Australasian Transport Research Forum 2021 Proceedings
8 – 10 December, Brisbane, Australia
Publication website: http://www.atrf.info

The development and application of a land use, transport and economy interaction model

Henry Le[1], Finn Gurry[1], Michael Byrne[2], Neville Wood[3] and James Lennox[4]

[1]AECOM Australia, Collins Square, Level 10, 727 Collins Street, Melbourne, VIC 3008, Australia

[2]Arup, Sky Park, One Melbourne Quarter, 699 Collins Street, Docklands, VIC 3008, Australia

[3]Department of Transport, Level 5, 1 Spring Street, Melbourne, VIC 3000, Australia

[4]Victoria University, 300 Flinders Street, Melbourne, VIC 3000, Australia

Email for correspondence: henry.le@aecom.com

Acknowledgements

The development of the VLUTI model was initiated by Infrastructure Victoria which collaborated with Victoria University, Arup and AECOM in its development. Infrastructure Victoria has also reviewed and granted approval to publish this paper.

The authors also wish to acknowledge the Victorian Department of Transport (DoT) for granting approval to publish the paper.

The views expressed in this paper are of the authors and do not necessarily represent those of Infrastructure Victoria or DoT.

Abstract

Governments around the world need to assess the benefits of transport projects to prioritize investments. It is imperative for governments to have tools that can estimate closely the actual benefits and impacts of investments in significant transport projects.

Traditionally, the benefits of a transport project have been estimated by using a transport model, assuming fixed land use for the base and project case in the future. However, this approach cannot measure the impact of land use changes, as residents and businesses relocate to take advantage of lower travel and/or freight costs resulting from implementation of the project. Consequently, the benefits of the project may be under or overestimated, depending on its position within the transport network and how it reshapes land use patterns in the future. In order to overcome this drawback in existing models, this paper discusses the development of a land use, transport and economy interaction model for the state of Victoria, Australia (VLUTI). By integrating the Victorian Integrated Transport Model with a Spatial Computable General Equilibrium model, the VLUTI simulates land use and economic interactions across the whole state, and considers the costs of commuting travel, consumption travel, business travel and freight transport.

This paper will discuss an application of the VLUTI by looking at differences in the conventional transport benefits under both static and dynamic land use scenarios. In the static method, the land use in the project case is unchanged from the base case. In the dynamic case, the land use in the project case is endogenously adjusted within VLUTI. It will also present a method to correct, in the dynamic case, the benefits as estimated by the rule of a half, which usually assumes static land use.

1. Introduction

Governments around the world need to assess the benefits of transport projects to prioritize investment. It is imperative for governments to have tools that can estimate closely the actual benefits and impacts of investments in significant transport projects.

Traditionally, the benefits of a transport project have been estimated by using a transport model, assuming fixed land use for the base and project case in future. However, this approach cannot measure the impact of land use change as residents and businesses relocate to take advantage of lower travel and/or freight costs resulting from implementation of the project. Consequently, the benefits of the project may be under or overestimated, depending on its position within the transport system, and how the project would potentially reshape land use patterns in the future.

In order to overcome this drawback in existing models, this paper discusses the development of a land use, transport and economy interaction model for the state of Victoria, Australia. Infrastructure Victoria, in close collaboration with Victoria University, Arup and AECOM, led the development of the Victorian Land Use and Transport Integration model (VLUTI) which was used for the strategic assessment of major transport programs included in *Victoria's Infrastructure Strategy 2021–2051* (Infrastructure Victoria, 2021a). The VLUTI was developed by combining the Victorian Integrated Transport Model (VITM) with the Spatial Interactions Within and Between Regions and Cities in Victoria (SIRCV) model. SIRCV is a spatial computable general equilibrium (SCGE) model which simulates land use and economic interactions across the whole state, and considers the costs of commuting travel, consumption travel, business travel and freight transport.

Section 2 will present the model overview. Section 3 will discuss the methodology of the VITM. Section 4 will discuss in detail the SIRCV model. Section 5 will describe the model convergence and verification. Section 6 will present an application of the model to study a transport project. Section 7 provides our conclusions and suggestions for further development.

2. VLUTI Model Overview

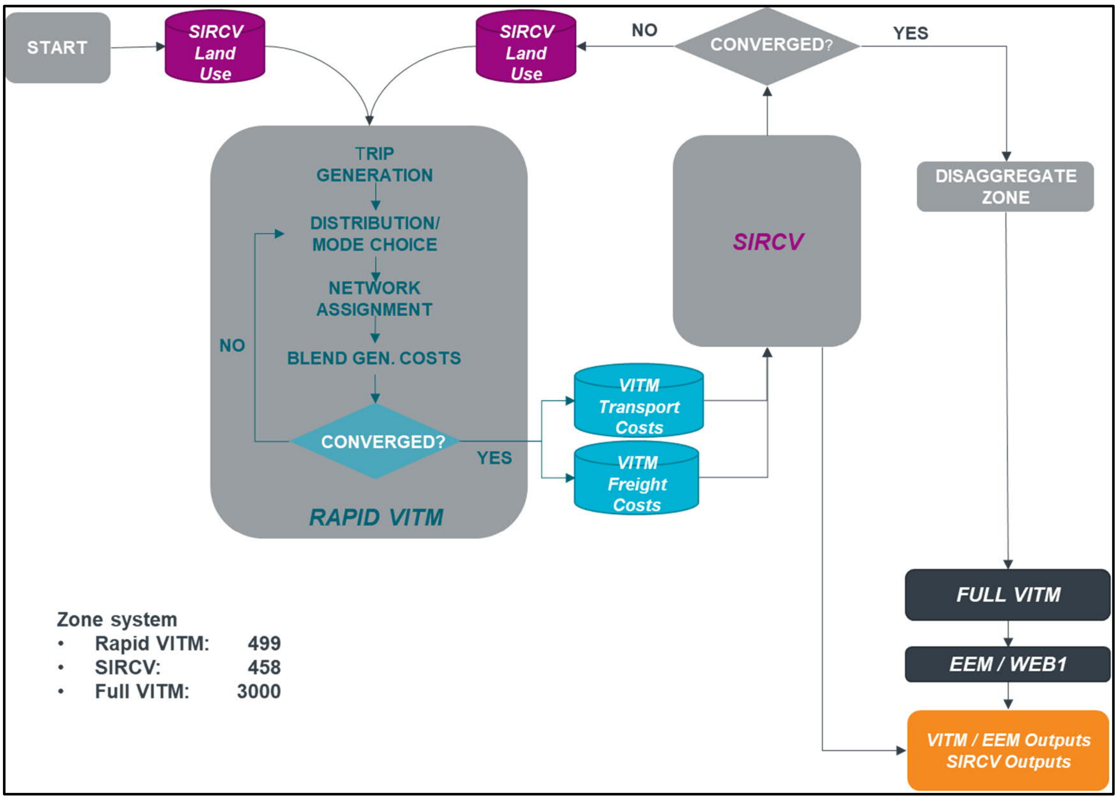
The need to use land use transport interaction (LUTI) models to consider the wider and city-shaping effects of major transport infrastructure projects has been recognised in the literature (Wegener, 2004; Acheampong and Silva, 2015). ATAP (2016) provides a brief review of development and application of LUTI in Australia. VLUTI is a recent application of LUTI in Victoria[1].

VLUTI (Infrastructure Victoria, 2021c) is an integration of the VITM with the SIRCV model built on the principle of long run spatial general equilibrium in terms of allocation of local land, capital, labour, and product through the processes of prices and quantities. VLUTI simulates not only a redistribution of land use (i.e. residents, jobs) but also the state of economy under the intervention of a transport infrastructure. An early example of this approach was the Regional Economy, Land use and Transportation Model developed for the

[1] Another recent application of LUTI in Victoria is the development of CityPlan. by KPMG (2021), which was used to study the impact and benefits of the Suburban Rail Loop. CityPlan was built on the UrbanSim platform (Waddell, 2002) representing a dynamic disequilibrium model. Unlike VLUTI, it assumes that a city is constantly evolving in response to changing conditions and would never reach a state of equilibrium.

Chicago Metropolitan Statistical Area (Anas and Liu, 2007). The structure of the VLUTI model is presented in Figure 1.

Figure 1 VLUTI Model Structure



The Rapid VITM is a transport model with the same structure and components as the Full VITM but having a smaller number of zones to speed up model run time. The Rapid VITM has the following main inputs:

- Transport network representing the road system and public transport services
- Land use inputs in terms of population and employment by industry class
- A 499-zone system

After running for six iterations (to achieve acceptable convergence), the rapid VITM provides the following outputs that will feed into the SIRCV model:

- Composite personal travel generalised costs
- Freight travel generalised costs

Taking the generalised costs from the rapid VITM, SIRCV will produce updated land use in terms of population and employment distribution, which are in turn input back into the rapid VITM. This process is undertaken in loop to achieve convergence within and between the two models (referred to as "VLUTI convergence").

When VLUTI converges, SIRCV will provide the following main outputs:

- Spatial distribution of land use in terms of residential and job locations,
- Spatial distribution of economic metrics such as wage, land rental, and gross state product (GSP) decomposition which could be used to estimate Wider Economic Benefits (WEBs).

The smallest spatial representation of SIRCV outputs is at the SA2 level. The final output of land use produced by SIRCV is disaggregated into 3000 zones and used as the input to the Full VITM run. Subsequently an adjusted version of the DoT's Economic Evaluation Model (EEM) and a WEB module are run to estimate the conventional benefits and WEBs of a project.

3. VITM

The Victorian Integrated Transport Model (VITM) is a state-wide strategic transport model owned and maintained by the Victorian Department of Transport (DoT). It was developed initially in 2010 to cover the greater Melbourne metropolitan area and expanded in 2013 to cover the whole state of Victoria (Le, Somerville and Wood, 2013). VITM is a conventional four-step travel model including trip generation, trip distribution, mode choice and trip assignment, and can be used to:

- Assess transport policies and strategies,
- Estimate future demands on the transport network,
- Analyse the potential impacts of road, public transport and land-use planning projects, and
- Identify the quantum and location of congestion.

This model has been used by different government departments including DoT and VicRoads to evaluate the impacts of alternative transportation and land use investments on transport demand and assess the performance of the transport system under existing and future demands.

VITM is a multi-period, multi-purpose and multi-modal strategic transport model which considers car, public transport and active transport modes modelled on an average school day. VITM uses population and employment forecasts to examine the future impacts of changes to the road and public transport networks in Victoria. A specific version of VITM (VITM19_v2_02) was employed as part of VLUTI. This incorporated:

- 6,973 transport zones, representing travel within the state of Victoria, which are aggregated to 499 zones to form the Rapid VITM and 3,000 zones to form the Full VITM in this VLUTI framework,
- Four time periods, encompassing AM peak (7AM – 9AM), interpeak (9AM – 3PM), PM peak (3PM – 6PM) and off-peak (6PM – 7AM),
- Road and public transport modes,
- Multiple vehicle types including car, rigid trucks and articulated trucks,
- Multiple public transport modes including train (metro and V/Line), trams and busses,
- Integration of the Freight Movement Model (FMM) to forecast truck movements and volumes.

The heart of VITM is a simultaneous destination and mode choice model based on discrete choice theory. The highway assignment incorporates toll modelling based on a distributed value of time, while the public transport assignment employs double capacity constraints, one involving public transport vehicle capacity constraint and the other considering the capacity of park and ride parking capacity at railway stations. VITM has been used to study and support the business cases of transport infrastructure projects in Victoria.

4. Land use and economic model

The Spatial Interactions within and between Regions and Cities in Victoria (SIRCV) model is an SCGE model developed at the Centre of Policy Studies, Victoria University (Lennox, 2020).

Like any CGE model, an SCGE model provides a comprehensive representation of production and consumption activities of firms and households in an economy. Households earn income by supplying labour, land and capital to firms in different industries. Firms use primary factor and intermediate inputs to produce the good or service particular to their industry. These goods and services are purchased as intermediate inputs by other firms, and as final goods or services by households. Goods and services may also be imported and exported.

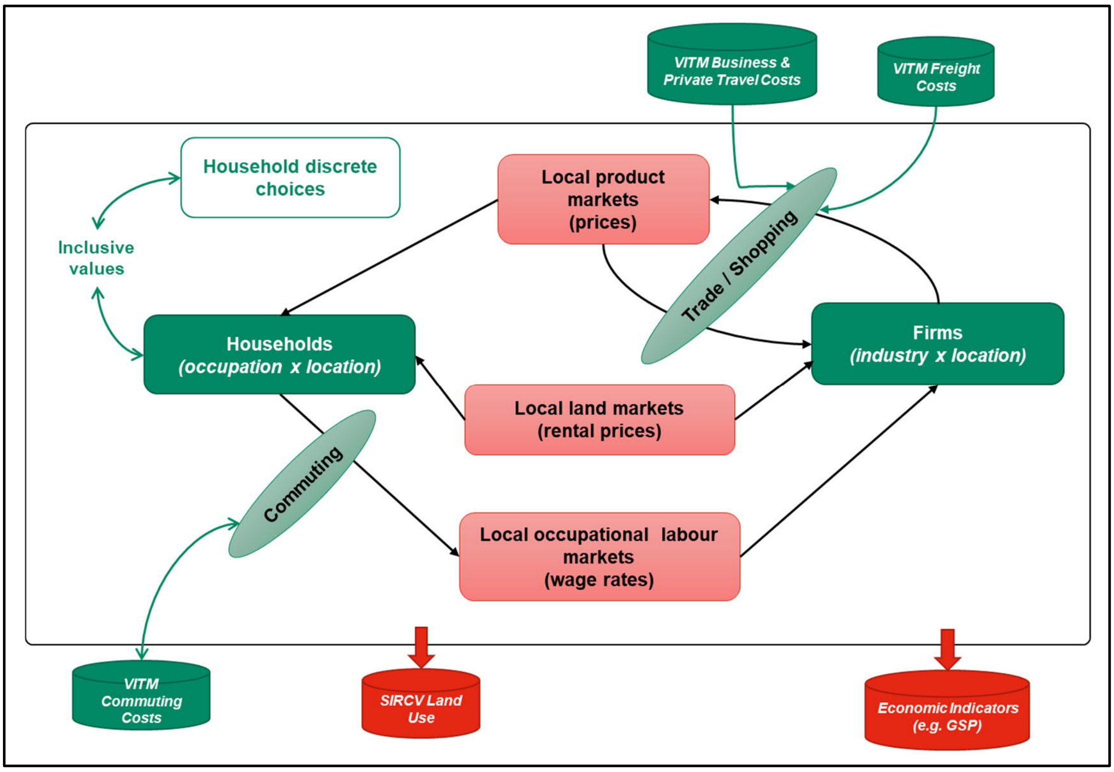
SCGE models are differentiated from CGE models (and to a lesser extent from multiregional CGE models, e.g. Horridge et al., 2005) by their emphasis on space. Firstly, all production and consumption activities are located in and compete for space, i.e. for land. Secondly, there are dense networks of spatial interactions linking these activities, which are especially important at smaller scales. Local labour markets are connected by commuting flows, local goods markets by trade flows and local services markets by business and private travel. In the long run, residential and employment location choices are also important sources of spatial interaction. As in SIRCV, these are usually treated as discrete choices. Thirdly and finally, the role of transport costs in mediating spatial interactions via commuting and trade flows is made explicit.

The SIRCV model distinguishes 458 regions/zones in Victoria, corresponding to ABS Statistical Area Level 2 (SA2). Note that four SA2s containing negligible economic activity are omitted. The SA2s in SIRCV map to the 499 transport zones used in the Rapid VITM. The extra 41 transport zones in the Rapid VITM represents the special generators required for the FMM run within the Rapid VITM.

There are two classes of household in SIRCV: working and non-working. Individual households of either class face a set of discrete choices. The choice set of working households is very large. Firstly, a worker chooses between 43 occupations, corresponding to ABS ANZSCO 2 digit occupational classifications. Secondly, the worker chooses between residing in one of 22 different urban areas in Victoria (ABS Significant Urban Area (SUA)) or in rural Victoria. Thirdly, the worker chooses a specific SA2 of residence within their chosen SUA, and an SA2 of employment. A non-working household has only to choose their SUA and SA2 of residence.

The SA2 of residence implies a particular living cost, reflecting both the local cost of housing in that SA2 and the overall costs of goods and services in that location. The latter takes into account both producer prices in all locations and transport costs (i.e. for freight or travel) between those locations and the place of residence. The combination of SA2 of residence and of work implies a particular commuting cost. The combination of occupation and SA2 of employment implies a particular wage rate. Note that wage rates differ by location and by occupation (by industry). Each worker-household takes all of these various factors into account alongside their individual idiosyncratic preferences in choosing their preferred combination of options. The model does not explicitly represent individual persons or households, but determines the proportion of each population choosing each option.

Figure 2 SIRCV Model Structure



Within VLUTI, the key inputs to SIRCV are transport costs: commuting costs, private travel costs, business travel costs and freight costs. Freight costs apply to trade in goods. For trade in services, VITM travel purposes are mapped according to the type of service concerned. For example, trade in 'Computer Systems Design and Related Services' is predominantly between firms, so is associated with business travel, whereas 'Food and Beverage Services' services are predominantly used almost exclusively by households and are associated with 'Shopping'. For commuting, costs for blue collar and for high- and low-skilled white collar jobs are mapped to relevant occupations. The commuting costs for blue collar and white collar workers are different because of differences in their chosen transport mode and workplace.

In response to changed transport cost inputs, a SIRCV simulation within the VLUTI system will produce a new spatial economic equilibrium. This includes changes in residential and job locations, which are (appropriately mapped and then downscaled to transport zone level) fed back into VITM. Other model variables may be extracted directly from SIRCV. However, given the high dimensionality of most variables, it is usually most useful to aggregate out one or more dimensions. For example, one may be interested in the change in average wage rate by occupation (aggregating over locations) or the change in average wage rate by place of employment (aggregating over occupations). At the highest level, a scenario may be evaluated in terms of aggregate indicators. These are, most notably, the expected utility of each household type and GSP. By the comparison of the GSP between a project case and the base case, the WEBs can be estimated.

The responsiveness of SIRCV to changes in transport costs is most strongly influenced by parameters of the nested logit model governing location choices, and secondarily by trade elasticities for goods and services. The majority of these parameter values are drawn from the literature (see section 3.4 in Lennox, 2020) as their estimation would require data that are difficult to obtain at the SA2 scale. One exception to this is that commuting cost parameters were estimated to fit Victorian Census data on places of residence and work by occupation.

5. Model Convergence and Verification

It is necessary for a land use transport model which involves iterations to converge to a stable and preferably unique solution so that it can be used with confidence to study the impact of transport on the redistribution of land use. In this section we show that VLUTI has converged in just six iterations.

It is usual to validate transport models by comparing the model outputs such as modelled highway traffic volumes and public transport loadings for a base year with the observed data. This is the case with VITM. However, a quasi-experimental approach to model validation applying to land use models that seek to represent long-run responses is very difficult. Applying this form of validation to SIRCV would firstly require a wider range of spatial data than is currently available, over a period of several decades. Secondly, some natural experiment(s) would need to be identified that allowed us to isolate long-run responses to specific transport interventions from responses to all manner of other time-varying phenomena. Neither of these is currently feasible.

Consequently, we focus firstly on verifying that VLUTI performs in a way that is technically correct. Secondly, we demonstrate that it generates a relationship between the spatial distributions of residents and jobs that is broadly consistent with that generated by an alternative, bottom-up modelling approach.

5.1. Model Convergence

The VLUTI design has aimed for internal consistency to ensure model convergence. Considering discrete choice models for a working household, the parameters were set so that choice decisions follow a hierarchy. At the highest level, the household considers the choice of specific occupation, then followed by residential location, and next workplace, which are above the choice of mode and destination, and at the lowest level, the choice of route. In responding to a change in the transport system, the household's sensitivity would follow a reverse hierarchy, i.e. to consider a change of route first, then change of mode or destination, and the change of occupation last.

Ideally, each iteration of the model processing loop moves closer towards a stable combination of demographic distribution and network performance. Once the model has reached this stable state, it can be said to have converged. Several different variables produced by both the Rapid VITM and the SIRCV Model were selected to monitor this process during scenario testing. Two variables: change in population distribution and accessibility, have been selected through testing to provide the clearest indicators that the model is converging.

Figure 3 shows the differences in resident workers per SIRCV zones over successive model iterations for a base case in 2036. The plot indicates that at the first iteration, the differences in resident workers are significant, but these differences became smaller at subsequent iterations, and insignificant at the sixth iteration. Numerically, the model has been set to achieve convergence if the percentage change of residence workers is 0.2% or less between iterations. The method of cost averaging was implemented to smooth the changes in transport costs and speed up the overall convergence. The model usually achieves convergence at the 4^{th} iteration, but six iterations were set as a default to ensure consistent model convergences between project cases and bases over different modelled years.

Figure 3: Convergence of Resident Workers – 2036

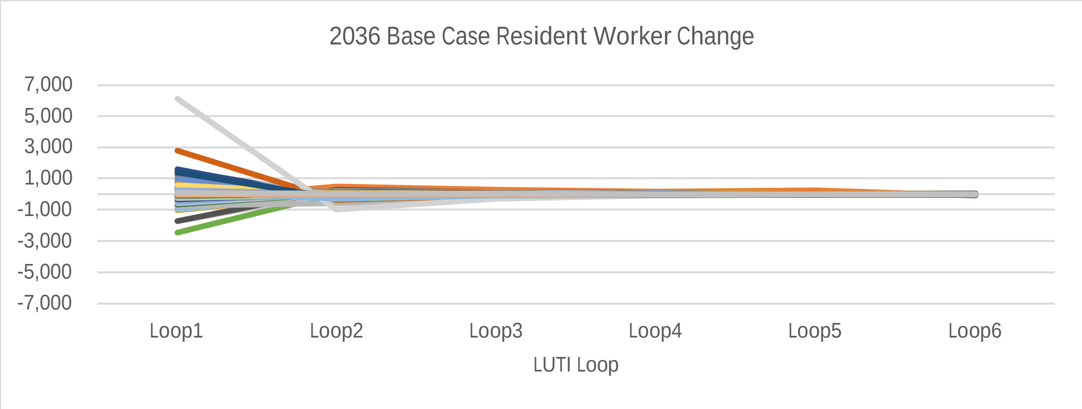
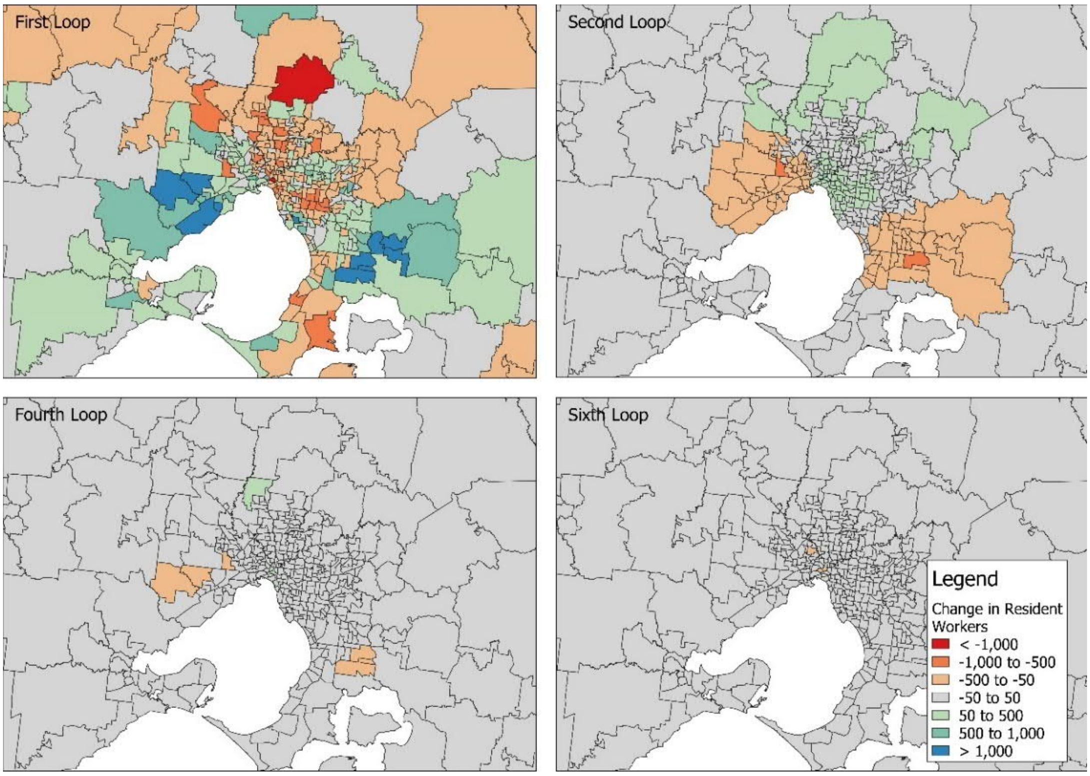


Figure 4 shows the same metric as above but at a spatial level for loops 1, 2, 4 and 6. It is shown that by the final loop (bottom right) there are little changes in residential location.

Figure 4: Spatial convergence of Resident Workers



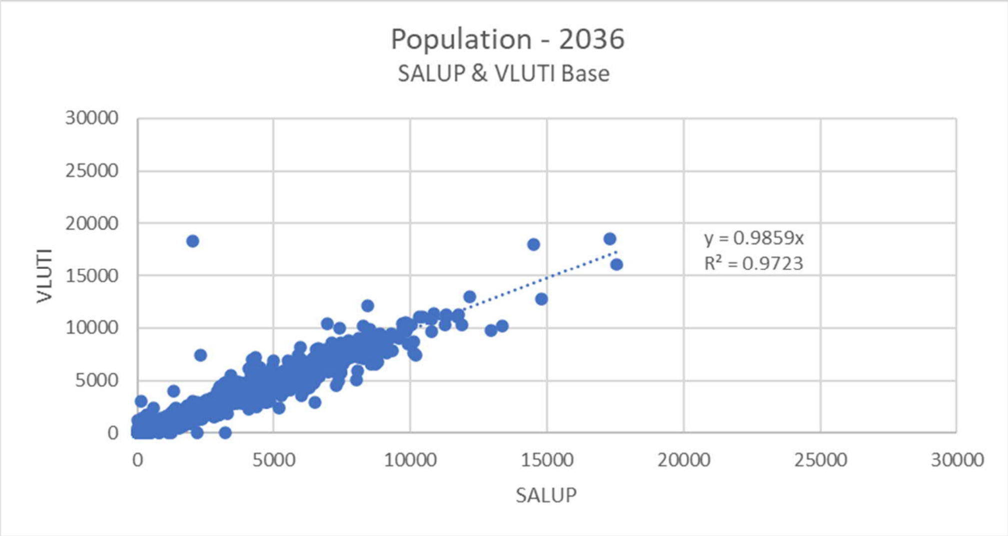
5.2. Verification

As discussed previously, the validation of land use models has not been advanced due to unavailability of sufficient observed data and the inherent difficulty of such a process. In this case, only the verification of VLUTI was considered to check if VLUTI has operated in a logical way and produced the output as expected. Small Area Land Use Projections (SALUP), which have been used as the standard land use data input to VITM for business case modelling in Victoria, were used to calibrate and verify the VLUTI forecasts of population and employment in future years (2036 and 2051).

Figure 5 shows a scatter plot comparing the SALUP population per transport zone against the VLUTI results at the same level. Since SALUP population was used to calibrate the

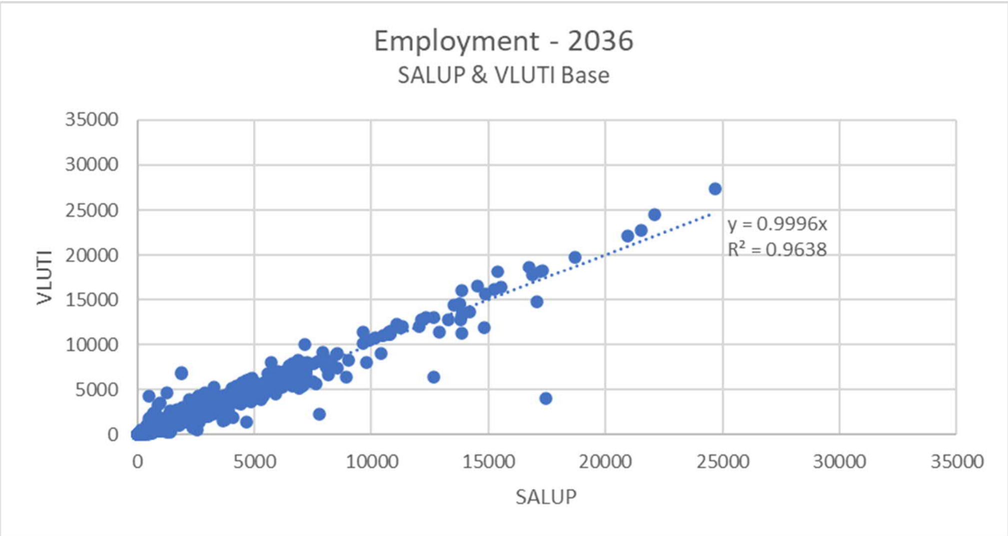
VLUTI projections of population, it is expected that aside from a few outliers there is a strong relationship between the two population datasets with R^2 of 0.97 and x coefficient of 0.99.

Figure 5: SALUP and VLUTI Population



However, the forecast of employment by VLUTI is completely independent of the SALUP employment projections. The comparison of employment in Figure 6 shows a strong correlation R^2 of 0.96 and x coefficient of 1 at the transport zone level. This gives us some confidence in the VLUTI forecast of employments.

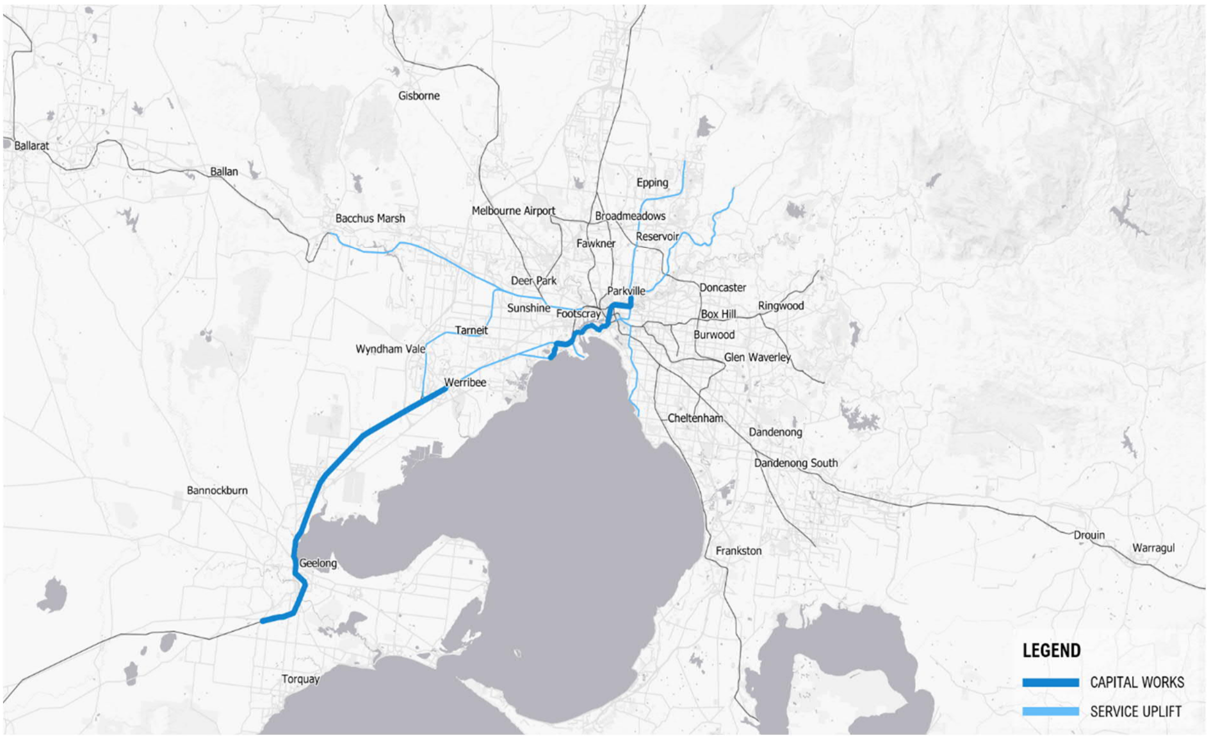
Figure 6: SALUP and VLUTI Employment



6. Model Application

To illustrate an application of VLUTI, a proposed Melbourne Metro Two and Direct Geelong Rail line (MM2G) was used. MM2G is a project recently assessed by Infrastructure Victoria as part of its 30-year infrastructure strategy presented to the Victorian Parliament and Government (Infrastructure Victoria, 2021a). MM2G consists of the construction of tunnels through Melbourne's CBD, connecting Newport and Clifton Hill via Fisherman's Bend and Parkville. Coupled with the tunnels, train services travelling on the Geelong, Werribee, Hurstbridge, Mernda, Laverton, Williamstown, Sandringham, Wyndham Vale and Grampian lines are able to receive uplifts, as outlined in Figure 7.

Figure 7: MM2G Project Overview



6.1. Estimate of changes in land use

This section presents the impact of a transport project on land use redistribution by looking into the change of employment accessibility, the redistribution of population and employment when compared against the base case.

Figure 8 to Figure 10 show the spatial change in accessibility, population and employment due to the MM2G in 2051 (Infrastructure Victoria, 2021b).

The employment accessibility (EA) is calculated using the equation below:

$$\boldsymbol{EA_i = \sum_j \frac{E_j}{E} e^{-\beta T ij}}$$

where:

$\frac{E_j}{E}$ is the share of employment at Transport Zone j of the total employment E

T_{ij} is the composite transport cost from zone i to zone j.

β is the decay parameter adopted from the VITM mode choice

The EA is a number between 0 and 1 representing the accessibility from one zone to all other zones weighted by employment share at destination. It is the inverse of an exponential function of generalised cost to employment. The lower the generalised cost the higher the EA.

Figure 8 shows that the MM2G has resulted in increased accessibility along the project corridor up to Geelong, as well as the areas enjoying service uplifts. Each point in the plot represents a 0.1% change in accessibility for the underlying transport zone it resides in.

Figure 8: Change of employment accessibility

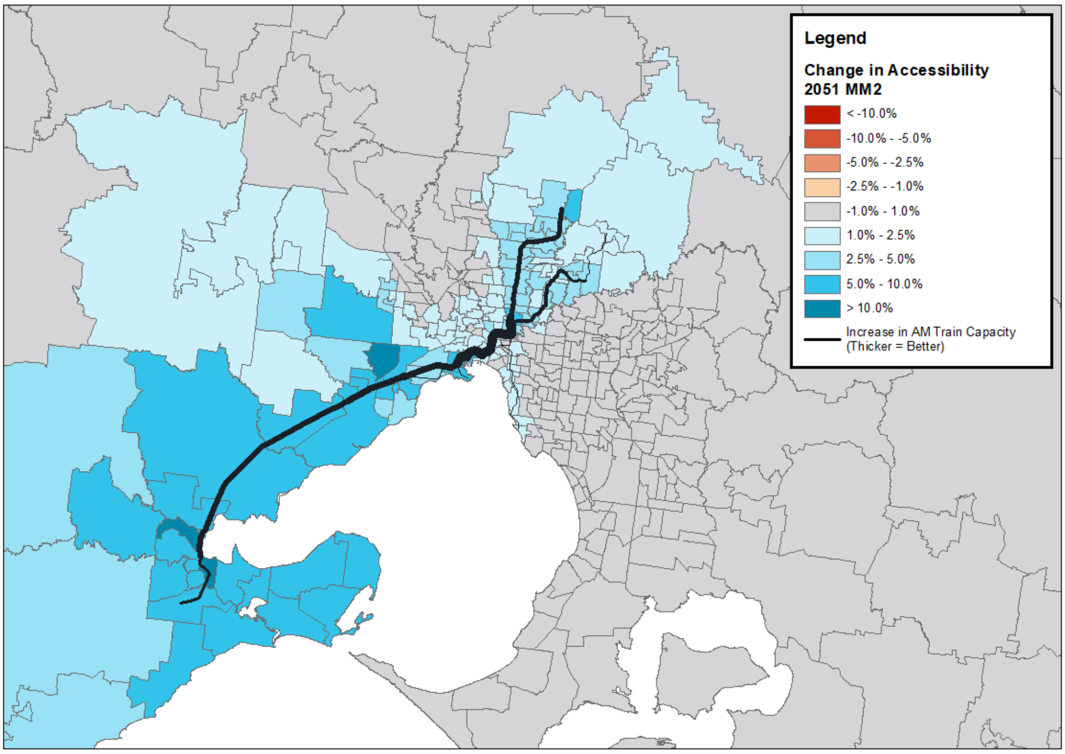


Figure 9 and Figure 10 show that the change in population and employment follows similar patterns to the accessibility change.

Figure 9: Change of population (1 dot = change of 5 persons)

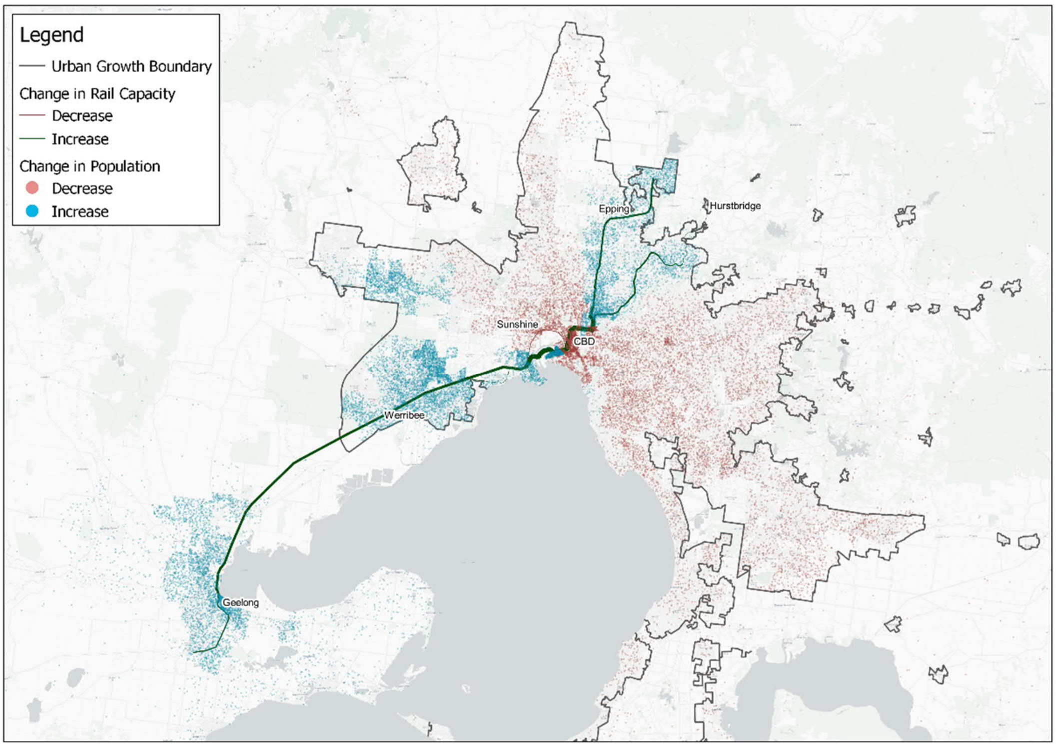
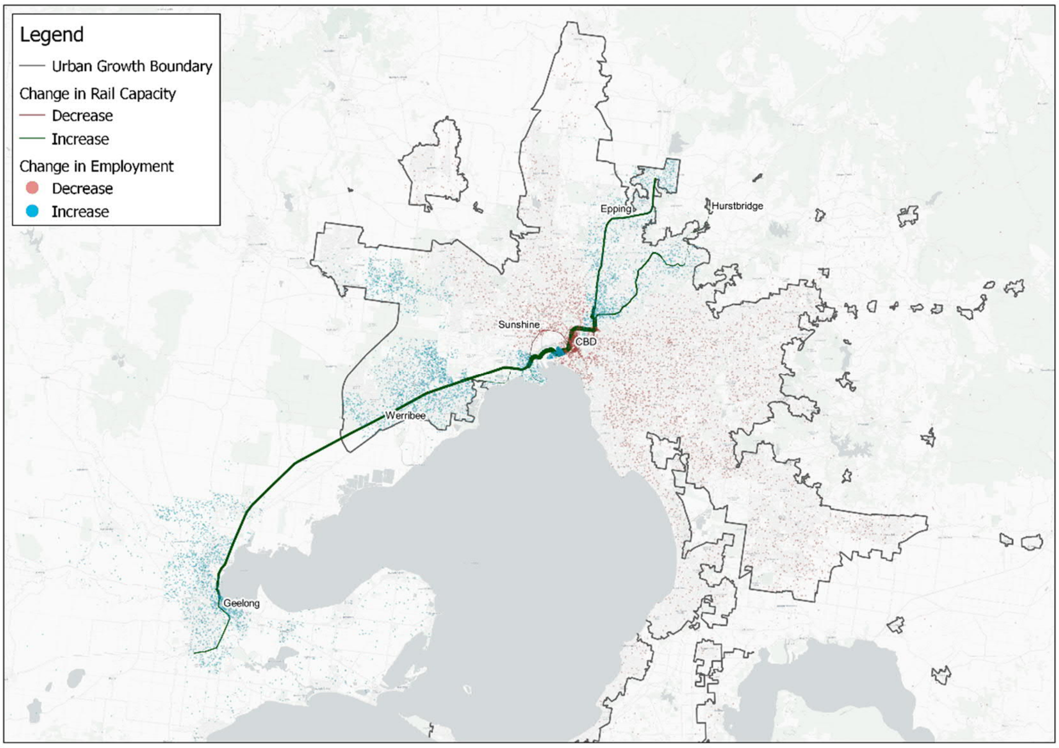


Figure 10: Change of employment (1 dot = change of 5 jobs)



Population and employment shift from peripheral suburbs in Melbourne to population centres along the project corridor and impacted rail service corridors. This is expected as the reduction in commuting costs estimated by VITM in this corridor would increase the accessibility, and hence the utility of choosing those areas for residential location, and workplace.

6.2. Estimate of benefits

The Australian Transport Assessment and Planning Guidelines (ATAP) Guidelines, T2 Cost Benefit Analysis indicates that the conventional benefits for a transport project could include:

- Travel time cost savings
- Vehicle operating cost savings
- Crash cost savings
- Environmental externality cost savings
- Residual asset value if applicable

The estimation of benefits for a transport project in Victoria has been performed using EEM together with VITM.

EEM calculates the travel time cost savings or broadly the generalised cost (measured in time unit) savings for both highway and public transport modes based on consumer surplus methodology.

EEM also produces the network performance such as travel distance change between a project and the base case, which can be used to estimate the vehicle operating cost, crash cost and environmental externality cost savings.

Traditionally the conventional benefits have been estimated by using a demand model where the land use inputs are static or constant in both the base and project cases. In this project, with the application of the VLUTI the land use inputs to the demand model become dynamic and there is a relocation of job and population as a result of improvements to transport in the project case.

With the introduction of dynamic land use, we modified the EEM to enable it to correctly calculate the generalised cost savings based on the consumer surplus, which represent a significant component of conventional benefits. However, the estimation of other benefits based on change of network travel distance remains unchanged.

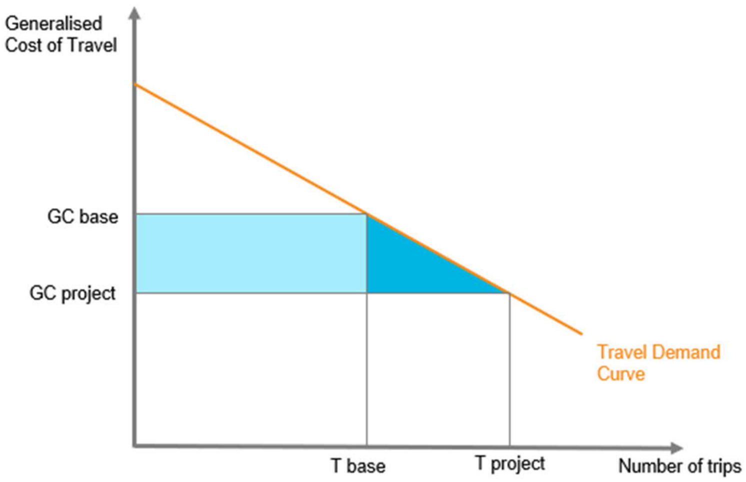
This section first reviews the calculation of generalised cost saving benefits in the case of static land use, then discusses the estimation of benefits in the case of dynamic land use.

6.2.1. Static land use

Figure 11 shows the benefits or consumer surplus of a project as a result of reduction of generalised cost (GC) from the base to the project case. The benefits are determined commonly by the "rule-of-a-half". They can be divided into two parts:

The benefit to existing users (the shaded rectangle). It is calculated as the reduction in cost for all the existing users. The benefit to new (diverted or generated) users (the shaded triangle). It is calculated as the triangle area. The same calculation applies to lost users.

Figure 11 Estimation of Benefit from a Transport Improvement (Source: ATC Guidelines Vol.5, page 41)



The Economic Evaluation Module calculates the consumer surplus for three user types: Existing, New, and Lost.

The existing users are the one who do not change their mode of travel nor their destination as a result of the project. Their benefits are simply the product of the existing users to the reduction of travel cost as below:

$$Benefit_{existing\ users} = Min(Trips_{base}, Trips_{project}) \times (GCost_{base} - GCost_{project})$$

Please note that the number of existing users is defined as the minimum number of trips between the base and the project case. In the case of increase of demand in the project case, the number of trips in the base is the existing users. Whereas in the case of demand reduction in the project case, the number of trips in the project is the existing users.

New or lost users are defined as those who change their mode or destination as a result of the project. They are identified by calculating the difference of demand for an origin destination pair between the project and the base case. If the difference is positive, the increase of demand is new users. Similarly, if the difference is negative, the reduction of demand is defined as lost users.

The new and lost user benefits are based on the rule-of-a-half, applying half of the change in travel cost to the new and lost users. The number of trips is calculated as the absolute trip difference between base and project cases. The benefit would be positive or negative (benefit or disbenefit) depending on the change in cost being positive or negative.

For example, in the case of an improved public transport option between two zones, the benefit to a new user switching from car to PT would include half of the benefit of the decrease in public transport cost (their new mode):

$$Benefit_{new/lost\ users}) = 1/2 \times \left|Trips_{project} - Trips_{base}\right| \times \left(GCost_{base} - GCost_{project}\right)$$

6.2.2 Dynamic land use

As the VLUTI is capable of simulating the relocation of jobs and population (i.e. land use change) as a result of transport improvements, transport users can now be divided into three main categories:0

- New and lost users who shift from one mode of transport to the other or change their destination due to job relocation or trip redistribution
- Existing users who stay at the same location (existing-staying users).
- Existing users who relocate to a new location (existing-moving users).

The benefits of new/lost and existing-staying users are conventional benefits, but those of existing-moving users are considered as part of land use change benefits. The latter's benefits will be calculated similarly to that of traditional transport users (i.e. full benefits) but considering the user's moved location. Strictly speaking, the benefits/disbenefits of new/lost users due to job relocation could also be classified as land-use change benefits related to change at destination. However due to the complication of separating this user movement, the land use change benefits at this stage consider only existing users who relocate to a new location or existing-moving users.

The benefit of existing-staying users for example i-j (travelling from zone i to j) is calculated in the same way as in the static land use, because i-j was the same in the base and project case.

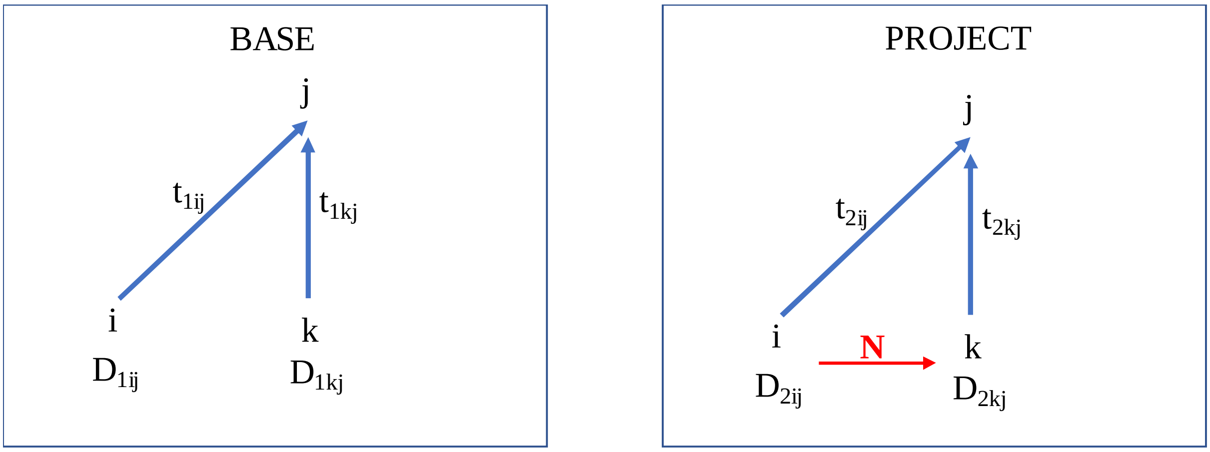
$$Benefit_{existing\text{-}staying\ \ users} = Min(Trips_{base\ i\text{-}j}, Trips_{project\ i\text{-}j})\ \times (GCost_{base\ ij} - GCost_{project\ ij})$$

The benefit of existing-moving users – for example a user (travelling from zone i to j in the base case) moving her residence from zone i to k (in the project case) and her destination remains as j – is estimated as below:

$$Benefit_{existing\text{-}moving\ \ users\ (i\ to\ k)} = Trips_{base\ i\text{-}j\ via\ k} \times (GCost_{base\ ij} - GCost_{project\ kj})$$

Figure 12 below shows an example to illustrate the calculation of benefits in the case of land use change.

Figure 12 Illustration of land use change benefits



Where:

D_{1ij}, D_{2ij} Is the travel demand or number of trips from i to j for the Base (1) and Project case (2) respectively

t_{1ij}, t_{2ij} Is the travel time from i to j for the Base and Project case respectively

N Is the number of trips moving from i to k due to population relocation ($N > 0$; $D_{1ij} > D_{2ij}$; $D_{1kj} < D_{2kj}$)

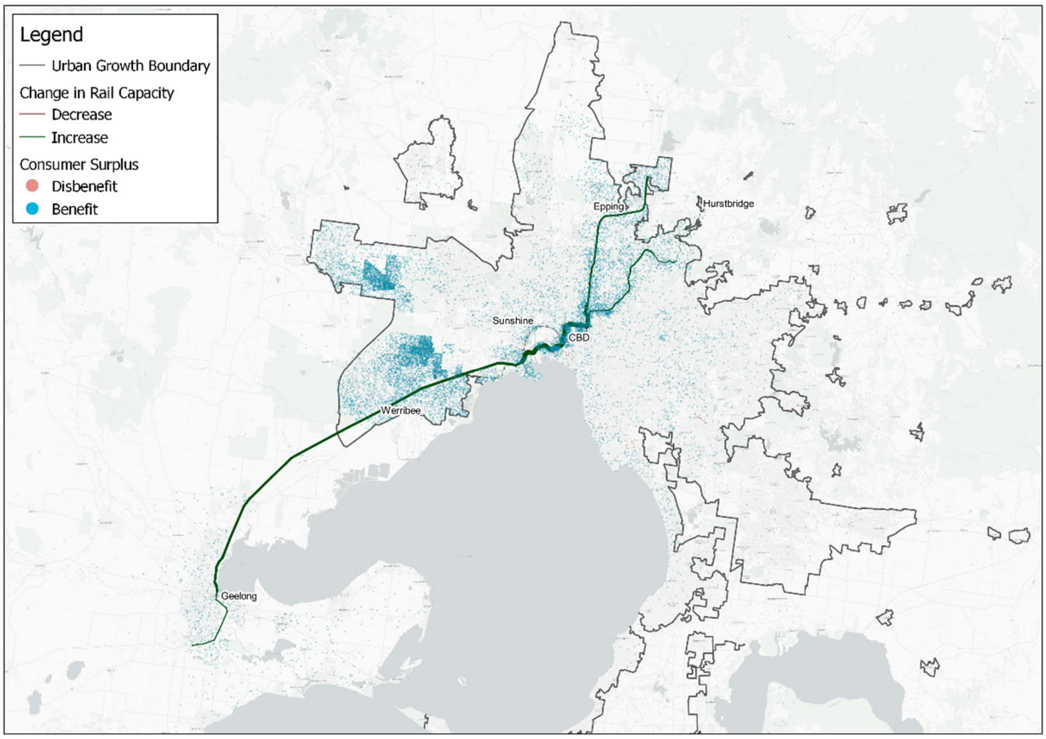
Table 1 Calculation of benefits for different user types

Static Land Use	Dynamic Land Use
Existing users $E_{ij} = D_{2ij} \times (t_{1ij} - t_{2ij})$ $E_{kj} = D_{1kj} \times (t_{1kj} - t_{2kj})$	Existing staying users $E_{ij} = D_{2ij} \times (t_{1ij} - t_{2ij})$ $E_{kj} = D_{1kj} \times (t_{1kj} - t_{2kj})$ Existing moving users $M_{ij\ via\ k} = N \times (t_{1ij} - t_{2kj})$
New users $N_{kj} = \lvert D_{2kj} - D_{1kj} \rvert \times (t_{1kj} - t_{2kj}) \times 1/2$	New users $N_{kj} = (\lvert D_{2kj} - D_{1kj} \rvert - N) \times (t_{1kj} - t_{2kj}) \times 1/2$
Lost users $L_{ij} = \lvert D_{1ij} - D_{2ij} \rvert \times (t_{1ij} - t_{2ij}) \times 1/2$	Lost users $L_{ij} = (\lvert D_{1ij} - D_{2ij} \rvert - N) \times (t_{1ij} - t_{2ij}) \times 1/2$

As indicated in Table 1, when calculating the benefits for N existing-moving users moving from origin i to origin k, it is necessary to reduce the number of lost users at i by N and also reduce the new users at k by N, to avoid double counting.

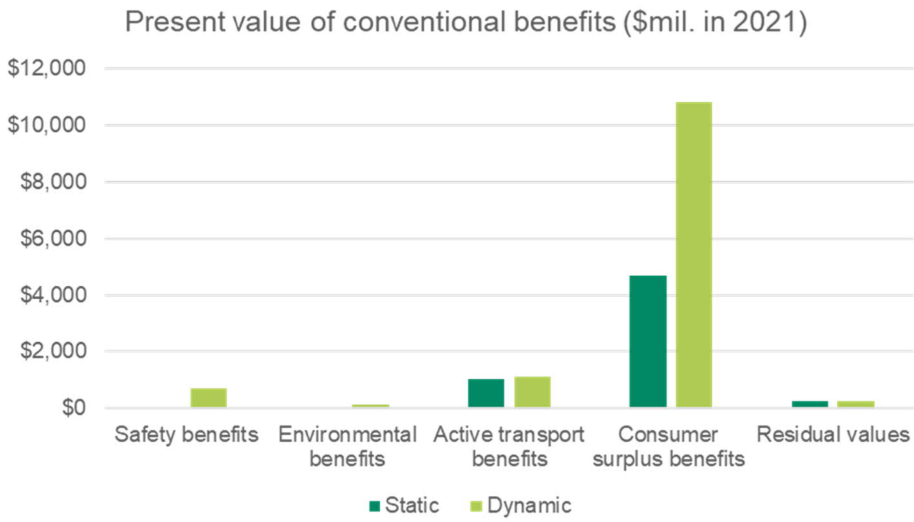
Figure 13 shows the distribution of conventional consumer surplus for the public transport (PT) users for the project with dynamic land use. There is a clear benefit to the areas along the project corridors, with minor disbenefit record in parts of the city's east. This is logical, as the greater accessibility in these areas would lead to reduced travel times.

Figure 13 Dynamic Land use - Consumer surplus for PT users (1dot= 120 mins)



The pattern and extent of consumer surplus for PT users with the static land use is similar to that of the dynamic land use. But, the consumer surplus for car users with the dynamic land use is significantly higher than that with the static land use. As illustrated in Figure 9 and Figure 10 with the relocation of population and employment from peripheral suburbs in Melbourne to population centres along the project corridor, there is a corresponding shift of car users to PT, and that generates significant decongestion benefits in the peripheral suburbs.

Figure 14 Comparison of conventional benefits between static and dynamic scenarios



(Note: Dynamic land use benefits include static land use benefits)

Figure 14 compares the present values of conventional benefits for MM2G between the static and dynamic land use scenarios. The conventional benefits presented in this figure include safety, environmental, active transport, consumer surplus and residual value benefits, which were calculated from the streams of benefits using a discount rate of 4% (Infrastructure Victoria, 2021b).

Overall, the conventional benefits for MM2G with the dynamic land use are approximately double of those with the static land use. However, it is necessary to note that depending on project type and its location, a project could obtain more or less benefits associated with the application of dynamic land use. Therefore, it is essential to use a land use model like VLUTI to test the investment of significant infrastructure projects.

7. Conclusion

This paper has presented the development of a land use, transport and economy model by integrating a strategic transport model, VITM, with a spatial computable general equilibrium model, SIRCV. The model convergence was achieved by implementing a hierarchy of discrete choice models to ensure internal consistency and built-in convergence tests. The paper discussed model verification by comparing the base land use produced by the model with the official land use datasets. An application of the model was illustrated by looking at the land use change in response to a proposed MM2G. Finally, a methodology to estimate the consumer surplus in a dynamic land use was introduced and the differences in the project conventional benefits between static and dynamic land use scenarios were presented.

The strength of VLUTI is in its internal consistencies and model convergence built on a hierarchy of discrete choice models from the choice of occupation and residential location at the top to the choice of travel destination, mode and route at the bottom, all based on the state of equilibrium. Secondly, although SIRCV is a large model, the theoretical approach is well established in the literature and the parameter values adopted are within the ranges of empirical estimates made using single sector spatial equilibrium models.

The limitation of VLUTI, as is the case with almost all LUTI models, is that the validation of the land use component or the estimation of some of its key parameters has not been advanced due to the insufficiency of data and the difficulty of finding natural experiments suitable to validate long-run structural economic relationships. Another limitation is the long execution time due to its two-stage executing process: Rapid VITM and SIRCV are run consecutively in the first stage, and Full VITM is run in the second stage. The efficiency and transparency of VLUTI could be further improved by further integrating the two models, removing interface programs and duplications, and using the same disaggregated VITM zones for all processes.

The paper concludes that while VLUTI has certain strengths and limitations, it can be used to better estimate and understand the impact of a transport project on land use changes and the corresponding project benefits with dynamic land use than the traditional application of static land use.

References

Acheampong, Ransford Antwi and Elisabete Silva (2015). Land use–transport interaction modelling: A review of the literature and future research directions. *Journal of Transport and Land Use* 8 (3).

Alonso, W. (1977). Location and land use: toward a general theory of land rent. Cambridge/Mass.: Harvard Univ. Press

Anas, Alex and Yu Liu (2007). A Regional Economy, Land Use, and Transportation Model (RELU-TRAN): Formulation, Algorithm Design, and Testing. *Journal of Regional Science* 47 (3):415–455.

Australian Transport Assessment and Planning (ATAP) Guidelines (2016). T1 Travel Demand Modelling.

Infrastructure Victoria (2021a). Victoria Infrastructure Strategy 2021-2051 (Vol-1). Melbourne: Infrastructure Victoria.

Infrastructure Victoria (2021b). Major Transport Program Strategic Assessment Report. Melbourne: Infrastructure Victoria.

Infrastructure Victoria (2021c). Victorian Land Use and Transport Integration (VLUTI) model architecture report.

Infrastructure Victoria (2021d). Economic Outcomes Report – Major Transport Infrastructure. Prepared by AECOM for Infrastructure Victoria.

KPMG (2021). Suburban Rail Loop Economic Appraisal Report, Appendix C2, 15 February 2021, (https://suburbanrailloop.vic.gov.au).

Le H., Somerville C., Wood N. (2013). Development of a Statewide Transport Model. 2013 *AITPM National Traffic and Transport Conference Proceedings*, PERTH Western Australia.

Lennox, J. (2020). More working from home will change the shape and size of cities. CoPS Working Paper No. G-306, August 2002.

Lennox J., Sheard N. (2019). Spatial general equilibrium analysis of a large urban rail project. Centre of Policy Studies (CoPS) Victoria University, Melbourne, Australia

Waddell, Paul (2002). UrbanSim: Modeling urban development for land use, transportation, and environmental planning. *Journal of the American planning association* 68.3 (2002): 297-314.

Wegener, Michael (2004). Overview of land-use transport models. *Handbook of transport geography and spatial systems* 5:127–146.