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Research paper

# An application of land use, transport, and economy interaction model

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ABSTRACT

Governments need to assess the benefits of transport projects to prioritize investments. It is imperative for governments to have tools that can closely estimate 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 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. To overcome this drawback in existing models, this paper firstly presents a literature review of advances in the land use transport interaction model (LUTI), then discusses the development of a LUTI model for Victoria, Australia (VLUTI) by integrating the Victorian Integrated Transport Model with a Spatial Computable General Equilibrium model (SCGE). The land use component (SCGE) was developed to represent a highly resolved zone system, detailed classifications of occupations and industries, and spatial interactions via commuting, and trade in goods and services, and thus enables VLUTI to simulate a detailed and nuanced picture of land use and transport interactions in a complete economic environment.

The literature review also indicates limited research in applying a LUTI to estimate land use change benefits. This paper presents an application of 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, at a future point in time, is endogenously adjusted within VLUTI. It presents a method to correct, in the dynamic case, the benefits as estimated by the rule of a half, which usually assumes static land use. The paper concludes with suggestions for further developments and improvements of VLUTI such as incorporating an activity-based transport model and an environmental model to progress toward an integrated land-use, transport, economy, and environment model capable of assessing the full impact of a transport project in a holistic way.

## 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 closely estimate 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 change as residents and businesses relocate to take advantage of lower travel and/or freight costs resulting from 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. To overcome this drawback, 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).

Section 2 presents a literature review of developments in the land-use transport interaction (LUTI) model. The review focuses on a

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branch of the land-use model, the spatial computable general equilibrium (SCGE), which brings in not only the location choice but also the economic aspect of land use. This led to the formation of VLUTI by combining the Spatial Interactions Within and Between Regions and Cities in Victoria (SIRCV) model, an SCGE model with the Victorian Integrated Transport Model (VITM). Section 2 also highlights our contributions to the estimation of land use changes benefits.

Section 3 presents an overview of VLUTI. Section 4 discusses the methodology of the VITM. Section 5 discusses in detail the SIRCV model. Section 6 presents an application of the model to study a transport project. Section 7 discusses in detail our approach to estimating land use change benefits. Section 8 provides our conclusions and suggestions for further developments.

## 2. Literature review

The value of land use transport interaction (LUTI) models for assessing broader and city-shaping effects of significant transport infrastructure projects is well established (Wegener, 2004; Acheampong, Antwi, & Silva, 2015). LUTI modelling first emerged in the 1960s with Lowry's (1964) "Model of a Metropolis" being a seminal contribution (Cordera et al., 2017). Building on Isard's (1956) location theory, transport network changes in Lowry's model affected the accessibility of locations and gains (or losses) in accessibility would attract (or repel) population. Other early LUTI models including MEPLAN (Echenique et al., 1969) and TRANUS (de la Barra & Rickaby, 1982), built on these foundations.

In the 1970s and 1980s, Echenique et al. (1974), Anas (1983) and others showed how empirically derived gravity models might be underpinned by microeconomic theory and began to consider land markets and development explicitly. Although many contemporary LUTI models maintain a partial equilibrium approach (e.g. Coppola & Nuzzolo, 2011), some recent contributions adopt a spatial computable general equilibrium (SCGE) framework. In an SCGE model, not only do local markets for land, housing and labour depend on accessibility, but so too do most local markets for goods and services. All these markets are interconnected through the choices, incomes and expenditures of households, and the technologies, revenues and expenditures of firms.

An important contribution to the literature on SCGE-based LUTI modelling is Anas and Liu (2007). In their model RELU-TRAN, the SCGE component (RELU) features multiple types of labour, buildings and industries (four of each) operating in fifteen zones that cover Greater Chicago. They also show that the model can be solved using an iterative algorithm: solving the static market equilibrium of RELU and the user equilibrium of TRAN in turn.[1] Anas (2013) describes applications of this model to Chicago, Los Angeles and Paris. In Australia, a similar approach is taken by Truong and Hensher (2012), Hensher et al. (2012) and Robson & Dixit (2017). The latter two contributions involve applications of SCGE-based LUTI models to assess the impacts of transport projects in Greater Sydney. Similar modelling approaches have been applied to cities in other countries; for example, Zhang et al. (2016) developed a model of Changzhou, China. Robson et al. (2018) review the application of SCGE models in transport project appraisal.

Contemporary SCGE models are also influenced by developments in quantitative urban economics (Ahlfeldt et al., 2015). This literature focuses on estimating more simply structured but highly resolved spatial general equilibrium models, distinguishing many hundreds of zones within a city or region. Similar levels of spatial detail are now adopted in the more elaborately structured SCGE-style simulation models and parameters from simpler, estimable models are adopted. For example, Ishikura & Yokoyama (2022) distinguish 376 municipalities in the Greater Tokyo Area, while Wan and Jin (2019) model 209 zones in the Beijing region. The VLUTI model builds on this literature. The SCGE component provides a similar level of spatial detail to Ishikura & Yokoyama (2022) and Wan and Jin (2019). However, the former focuses exclusively on freight transport (commuting in Tokyo occurring mainly by rail). The latter adopts a highly stylised production structure, with a single sector, although it adopts a form of recursive dynamics. While VLUTI is a comparative static framework, its SCGE component is distinguished by detailed classifications of occupations and industries, and spatial interactions via commuting and trade in goods and services. Thus, VLUTI simulations provide a detailed and nuanced picture of land use and transport interactions in a complete economic environment.

While this paper focuses on an SCGE-based LUTI modelling approach, another LUTI model, CityPlan (KPMG, 2021), was recently introduced in Victoria, Australia. CityPlan was built on the UrbanSim platform (Waddell, 2002) and employs agent-based and micro-simulation approaches rather than equilibrium theory. Unlike VLUTI, CityPlan assumes that a city constantly evolves in response to changing conditions and would never reach a state of equilibrium.

As concerns the application of LUTI models, the estimation of conventional benefits by applying the rule of a half to a static land use case where the land use for the project case is assumed to be the same as the base case has been well applied in practice. However, when a LUTI model is applied to study the benefits of a transport project, the land use becomes dynamic. In other words, the land use for the project case is no longer the same as the base. This raises the question of whether the rule of a half would hold and how the benefit of land use changes is estimated in this situation. A review of the literature shows that research and practical applications in this area are limited (Rosik and Wojcik (2023); Wang et al. (2019); Eliasson et al. (2020)). In Victoria, Australia, CityPlan was used to study the impact and land use change of the Suburban Rail Loop. However, a method to estimate land use change benefits using this model has not been discussed. Section 7 of this paper will attempt to overcome these aspects in literature by presenting a methodology to estimate land use change benefits.

## 3. VLUTI model overview

VLUTI (Infrastructure Victoria, 2021c) is the product of the integration of VITM with SIRCV. The basic architecture follows the approach introduced by Anas and Liu (2007): an SCGE model is linked with a four-step transport model, and an iterative solution algorithm is employed. The SIRCV model is built on the principle of long-run spatial general equilibrium in terms of the 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 the economy under the intervention of transport infrastructure. The structure of the VLUTI model is presented in Fig. 1.

The Rapid VITM is a transport model with the same structure and components as the Full VITM but has fewer zones to speed up the 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, and
- 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

[1] The term "spatial computable general equilibrium" was not coined by Anas and Liu themselves, who refer to a "computable general equilibrium" model with "fully interdependent model zones" (ibid. p416). Alternative terms have been adopted in different strands of the literature, most notably "computable urban economic" (CUE) models (Ueda et al., 2013).

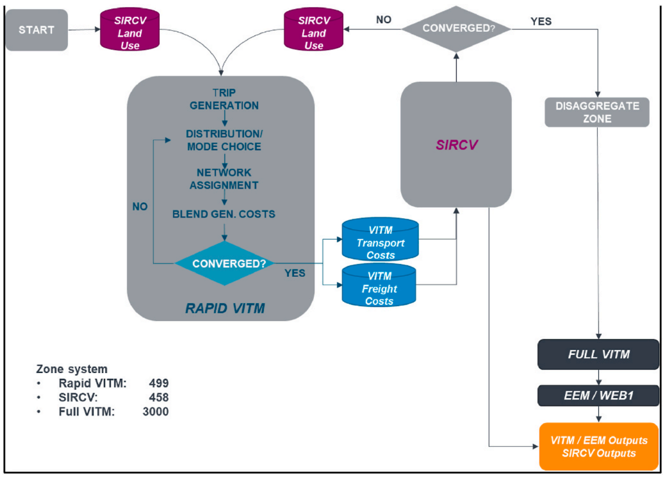


**Fig. 1.** VLUTI model structure.

Taking the generalised costs from the rapid VITM, SIRCV will produce updated land use in terms of population and employment distribution, which are input back into the rapid VITM. This process is undertaken in a 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 DTP's Economic Evaluation Model (EEM) and a WEB module are run to estimate a project's conventional benefits and WEBs.

## 4. VITM

The Victorian Integrated Transport Model (VITM) is a state-wide strategic transport model owned and maintained by the DTP. 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 et al., 2013). VITM is a conventional four-step travel model, including trip generation, trip distribution, mode choice, and trip assignment.

VITM represents traffic conditions 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 cars, rigid trucks and articulated trucks,
- Multiple public transport modes including trains (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 by government agencies to assess the impacts of transport investments and the performance of the transport system under existing and future demands. It is also used to support the business cases of transport infrastructure projects in Victoria.

DPT is currently developing VITM2, a new generation of VITM based on the activity-based approach to enable it to simulate the travel choice of an individual across all transport modes, including walking, cycling, public transport, car, and electric and autonomous vehicles. In parallel, an emission model covering both private and public transport vehicles has been developed and integrated with VITM. This could be extended to cover the impact of greenhouse gases, air pollution and traffic noise generation. However, these potentially advanced features have yet to be included in the current VLUTI.

## 5. 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). Fig. 2 shows the SIRCV model structure. Like any CGE model, an SCGE model provides a comprehensive representation of the 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 factors and intermediate inputs to produce the goods or services 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, Madden, & Wittwer, 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

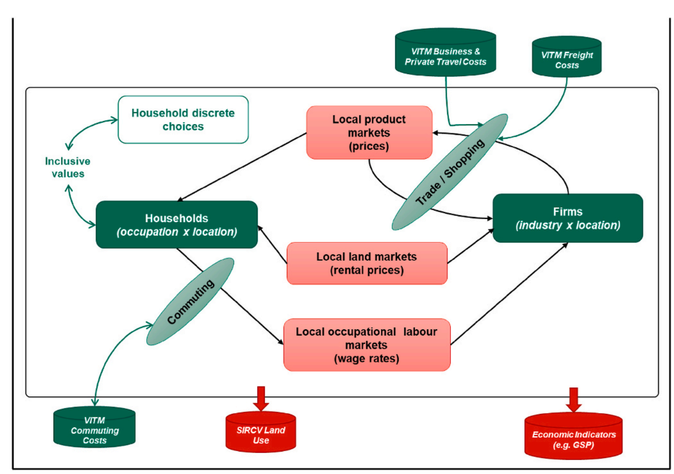


**Fig. 2.** SIRCV model structure.

important sources of spatial interaction. As in SIRCV, these latter are 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 the 499 transport zones used in the Rapid VITM. The extra 41 transport zones in the Rapid VITM represent the special generators required for the FMM run within the Rapid VITM.

There are two classes of households in SIRCV: working and non-working. Individual households in 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 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, but not by industry of employment. 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 that chooses each option in the relevant choice set.

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 used almost exclusively by households, so are associated with 'Shopping'. For commuting, costs for blue-collar and 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 modes and the spatial distribution of different types of workplaces within SA2s.

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 comparing 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. Most 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 is that commuting cost parameters were estimated to fit Victorian Census data on places of residence and work by occupation.

## 6. Model application

Le et al. (2021) discussed the convergence and verification of the VLUTI. It showed that the model was able to achieve convergence in six iterations. Since the validation of land use models has not been advanced due to the unavailability of sufficient observed data and the inherent difficulty of such a process, VLUTI was verified to check if it has operated logically and produced the output as expected. The verification was undertaken by comparing the VLUTI forecasts of population and employment in future years (2036 and 2051) with Small Area Land Use Projections (SALUP) data which have been used as the standard land use data input to VITM for business case modelling in Victoria. An application of VLUTI to study a significant rail project, the proposed Melbourne Metro Two and Direct Geelong Rail line (MM2G) was also discussed.

This paper presents an application of VLUTI to the proposed Outer Metropolitan Ring Road (OMR), a significant road project in Victoria. OMR 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). As shown in Fig. 3 OMR comprises.

- the northern segment, the OMR/E6, connecting the M80 Ring Road, Hume Freeway, and Calder Freeway by 2036, and
- the southern section, connecting Calder Freeway, Western Freeway, and Princes Freeway by 2051.

### 6.1. Estimate of changes in land use

This section presents the impact of a transport project on the redistribution of population and employment compared to the base case.

Figs. 4 and 5 show the change in population and employment due to OMR in 2051 (Infrastructure Victoria, 2021b).

Fig. 4 shows a population shift from the new growth areas in the north of Melbourne to the already established suburbs in the north and west of the CBD. By contrast, the fast-growing and newly established urban areas to the north and west of the OMR would see a slight reduction in population compared to the base case. This indicates that the OMR may have the effect of reducing traffic in the north and west of Melbourne, resulting in an increase in people opting to live in these areas. As the OMR pushes traffic out of the established urban areas, this appears to enhance amenities (mainly through reduced traffic and

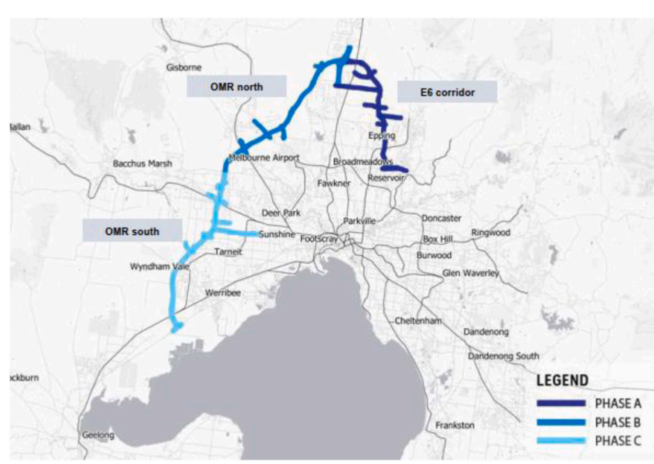


Fig. 3. OMR Project alignment and phases.

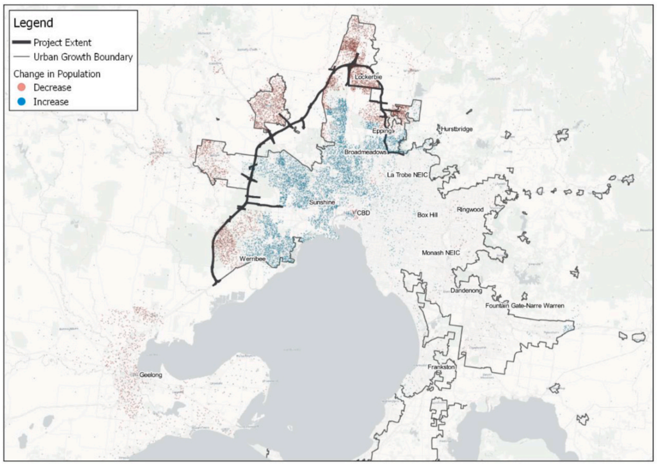


**Fig. 4.** Change of population in 2051 (1 dot = change of 5 persons).

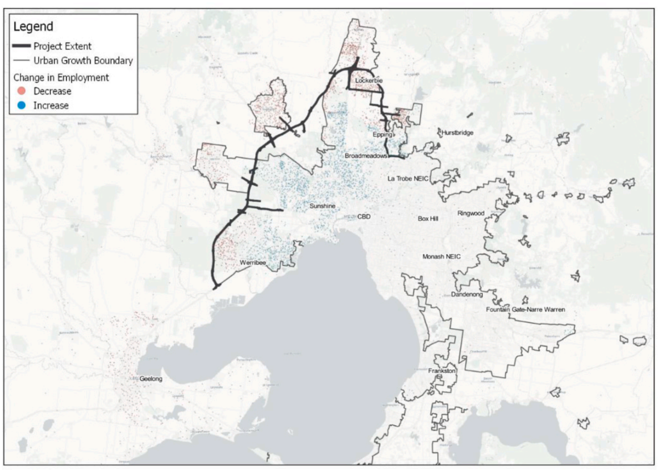


**Fig. 5.** Change of employment in 2051 (1 dot = change of 5 jobs).

emissions) in these suburbs, leading to a slight uptick in population. By contrast, the changing traffic patterns as a result of the OMR may somewhat reduce the attractiveness of new urban growth areas compared to existing urban areas, for the reasons described above.

The impact of OMR on employment redistribution is illustrated in Fig. 5.

Fig. 5 There is a minor redistribution of jobs from the outer north and west to established suburbs in the north and west of the CBD. This employment redistribution is likely to be for similar reasons for the redistribution of population, that being reduced traffic and improved amenity in established suburbs encouraging employers to locate jobs in these areas.

### *6.2. Estimate of changes in economic indicators*

In addition to estimating changes in land use, VLUTI can also estimate changes in individual prices and quantities, and in derived economic indicators. For example, Fig. 6 shows percentage changes in real value added for the OMR scenario when compared against the base case. These results were aggregated to the SA3 level and over industries.

Overall, the OMR increases Gross State Product by 0.3% relative to the reference case in 2056. Local value added is a measure of local economic output. It includes the value added by firms producing goods or services, plus actual and imputed rents generated in the housing sector. Percentage changes are used because the resulting patterns are

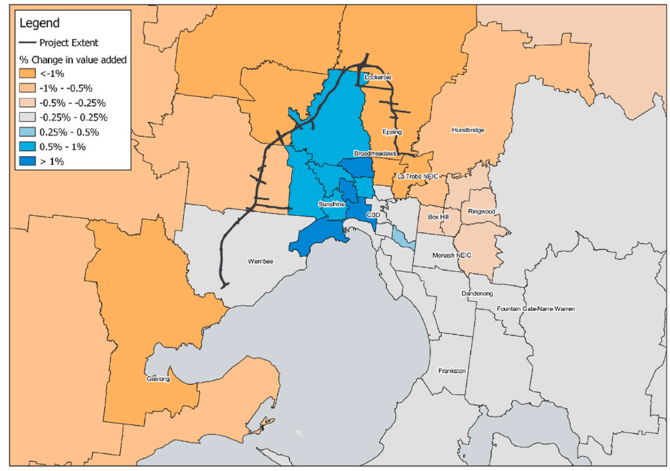


**Fig. 6.** Changes of real local value added (%) in 2051.

usually easier to relate to the effects of transport interventions on the economy. However, it should be noted these percentages are calculated with respect to the base case levels, which may differ by orders of magnitude. It can be seen that more economic value is generated in inner SA3s, extending to the northern areas within the OMR. The gains and losses in local value added are broadly reflective of the changes in residents (reflecting the production and consumption of housing services) and jobs (reflecting the production of goods and services).

Given the modelling assumption of a fixed Victorian population, the reduction of transport costs along the OMR corridor tends to draw in economic activity from elsewhere in the state to the areas inside OMR. Consequently, there is a relative reduction of economic activity in the areas immediately outside OMR and in Geelong, in the south west. In Werribee, which is traversed by the OMR, the net effect is neutral, as increased activity inside the OMR offsets decreased activity outside. On the other hand, impacts in south-eastern Melbourne suburbs are generally neutral, as there is no significant change in traffic congestion in these areas.

## 7. 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 and VITM.

EEM calculates the travel time cost savings or broadly the generalised cost (measured in time units) 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, 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. With the application of the VLUTI, the land use inputs to the demand model become dynamic and there is a relocation of jobs and population as a result of improvements to the transport network in the project case. It should be noted that the term *dynamic* used here and in the subsequent text refers to the change in land use at a future point in time. VLUTI does not explicitly simulate year-by-year land use changes from the present to the future point. This will be discussed further at the end of the paper on future model developments.

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 represents a significant component of conventional benefits. The estimation of other benefits based on the change in 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.

### 7.1. Static land use

Fig. 7 shows the benefits or consumer surplus of a project as a result of the reduction of generalised cost (GC) from the base to the project case. The benefits are commonly determined 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.

EEM calculates the consumer surplus for three user types: Existing, New, and Lost.

The existing users are the ones who do not change their mode of travel or 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:

$$Benefit_{existingusers} = Min\left(Trips_{base}, Trips_{project}\right) \times \left(GCost_{base} - GCost_{project}\right)$$

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 in 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

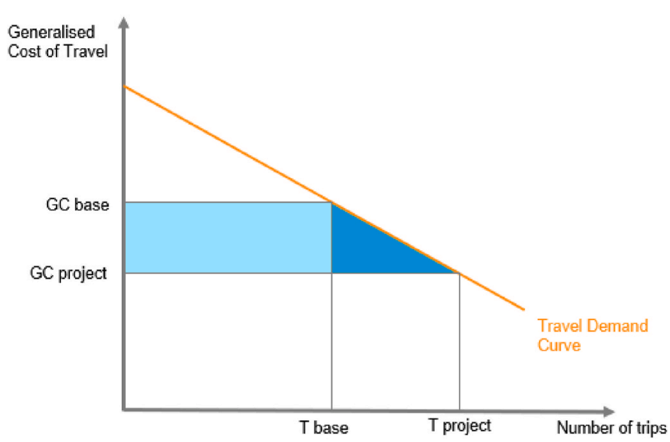


**Fig. 7. Estimation of Benefit from Transport Improvement** (Source: ATC Guidelines Vol.5, page 41).

(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 public transport would include half of the benefit of the decrease in public transport cost (their new mode):

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

### 7.2. 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.

- 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 the 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.

$$Benefit_{existing-stayingusers} = Min\left(Trips_{basei-j}, Trips_{projecti-j}\right) \times \left(GCost_{baseij} - GCost_{projectij}\right)$$

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:

$$Benefit_{existing-movingusers(i|k)} = Trips_{basei-jviak} \times \left(GCost_{baseij} - GCost_{projectkj}\right)$$

As discussed in Le et al. (2021), 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 number of new users at *k* by *N*, to avoid double counting. In order to be able to determine if a user is a stayer or a mover, the population change produced by SIRCV between the base and project case was used to estimate a transition matrix recording the movement of the population from one zone to the others.

Fig. 8 shows the distribution of conventional consumer surplus for car users for the project with dynamic land use. There is a clear benefit to the areas along the OMR corridor. This is likely to be because of the increased road capacity affected by the OMR, leading to reductions in travel times and increased travel efficiency for road-based transport.

Fig. 9 compares the present values of conventional benefits for OMR 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 7% (Infrastructure Victoria, 2021b). The consumer surplus is the most significant benefit, while the environmental and active transport benefits are negative and insignificant. This would be due to the increase in

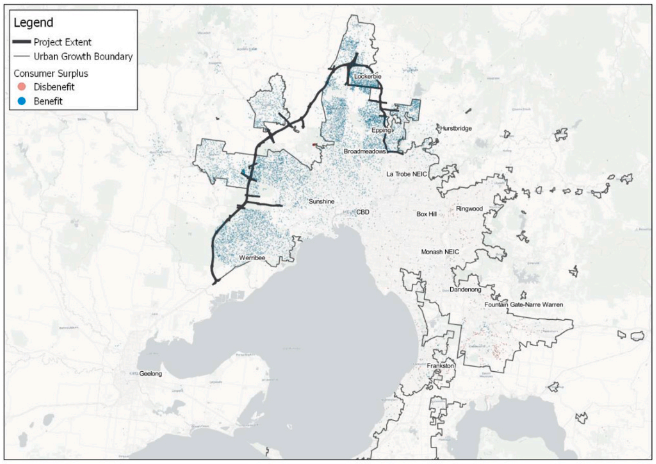


**Fig. 8.** Dynamic Land use – Consumer surplus for private vehicles, 2051

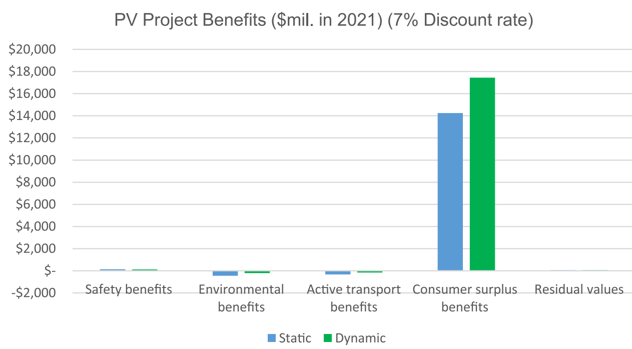


**Fig. 9.** Comparison of conventional benefits between static and dynamic scenarios
(Note: Dynamic land use benefits include static land use benefits).

vehicle km travel in associating with OMR. It is interesting to note that the environmental and active transport benefits were improved although insignificantly under the dynamic land use.

Overall, the conventional benefits for OMR with dynamic land use are approximately 24% higher than those with static land use. However, it is necessary to note that depending on the project type and its location, a project could obtain more or fewer benefits associated with the application of dynamic land use. Therefore, it is useful to use a land-use model like VLUTI to test the investment of significant infrastructure projects.

## 8. Conclusion and further developments

### 8.1. Conclusion

This paper has presented the development of land use, transport and economy model by integrating a strategic transport model, VITM, with a spatial computable general equilibrium model, SIRCV. An application of the model was illustrated by looking at the change in land use and an economic indicator in response to a proposed outer ring road project. A methodology to estimate the consumer surplus in dynamic land use was introduced and the differences in the project's 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, ultimately it can be used to estimate and understand the impact of transport projects on land-use changes and the corresponding project benefits with dynamic land use, which are omitted from the traditional application of static land use.

### 8.2. Further developments

So far, VLUTI has not explicitly considered the spatio-temporal population and economic dynamics, that would represent processes of internal and international migration and fixed capital accumulation year by year from the present day to the future state. In ongoing work, we are investigating the potential to replace the comparative statics of SIRCV with a dynamic spatial model (see e.g. Kleinman et al., 2021). This would provide descriptively richer results by making the spatio-temporal transitions explicit; distinguishing short, medium and long-run changes. A dynamic spatial model would also naturally distinguish between *stayers* and *movers*, providing the output of population transition matrices facilitating welfare analysis.

On the transport component of VLUTI, DTP is currently developing VITM2, a new generation of transport model based on the activity-based approach, which simulates individuals choosing long-term workplace and daily travel choices. Once VITM2 is completed, it could be integrated with VLUTI to simulate the long-term choice of resident location, workplace and school place as the choice of individual and household rather than the aggregate and average zonal choice. In addition, the VLUTI could also be integrated with environmental models such as greenhouse gas emissions, air pollution and traffic-noise generation model to progress toward an integrated land use, transport, economy, and environment model capable of assessing the full impact of a transport project in a holistic way. This would enhance the ability of the framework to contribute to wider assessment frameworks based on concepts of wellbeing, sustainability and resilience.

## CRediT authorship contribution statement

**Henry Le:** Conceptualization, Methodology, estimation of benefits, Writing – review & editing. **Finn Gurry:** Formal analysis, modelling, writing. **James Lennox:** Conceptualization, Methodology, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The authors do not have permission to share data.

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