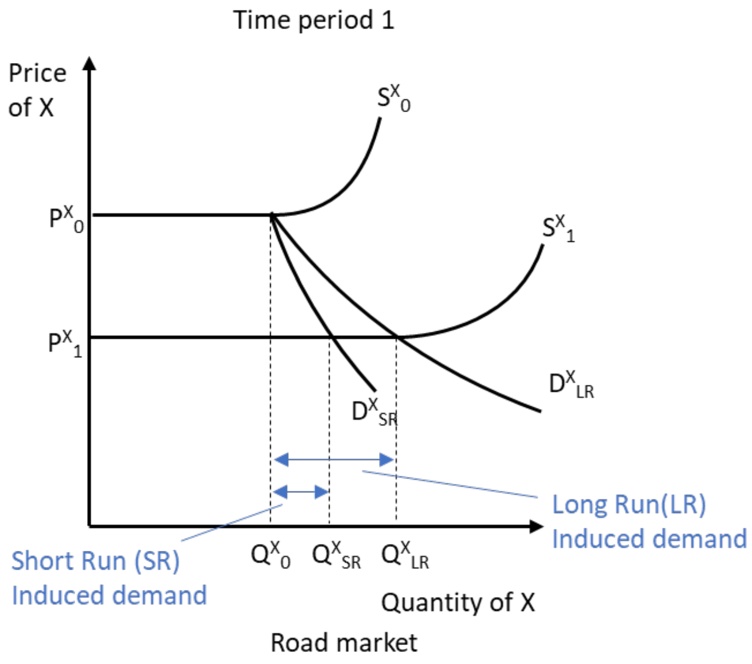
The elasticities applied in this tool start from a long-term perspective, with VKT effects often evident within 10 years, or sometimes longer.

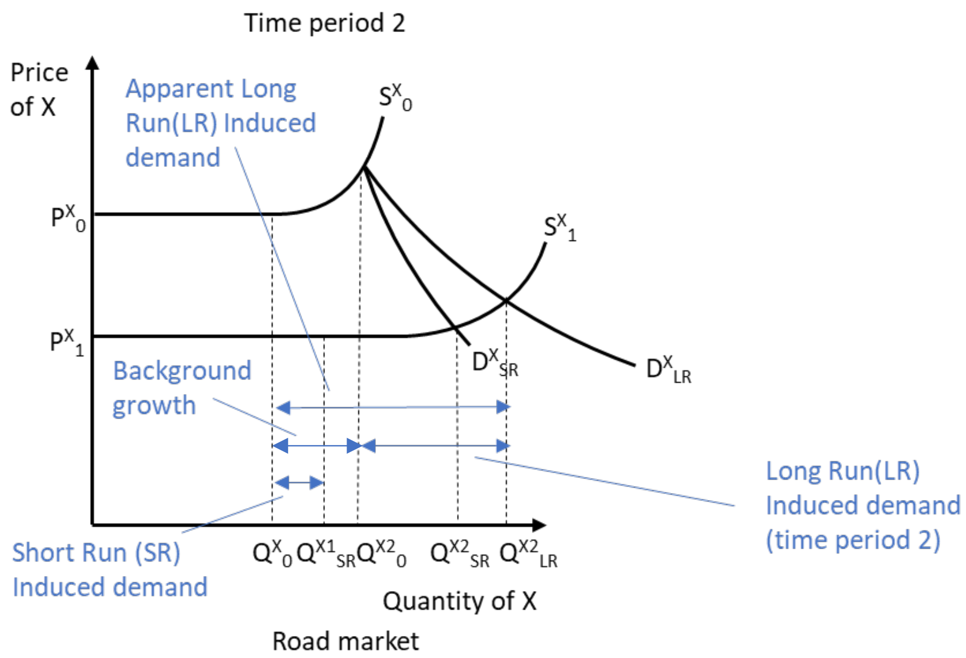
Often a large proportion of the effect will emerge within three years, referred to here as the short-term (although, be warned, the literature is not consistent in the use of short-term terminology). This short-term proportion of full effects can vary, especially where road projects facilitate land-use projects. For this tool, a simple ratio of '60% of effects within 3 years' is applied, as a reminder of the immediacy of some effects.

More detail

The different behavioural responses that give rise to induced demand occur over different timeframes, ranging from instantaneous to years-long. Changes within the transport market such as changes in route, time period, and mode may occur quickly (ie, in the short run, typically taken to be within one year). Changes in housing location may take longer to occur (eg, construction of new housing and migration). This can be depicted as short-run (D^X_{SR}) and long-run (D^X_{LR}) demand curves, as in the top panel of Figure 2.4. The full measure of induced traffic will only occur in the long run (ie, Q^X_{LR} - Q^X_0). However, background changes due to changes in income, fuel prices, technology, etc, will occur over the time that it takes the induced traffic to appear. This is depicted in the lower panel of Figure 2.4. Here, background growth leads to base levels of demand in the 'do-min' shifting from Q^X_0 to Q^{X2}_0. The full amount of induced traffic now only occurs at Q^{X2}_{LR}. The uplift in traffic ($Q^{X2}_{LR} - Q^X_0$) is therefore split into two components: background growth ($Q^X_0 - Q^{X2}_0$), and induced traffic ($Q^{X2}_{LR} - Q^{X2}_0$).

Short-run and long-run demand curves and background growth (copy of Figure 2.4)





Diverted traffic

In a nutshell

It is known that some extra VKT on a new/improved road will be diverted from other routes, but it is uncertain how much is due to diversion – the extent will likely be contextual. The tool simply (and conservatively) assumes 50% of new VKT results from diversion without land-use effects and then adjusts the diversion rate to exclude land-use effects from diverted VKT. The research suggests pure induced-traffic effects seem to be at the 25%–39% level of traffic volume changes. Demographic changes (including population growth, background levels of migration, and movement between locations induced by the project) make up the rest. Only Duranton and Turner (2011) provide an analysis that attributes the component of demographic change to the change in lane-km.

Examples (hypothetical to illustrate diversion rate calculation) …	--------- with other modes not strong -------			----------- when other modes strong -----------		
	(1) No land use effect	(2) More fringe city development*	(3) More central city development*	(4) No land use effect	(5) More fringe city development*	(6) More central city development*
Induced VKT long-term within locality per day	**100,000**	**139,000**	**86,000**	**50,000**	**89,000**	**36,000**
- VKT reduction on other roads (locally or nationally)	-50,000	-50,000	-50,000	-25,000	-25,000	-25,000
=Induced VKT long-term within NZ per day	**50,000**	**89,000**	**36,000**	**25,000**	**64,000**	**11,000**
... VKT change due to relatively more (less) residential development in vicinity of proj	0	39,000	-14,000	0	39,000	-14,000
… VKT change due to other behavioural changes	50,000	50,000	50,000	25,000	25,000	25,000
Diversion rate	**50%**	**36%**	**58%**	**50%**	**28%**	**69%**
Explanation of examples:						
(1) Default 50% of induced VKT within locality assumed to be due to reduced VKT in (a) other parts of the locality (from re-routing, destination changes) and/or (b) outside the loc						
(2) Extra VKT generated due to relatively more people taking longer trips (ie, relatively more people living in fringe area and less living closer to the CBD) - change in VKT due to l						
(3) Extra VKT now reduced due to relatively more people taking shorter trips (ie, relatively more people living in central area and less living further from the CBD) - change in VKT						
(4)-(6) (1)-(3) repeated but will lower initial VKT effect due to the presence of a strong PT service (NB land use effect calculated independent of PT effect - a simplification used for th						
** Relatively more/less development is in terms of future projections rather than current houses being relocated*						

More detail

Pells (1989) reviews two UK studies that interview respondents before and after project opening, (the Rochester Way Relief Road and the York Northern Bypass), and Wallis (2009) reviews the Amsterdam Orbital Ring Road and the Newlands Interchange in Wellington (New Zealand). Whilst all these studies are dated, they do reinforce the view that the largest behavioural responses are route change and trip re-timing (re-timing does not affect the daily VKT). Where substitution is more difficult (mode change and changing origins and destinations), fewer travellers change their behaviour, or at least the change happens slowly. These data also reinforce the ex-ante modelling evidence that responses within modes are the most sensitive (eg, changes in route, changes in time of day, and for some discretionary trips, changes in destination), and changes between modes, and trip generation arising from land-use change are the least sensitive responses – at least in the short term (Ortúzar and Willumsen, 2011, pp. 20–21). Unfortunately, these data, whilst describing how the induced demand comes about, do not tell us which behaviour changes lead to the largest change in VKT. For example, one trip switching from PT to car may generate more VKT than twenty trips changing route – even if a small change in route occurs. It all depends on the length of the trips in the before and after.

In terms of allocating VKT to different behavioural responses, there are very few studies. Rohr et al. (2012) found induced traffic from the orbital motorway around Manchester to be around 15%–17% of which 4% was due to mode shift, 9% due to destination shift and 2%–13 due to changes in demographics. They exclude re-assignment from their analysis of induced demand, focusing instead on what SACTRA termed ‘generated traffic’ (ie, traffic arising from anything other than changes in route). They also found that commute length had increased by 10% on average. Duranton and Turner (2011) estimate that the induced traffic on the new urban inter-state highway links arise as follows: up to 29% are from increases in commercial vehicles, up to 21% from migration to the city, up to 10% from re-routeing, and up to 39% from changes in household behaviour. In our induced traffic framework these ‘migrating’ trips are those with new remote origins and new remote destinations.

Method 2

In a nutshell

(2) **Cost elasticity** approaches are common in economics. In general, the approach measures the response to expect in the quantity demanded for a change in the price of a good or service (service in this case), often in response to a change in supply conditions. In transport economics, the quantity demanded is the volume of trips between an origin and destination pair, the quantity supplied is the transport network available (mainly roads, rail tracks and PT services) and the 'price' is the GTC of the trip (see note GTC for more on cost composition).

The basic steps are shown below using an example of a new Christchurch motorway.

Step 1) Base trip-demand data:

- The current AADT within the scheme corridor = 32,000 vehicles/day
- The current average trip distance associated with the above demand is 27 km (which in this case was derived from a transport model)
- The current average GTC (expressed in minutes) associated with the above demand is 29 minutes (again derived from a transport model in this case)
- The average daily base VKT associated with the trip demand is 864,000 km/day (estimated in this case as 32,000 vehicles/day x 27 km/vehicle).

Step 2) Calculate Change to GTC

- The proposed scheme is indicated to improve average GTC by 2 minutes (estimated in this case using volume delay curves applied to the scheme area).
- This results in a 6.9% reduction in GTC (ie, 2/29).

Step 3) Apply Cost Elasticity

- The change in local corridor demand associated with the scheme then is estimated by applying a GTC elasticity (−0.5) as follows:
  - Change in VKT% = ΔGTC x cost elasticity = 6.9% x −0.5 = 3.4%
  - Change in VKT = base VKT x change in VKT% = 864,000 x 3.4% = 30,000 km (rounded).

More detail on the calculation used in the tool

Road classification and the length and number of lanes added (from Step 1) are combined with the following additional inputs.

- Annual average daily traffic (AADT) – if unknown, then the average AADT for the road class and region selected in Step 1 will be used.
- An option to change the road classification type for the proposed road is also provided.
- The general location of the road within the city is used to establish the average trip distance and average speed from lookup tables (which informs both the travel time and vehicle operating cost components of the full trip).
- Posted speed limits of both the existing and proposed road (used to select flow-delay curves used for calculating the travel time component of GTC).
- Tolls (in dollars per trip) can be added to either, or both, the existing and proposed roads. Alternatively, this field can be used to represent any other elements of GTC not already included.

The GTC is calculated for an average user of the existing road over the average trip length from the inputs above. Elements included in the GTC are travel-time cost (TTC), vehicle-operation costs (VOC) and other (tolls).

- TTC is calculated using volume-delay relationships in sheet 'aCASTCI'. These (for now) are based on the Christchurch CAST SATURN Model. Specific volume-delay curves are selected based on user input 'road type', 'number of lanes', and 'posted speeds'. (Ideally an allowance for intersection delay would also be included, but this remains a feature for a future iteration of the model).
- VOC is based on congested speed (calculated as part of TTC) and distance, using values (including value of time for selected road type) from NZTA's Monetised Benefits and Costs Manual.
- Tolls are a direct user input.

A subsection of the existing road, based on the specified length of improvements (user input in Step 1), then has a revised GTC calculated based on the inputs for the proposed road. Outside of this subsection, the existing road GTC is used for the balance of the trip.

The change in GTC between the existing and proposed road can then be calculated.

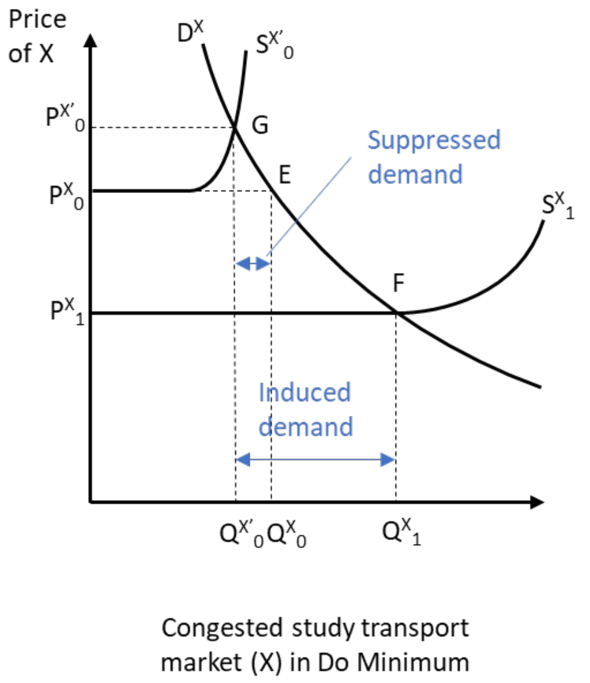
Generalised Cost elasticities (currently sourced from Table A14 of the MBCM) are then used to estimate the change in demand (AADT) for the road. The change in demand then affects the GTC, so several iterations are required before the proposed road AADT and GTC converge.

The change in AADT can then be applied to the average trip length to get the estimated change in VKT.

More on economic background

The economic background to the calculation is shown in the accompanying diagram, illustrating that additional road capacity (eg, additional lanes on an existing road or lanes on a new road) creates an increase in supply from S_0 to S_1. Consequently, given the current demand structure, the price (ie, GC) of travelling by road between an origin zone and a destination zone (ie, the market in this case) declines from P_0 to P_1 and the quantity demanded (number of trips or VKT in this case) increases from Q_0 to Q_1 – this is the induced demand, which in turn, can be decomposed as demand that had been suppressed due to congestion and other demand arising from the more general decrease in travel cost.

Induced demand and trip suppression (Copy of Figure 2.3)



Typically, the responsiveness to price changes is measured as the cost elasticity of demand, and is inferred from changes in demand observed elsewhere. A typical result is that noted by Goodwin (emphasis in bold and notes in brackets added):

> *The amount of extra traffic must be heavily dependent on the context, size and location of road schemes, but an appropriate average value is given by an* ***elasticity of traffic volume with respect to travel time*** *[a component of GC] of about -0.5 in the short term, and up to -1.0 in the long term. As a result, an average road improvement [in the UK] has induced an additional 10% of base traffic in the short term and 20% in the long term:* ***individual schemes with induced traffic at double this level may not be very unusual****, especially for peak periods.* ***Induced traffic is particularly seen on the alternative routes that road improvements are intended to relieve****.* (Goodwin, 1996, p. 35)

Note, the changes in demand observed for a corridor that includes a road project will be the sum of extra demand between the various origins and destinations that use the corridor (ie, there are multiple supply and demand curves). While each demand curve response can be estimated separately, a common shortcut is to estimate a weighted-average change in GC and use this to estimate the combined demand response.

Method 3

In a nutshell

(3) **Transport models** are widely used within New Zealand although are not available for all towns and regions. Such models are not part of this tool but naturally follow as the next step of analysis where induced demand is a key issue.

See references below for more detail:

de Dios Ortúzar, J., & Willumsen, L. G. (2011). Modelling transport. John Wiley & Sons.

Glossary

Induced demand	The increase in demand for a good or service that results from an increase in its supply (in this case demand for road trips and supply of road capacity).
Suppressed traffic demand	The amount of traffic demand that is suppressed by high travel costs, including additional costs created by congestion.
Latent travel demand	Demand for travel that cannot be met because the supply (road or PT service) does not exist or the purchaser lacks knowledge of the service.
Price elasticity of demand	The percentage change in quantity demanded given a percentage change in price (which potentially can vary for different price changes).
Transport model	Can be a wide variety of models but often referring to a four-step travel model
Lane-kms	The kilometres of lane, typically measured within a road class and a region (eg, a 10-km 4-lane highway consists of 40 lane-kms).
Dual and single carriageway	Dual carriageways are separated lanes, typically referred to as motorways in New Zealand. A single carriageway does not have a centre separator.
Short-term and long-term	Induced demand effects are typically measured over a short term of three years or less, while long-term is often around 10 years.
Generalised travel cost (GTC)	The sum of the monetary and non-monetary costs of a journey.