July 2021

Victorian Land Use and Transport Integration (VLUTI) model architecture report

Overview of the Victorian Land Use & Transport Integration model

INFRASTRUCTURE VICTORIA

About us

Infrastructure Victoria is an independent advisory body, which began operating on 1 October 2015 under the *Infrastructure Victoria Act 2015*.

Infrastructure Victoria has three main functions:

- preparing a 30-year infrastructure strategy for Victoria, which is refreshed every three to five years
- providing written advice to government on specific infrastructure matters
- publishing original research on infrastructure-related issues

Infrastructure Victoria also supports the development of sectoral infrastructure plans by government departments and agencies.

The aim of Infrastructure Victoria is to take a long-term, evidence-based view of infrastructure planning and raise the level of community debate about infrastructure provision.

Infrastructure Victoria does not directly oversee or fund infrastructure projects.

Aboriginal acknowledgment

Infrastructure Victoria acknowledges the traditional owners of country in Victoria and pays respect to their elders past and present, as well as elders of other Aboriginal communities. We recognise that the state’s infrastructure is built on land that has been managed by Aboriginal people for millennia.

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List of Abbreviations

Abbreviation	Definition
ABS	Australian Bureau of Statistics
ANZSCO	Australian and New Zealand Standard Classification of Occupations
ANZSIC	Australian and New Zealand Standard Industrial Classification
ASGS	Australian Statistical Geography Standard
CBA	Cost benefit analysis
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computable general equilibrium
CPI	Consumer price indices
DJPR	Department of Jobs, Precincts and Regions
DOT	Department of Transport
DTF	Department of Treasury and Finance
FMM	Freight Movement Model
GEMPACK	General Equilibrium Modelling PACKage
GSP	Gross state product
GTC	Generalised travel cost
HAR	Header Array files
HH	Households
IND	Industries
IOIG	Input-Output Industry Groups
LES	Linear Expenditure System
LFS	Labour Force Survey
LGA	Local Government Areas
LUTI	Land Use and Transport Integrated model
MSD	Melbourne Statistical Division
OD	Origin-destination
PA	Production-attraction
PHT	Passenger Hours travelled
PKT	Passenger Kilometres travelled
POP	Population
SA2	ABS Statistical Area Level 2
SA3	ABS Statistical Area Level 3
SA4	ABS Statistical Area Level 4
SALM	Small Area Labour Markets
SALUP	Small Area Land Use Projections
SCGE	Spatial computable general equilibrium
SIRCV	Spatial Interactions within and between Regions and Cities of Victoria model
SUA	Significant Urban Areas
TERM	The Enormous Regional Model
TPF	Time period factors
VISTA	Victorian Integrated Survey of Travel and Activity
VITM	Victorian Integrated Transport Model
VHT	Volume Hours travelled
VKT	Volume Kilometres travelled
VLUTI	The Victorian Land Use and Transport Integration model
VOF	Vehicle occupancy factors
VOT	The values of time
VU	Victoria University
VURM	The Victoria University Regional Model

Executive Summary

Executive Summary

Transport infrastructure supports economic productivity and growth and strengthens community and social benefits. This occurs through reduced costs benefiting businesses and individuals including lower freight and business trip costs, shorter travel times, improved safety and enhanced access to education, services, employment opportunities and recreational activities. Not all transport infrastructure projects produce the same benefits and governments therefore need to effectively assess projects to prioritise investments.

Transport modelling has long been used to effectively estimate the costs and benefits of projects. Traditionally, such models have assumed fixed land. However, over time businesses and residents will relocate to take advantage of benefits resulting from project implementation. Assuming fixed land uses can consequently result in over-estimation or under-estimation of project benefits. An integrated land use and transport model can overcome this drawback.

Given the importance of integrating land use and infrastructure planning, Infrastructure Victoria has led the development of the Victorian Land Use and Transport Integration model (the VLUTI model) in close collaboration with Victoria University (VU) and Arup/AECOM.

The purpose of the VLUTI model is to assess land use changes, transport network performance and broader economic impacts from major transport infrastructure interventions, policies and reforms. Infrastructure Victoria uses the VLUTI model to assess transport and infrastructure projects and policy options at a strategic level to inform development of its 30-year infrastructure strategy, research projects and provision of advice to the Victorian Government. In particular, the VLUTI model has been used in the Major Transport Program Strategic Assessment[1] that supports recommendations in *Victoria's infrastructure strategy 2021 – 2051 (Victoria's infrastructure strategy).*

The VLUTI model is comprised of two existing models: the Spatial Interactions within and between Regions and Cities of Victoria (SIRCV) model[2] and the Victorian Integrated Transport Model (VITM).[3]

SIRCV is a spatial computable general equilibrium (SCGE) model that simulates land use and economic interactions within and between 458 economic zones across Victoria (ABS SA2 level). The SCGE modelling approach can be seen as an evolution of the modelling method of comparative static computable general equilibrium (CGE) models that are well-established tools for estimating the wider economic impacts of policy changes. SCGE models use utility and production functions with substitution between inputs, while also allowing for both the geographical distribution and overall level of activity to be influenced by spatial policies and changes in transport costs. SCGE models are considered by many to provide the most comprehensive framework for modelling the local or regional impacts of an intervention in the infrastructure and transport sector[4].

VITM is well established and recognised by key government agencies including Department of Treasury and Finance (DTF), Department of Transport (DoT), and Department of Jobs, Precincts

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[1] See Infrastructure Victoria's Major Transport Program Strategic Assessment Report available from www.infrastructurevictoria.com.au

[2] The SIRCV model was developed by Victoria University (Lennox, 2020).

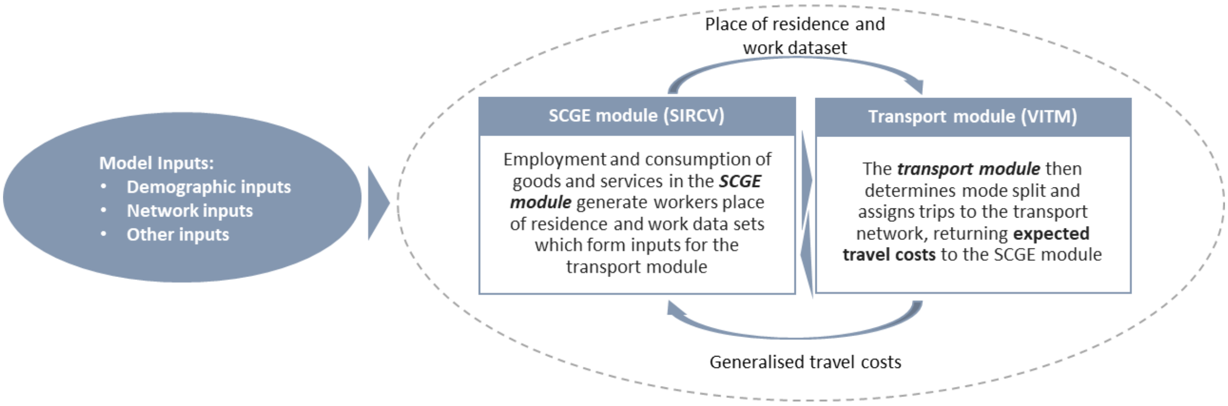
[3] VITM was developed by the Victorian Department of Transport.

[4] Robson et al (2018), Bröcker (2004), Tavasszy et al (2011), Koike et al (2009), Hansen and Johansen (2017), Oosterhaven and Knaap (2017), Lennox and Sheard (2019), Chen (2019).

and Regions (DJPR). VITM has been widely used for a number of years as a standard tool for assessing transport infrastructure projects. VITM is a conventional multi-mode, multi-period and multi-purpose four-step transport model covering the whole of Victoria with a flexible zone system operating from 450 to 6973 zones.

The VLUTI model features feedback mechanisms between land use and transport. Population and employment locations (land uses) in the model respond to changes in transport conditions and passenger flows between different zones respond to changes in land use conditions. This process starts with the transport module (VITM) generating generalised travel costs, which are an input into the SCGE module (SIRCV). The SIRCV model determines how changes in transport costs, and potentially other inputs, affect location choices and economic activities. Place of residence and location of jobs, determined in the SIRCV model, form inputs to VITM. VITM uses these population and employment distributions to examine the impacts to the road and public transport networks in Victoria, providing expected travel costs back to the SIRCV model. This process is repeated until convergence is achieved.

Figure 1. The VLUTI model components and integrated process



The VLUTI model is a powerful tool to develop land use and transport infrastructure related scenarios. The model can provide valuable insights into the economic impacts of transport infrastructure proposals – particularly at the regional and subregional level. The model can assess different types of transport infrastructure investments (such as significant improvements in public transport services or major new road and rail infrastructure), capturing potential land use changes, broad level traffic and travel patterns and changes, direct productivity impacts and wider economic benefits. The land use component within the VLUTI framework is an appropriate tool to build the long-term relationship between transport, agglomeration and productivity.

The VLUTI model can be used to assess medium to long-term (for example, 15 to 30 years) land use, economic and transport network impacts. However, the future is inherently uncertain and it is difficult to precisely predict the effect of individuals and businesses' activities in the longer term. This is a limitation for all long-term LUTI models developed around the world but the development of a LUTI model improves the analysis of transport and land use changes. The VLUTI model provides the scale and direction of land use, transport, and economic changes for any given scenario. This means the impacts of different policies and major transport investments can be better understood.

This report presents the theoretical and technical features of the VLUTI model and its components, the outputs of the VLUTI model, and strengths and limitations of the model in supporting transport and infrastructure planning decisions. A description of the VLUTI model developments to date and potential future improvements are also provided.

Introduction

1. Introduction

The Victorian Government is undertaking a significant program of road infrastructure and public transport projects. These projects will have significant impacts on land use and economic activity in Victoria. Theoretical and mathematical models have long been developed to assess the user benefits of transport and infrastructure projects and to provide modelling outputs to help better understand how these projects will impact the network. For transport projects, this has traditionally focused on the impacts on the transport network without allowing for changes to land use, for example, changes in where people choose to live, that may result from these projects.

In the research literature on transport and land use planning in different jurisdictions, integration across these domains has increasingly been recognised as an effective mechanism to attain more realistic assessment outcomes and to achieve long-term transport and infrastructure goals (Hrelja, 2015). In reality, land use and transport interactions occur in a constant feedback loop. For transport planners and decision-makers with different priorities, it is not appropriate to deal with major transport policies and land use as isolated choices.

How a region’s land use develops, that is, where people and businesses choose to locate within a region, will influence the nature of future infrastructure interventions. Those interventions, in turn, influence where people decide to live and work. There is a relationship between land use and transportation that comprises changes over spatial dimensions between the two systems. In choosing where to live, people will consider accessibility to employment, education, recreation and other services, amongst other things. Similarly, businesses will choose a location where, amongst other things, they can access an appropriate workforce and other business inputs, as well as ensuring customers can access their products and services. Accessibility is largely governed by the transport network and changes to this network will impact people and businesses’ choices. Traditional modelling approaches usually keep either land use or the transport network constant such that the other can be assessed. However, due to the interactions between these two systems, it is important to consider transport and land use, which are mutually interconnected, in an integrated way.

As mentioned above, infrastructure is interrelated with where people and businesses choose to live and invest. New transport infrastructure can improve the liveability of an area, resulting in higher population growth and greater demand on the transport network. The VLUTI modelling framework captures the interrelationship between land use and the transport network to better estimate the full impacts of infrastructure policies and transport infrastructure projects. This, in turn, also helps to understand the city-shaping effects of policies and investments. The model can be used to assess long-term land use and transport infrastructure implications of given transport infrastructure interventions.

The VLUTI model integrates two existing models, the SIRCV model and VITM. VITM is a conventional multi-mode, multi-period and multi-purpose four step transport demand model covering the whole of Victoria with a flexible zone system operating from 450 to 6973 zones. SIRCV is a spatial computable general equilibrium (SCGE) model that simulates land use and economic interactions within and between 458 economic zones (ABS SA2 level). The integration of the VLUTI model was undertaken considering many aspects of a modelling system such as initialisation, choice hierarchy and model convergence in all aspects of land use, transport, and the economy of regions.

The VLUTI model takes into account all economic agents, including households, firms, government, and foreign markets. This is a particularly important feature, as most sectors or markets in the economy are interrelated and could impact each other. For instance, improved transport connectivity to an area not only improves accessibility but can also affect property prices and demand for properties in different locations. The model can be used to assess the magnitude and distribution of both direct and wider economic impacts of land use and transport investments and to provide an understanding of people's behaviour - where people decide to live and work.

This technical report outlines the theoretical and technical features of the VLUTI model, VLUTI model outputs, and strengths and limitations of the VLUTI model in supporting an actual transport and infrastructure planning decision. The remainder of this report proceeds as follows. Section 2 (Subsection 2.1) provides key motivations behind the development of the VLUTI model. Section 2 (Subsections 2.2, 2.3, 2.4 and 2.5) provides the theoretical framework, methodology, major justifications for employing the VLUTI model, key inputs, and model outputs. Section 2 also provides details regarding how the VLUTI model has been constructed, including assumptions adopted in translating at the interface between the main components of the model. Section 3 focuses on the scenario testing structure to be used when operating the VLUTI model. The main strengths and limitations of the current version of the VLUTI model are summarised in Section 4. Section 5 provides a summary of the evolution of the VLUTI model and potential future improvements. Appendix A summarizes the basic theoretical starting point of CGE modelling and provides the theoretical framework of SCGE models. Appendix B provides detail on the calibration of the VLUTI model and the preparation of baselines for modelling underpinning *Victoria's Infrastructure Strategy*. Appendix C provides details of the regions, a complete list of industries, and list of occupations employed in the model.

VLUTI Model Framework

2. VLUTI Model Framework

2.1 VLUTI Model Overview

Infrastructure Victoria, through its recent work on modelling land use and transport interactions, has developed an integrated land use and transport demand model, the VLUTI model, to support the development of *Victoria's Infrastructure Strategy.*

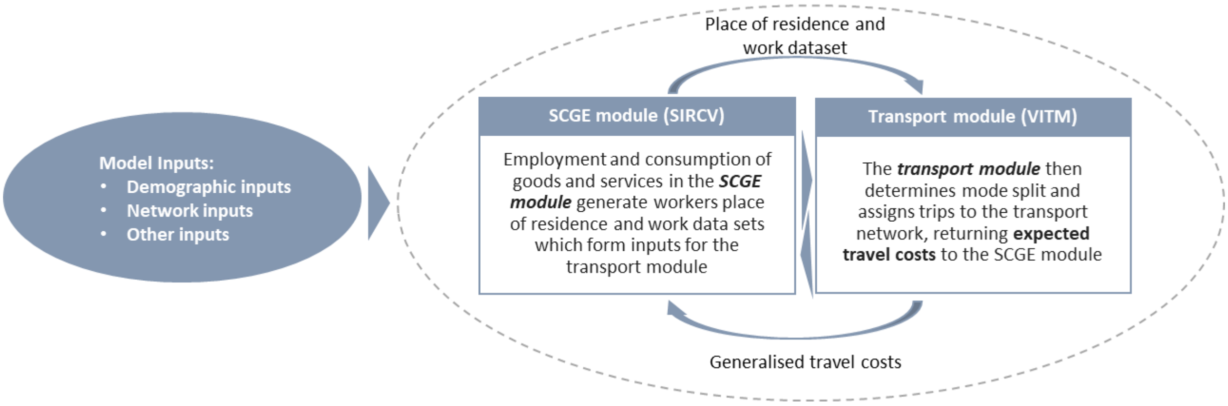
The purpose of the VLUTI model is to assess land use changes, broader economic impacts and transport sector network performance from transport policies and major transport infrastructure interventions and reforms. The impacts are modelled compared to a base case and include economic, land use and transport impacts. The model can be used to undertake studies such as:

- evaluate changes in the distribution of population and jobs from major infrastructure programs,
- evaluate effects of transport projects on land and housing prices,
- assess impacts of changes in the distribution of population and jobs directly on individual welfare, transport sector infrastructure demand and use, and overall economic activity,
- assess the macroeconomic and productivity benefits of changing the distribution of people and jobs,
- test transport projects and policies to mitigate urban sprawl or improve sustainability,
- support cost-benefit analysis of a transport project that incorporates benefits from changes in the distribution of population and jobs,
- provide an estimate of wider economic benefits, and
- undertake sensitivity testing of major transport recommendations against various policy reforms and future scenarios.

The VLUTI model links two existing models: 1) the Spatial Interactions within and between Regions and Cities of Victoria (SIRCV) model developed by Victoria University; and 2) the Victorian Integrated Transport Model (VITM) model developed by the Victorian DoT. SIRCV is an economic model that incorporates land use and is specifically a spatial computable general equilibrium (SCGE) model. VITM is a statewide, strategic transport model which considers car, public transport and active transport modes, and estimates demand for an average school day. Individually, the SIRCV model and VITM are well-tested and respected implementations for their particular applications.

These two models are integrated into a computational framework that allows them to be solved iteratively until convergence on an equilibrium in which land uses and transport costs are consistent with each other. Figure 2-1 shows the VLUTI model components and integrated process.

Figure 2-1. The VLUTI model components and integrated process



The VLUTI model process starts with the transport module of rapid VITM – a modified version of VITM,[5] to generate generalised travel costs, which are then an input into the SCGE module (SIRCV). The SIRCV model determines how changes in transport costs, and potentially other inputs, affect location choices and economic activities. Households are differentiated by employment status: working or non-working. Working households first choose to work in one of 43 occupations (see Table C-4 for the list of occupations). Households of both types choose a place of residence. This determines their housing costs as well as accessibility to goods and services from different locations. Finally, working households also choose a place of work. The combination of residence and workplace determines working households' commuting costs.

Place of residence and location of jobs, determined in the SIRCV model, form inputs to the transport module.[6] VITM uses population and employment forecasts to examine the future impacts of changes to the road and public transport networks in Victoria. The transport module focuses on understanding travel behaviour to determine travel demand, mode split and assigns trips to the transport network, providing expected travel costs back to the SIRCV model. This process is repeated until convergence is achieved.

Subsections 2.2 and 2.3 describe the structure of the SIRCV and VITM models. Subsection 2.4 describes the VLUTI model internal structure including how the two models are integrated.

[5] See section 0

[6] Place of residence and place of work are determined endogenously within the SIRCV model, see section 2.2.2 Core economic agents.

2.2 Spatial Interactions within and between Regions and Cities in Victoria model (SIRCV)

Infrastructure Victoria has collaborated with VU to develop a SCGE model of Victoria's economy.[7] The latest version of the model is called the Spatial Interactions within and between Regions and Cities in Victoria (SIRCV). While the use of SCGE models in transportation planning practice is a relatively recent development in Australia, this approach is well established internationally (Robson et al, 2018).

The SIRCV model is a long-run comparative static[8] model which represents the effects of interventions such as changes to the cost of private and business travel that alter population distribution, economic activity, and development intensity. SIRCV models interactions between industries and households, providing a framework for analysing transport infrastructure investments and infrastructure policies in metropolitan areas and regions throughout Victoria. The SIRCV model allows for both the geographic distribution and overall level of activity to be influenced by spatial policies and changes in transport costs. For example, lowered transport costs due to infrastructure investments tend to stimulate the actors in the economy to take advantage of the cost reduction in production and consumption. The model can identify changes in the location of the economic activities and the sensitivity of the level and location of those activities to changes in transport costs.

The model is a tool for:

i. analysing both direct and indirect (flow-on) effects of different policies and infrastructure investments such as land -use and transport interventions through linkages between the transport sector and the wider economy,
ii. capturing the responses of households and firms to changes in transport time/costs or other spatial policies,
iii. predicting the distribution of employment and workers throughout the state,
iv. capturing wider economic impacts of land use and transport improvements from the perspective of firms' productivity, and
v. estimating the impacts on different industries across different regions.

2.2.1 SIRCV regions

The model permits hundreds of locations to be delineated in Victoria and focuses on the long-run response to interventions. The current spatial resolution of the model is at Statistical Area Level 2[9] (SA2) of the Australian Bureau of Statistics' (ABS) Australian Statistical Geography Standard 2016 (ASGS) throughout Victoria. Each SA2 region represents a community that interacts together socially and economically. In major urban areas, SA2s often reflect one or more related suburbs. SA2s generally have a population range of 3,000 to 25,000 persons with an average population of about 10,000 persons. The ASGS defines 464 geographic SA2s in Victoria. The framework can also be applied to model larger regions in which there are multiple cities.[10]

7 See Appendix A for further information in SCGE models.

[8] Static SCGE frameworks model the reactions of the economy at only one point in time.

[9] ABS Statistical Areas Level 2 (SA2) are medium-sized general purpose areas built up from whole Statistical Areas Level 1 regions. Their purpose is to represent a community that interacts together socially and economically. There are 462 SA2 regions covering Victoria. Whole SA2s aggregate to form Statistical Areas Level 3 (SA3) regions.

[10] The original Spatial Interactions within and between Cities and Regions of Australia (SIRCA) model is Australia-wide.

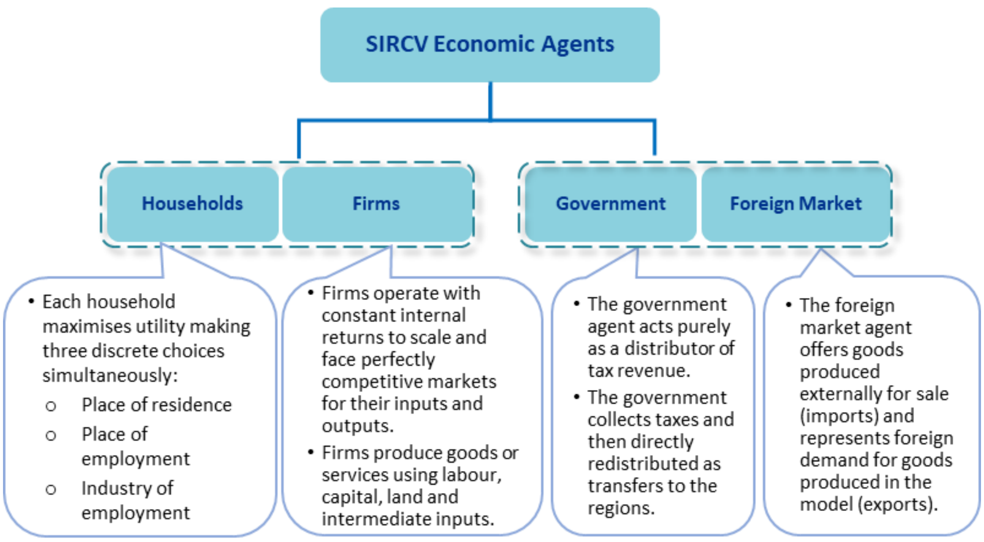
The SIRCV model distinguishes 459 SA2 regions in which residential and/or business activity occurs. Excluded from the model are Upper Yarra Valley, Alps West, Alps East, Wilsons Promontory, and Lake King in which there is no or negligible economic activity. While there are some jobs in every zone, not all industries operate in all zones and not all occupations are employed in all zones. Table C-1 in Appendix C presents all regions in Victoria from Statistical Area Level 2 (SA2) and above.

Of the 464 zones in Victoria, 355 are contained within 22 Significant Urban Areas (SUAs) in Victoria, as defined in the ASGS. The remainder cover diverse economically productive land uses including but not limited to towns of less than 10,000 inhabitants, rural or remote settlements, improved agricultural lands, unimproved grazing lands, forestry plantations, natural forests, and mine sites. Table C-2 in Appendix C presents all SUAs and the number of SA2s they contain. For the purpose of modelling residential location choice, the SUAs are treated as “cities”. The entire non-urban area in Victoria is treated as one additional location choice at the ‘city’ level.

2.2.2 Core economic agents

SIRCV simulates two core sets of economic agents (households and firms), as well as an Investment Sector and External Sector that interact with the core sets of economic agents. Figure 2-2 presents the key economic agents in the SIRCV framework. Households in the SIRCV framework maximise utility making occupational, residential and workplace discrete choices simultaneously. Firms produce goods and services in several industries using land, labour, capital and intermediate inputs. The government sector is not explicitly represented in the SIRCV framework. Tax revenues are directly redistributed to households along with non-wage primary income. In turn, households ‘purchase’ goods and services that are, in reality, obtained as government transfers in kind. In other words, for simplicity, households purchase public goods and services. The external market agent offers goods produced externally for sale (Victorian imports from the rest of Australia and foreign countries) and represents foreign demand for goods produced in the model (Victorian exports to the rest of Australia and foreign countries). The model uses the assumption of a small open economy in which supply of imports via any port of entry is perfectly elastic. However, there are finite elasticities of demand for exports from each Victorian location via any port of exit.

Figure 2-2. SIRCV economic agents



In general, the economic agents in the SIRCV framework trade goods (both production and retail), floor space, and factors of production (labour, capital and land) in competitive markets. Each production good represents the output of firm in a given industry and production location (SA2). Land, labour and capital are all owned by households and rented to firms. Returns to land and capital are shared by working households in proportion to their wage income while non-working households receive equal shares.

Land in each region is allocated between urban and non-urban uses. Urban land is allocated between industrial and non-industrial uses. Non-industrial urban land is allocated flexibly between predominantly residential and predominantly commercial uses.[11] In any given SA2, each industry uses only one of these four types of land—the available type most suitable to its needs. However, in many SA2s, commercial as well as residential land may be used for housing. In other words, these types permit mixed uses while the labels ‘commercial’ and ‘residential’ identify the dominant use. For each type of land in a given SA2, rental rates are equalized across all permitted uses.

The following sub-sections present the core elements of the SIRCV framework. This begins with households' discrete occupation, residence and workplace choices. This is followed by an elaboration of the household's utility function. The following sub-sections describe the behavior of firms, the way in which land resources are distinguished and how market interactions are modelled. This is followed by explanations of the key inputs to the model, how the model was calibrated and the modelling outputs.

Households

In general, a representative household in the SCGE framework chooses consumption of goods and services in a way that the consumption bundle maximizes a utility function subject to a budget constraint. Each household earns income from wages, land and capital rents and (implicit) transfers from the government. The wage rate depends on both occupation and SA2 of work, but is independent of industry. In the SCGE framework, household income from wages, rents and transfers constitute the household budget, which is spent on consumption of the different types of goods and services produced by the firms, as well as savings and taxes. The value of household expenditure in the model is balanced with household incomes.

The statistical definition of a household is that it corresponds to one or more persons, at least one of whom is at least 15 years of age, usually resident in the same private dwelling (ABS, 2018). The SIRCV model distinguishes two populations of households: working and non-working. No other demographic or labour market characteristics of households are considered. For theoretical, empirical and computational reasons, the two household types are modelled in a simplified way. Each working household in the model corresponds to one worker and (implicitly) an average number of adult and child dependents. Each non-working household corresponds to one adult over 65. An important implication is that the locational constraints facing multi-worker households are not considered.

[11] In reality, a small number of Victorian households live in small settlements or isolated dwellings within rural or remote areas. For modelling purposes, we reclassify corresponding land areas to urban residential. Consequently, rural land is used predominantly by agricultural industries and to a lesser extent by mining and some other industries (depending on location).

Each household in the SIRCV framework is represented by a set of demand and supply functions that can be incorporated in the market equilibrium equations. Every household of a given type, that is working or non-working, has identical preferences. Worker-households must make trips between their place of residence and place of work, incurring travel costs including private vehicle operating costs and public transport fares.

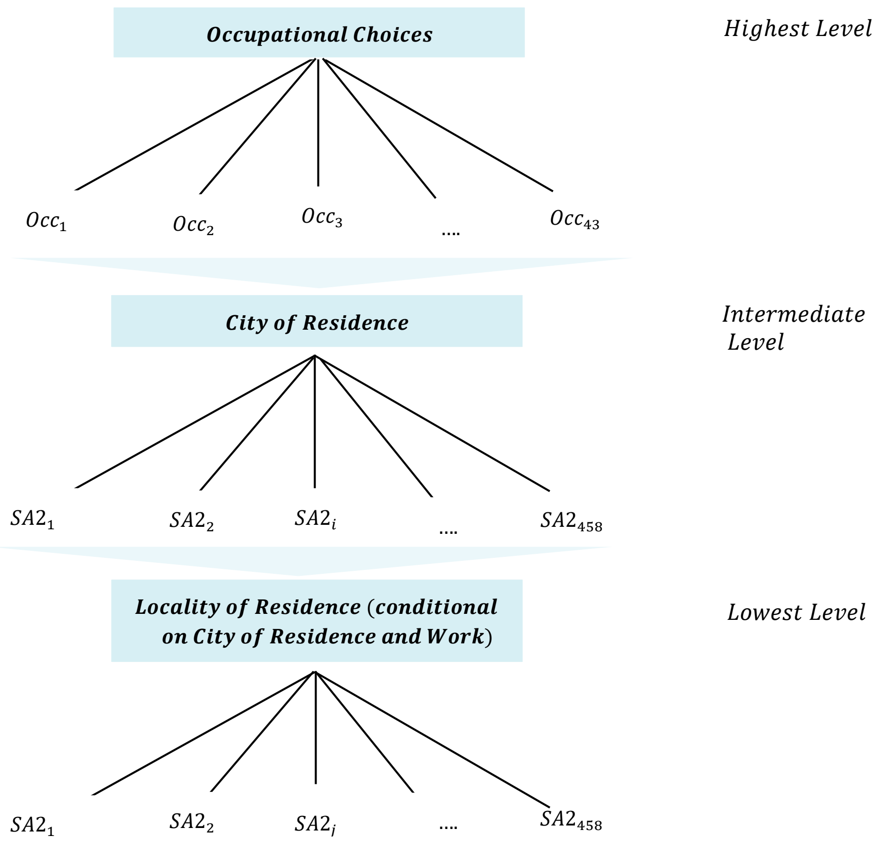
In the SIRCV model, working households are modelled as choosing their occupation (43 occupational groups[12]), locations to reside (458 SA2s nested within 22 SUAs and rural Victoria) and to work (458 SA2s), and expenditures on goods and services that maximise their utility. There are also non-working households who choose where to reside and their expenditures on goods and services.

For working households, utility depends positively on local residential amenities, wage rates and their idiosyncratic preferences (that captures idiosyncratic reasons for a working household living in region r and working in region s). The population of working households receives a fixed share of all land and capital income. This pool is shared amongst individual working households in proportion to their wage income. Utility depends negatively on the local level of prices, the rate of income tax and commuting costs. Different types of travel purposes such as consumption trips, business trips, social and recreation travels are distinguished in the SIRCV model. Households travel not only to work, but also in the process of consuming non-tradable services (for example, restaurant meals). For non-working households, utility depends positively on residential amenity, their fixed transfer and capital income, and idiosyncratic preferences over locations. Utility depends negatively on local price levels.

In the SIRCV model, working households' discrete choices are modelled using a three-level nested logit structure: (i) occupational choice; (ii) city of residence; and (iii) locality of residence within a city and locality of work (which may be in a different city). For non-working households, there are two levels of choice: (i) city of residence; and (ii) locality of residence within that city. Figure 2-3 presents the three-level nested logit structure of working households' discrete choices.

[12] *These correspond to Australian and New Zealand Standard Classification of Occupations (ANZSCO) Sub-Major Groups (or 2-digit codes).*

Figure 2-3. Three level nested logit structure of working households' discrete choices



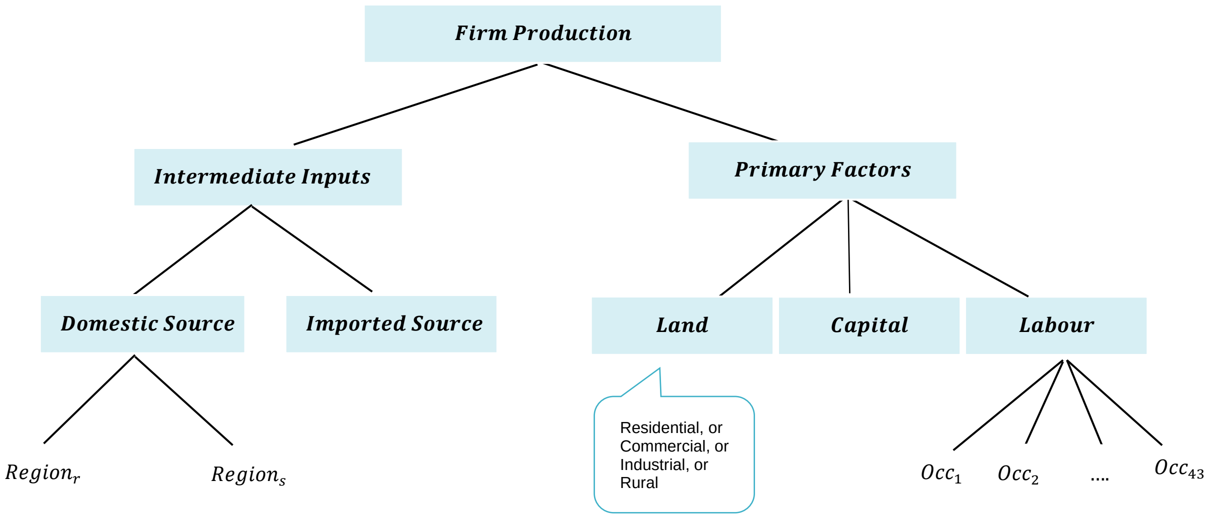
Firms

The SIRCV models perfectly competitive firms which use labour (supplied by working households), property (commercial, industrial, residential or rural) and non-structures capital (machinery, equipment, etc.) to produce tradable or non-tradable goods or services. Firms operate constant returns to scale technologies to produce intermediate goods or services.

The SIRCV model distinguishes 100 industries: 10 that produce primary products, 40 industries that manufacture goods, five that provide utilities, four that undertake construction activities and 41 that produce non-housing services. Each of the 100 industries corresponds to one or several ABS Input-Output Industry Groups (IOIG). A complete list of industries in the SIRCV model is presented in Table C-3 in Appendix C. Firms transform inputs and intermediate goods, produced by other firms.

In each industry and locality, firms produce goods and services using Cobb-Douglas technologies combining using land (one of the four categories), labour (up to 43 occupational groups), intermediate inputs (up to 100 types), and capital. Figure 2-4 shows the structure of firm production in the SIRCV model.

Figure 2-4. Structure of firm production



In any given location, firms in each non-housing industry may use only their most preferred available land type. For example, accommodation firms are assigned to the Commercial land type if available, but otherwise may be assigned to the Residential or even the Rural land type. This approach has been taken due to the lack of availability of data on actual land uses by industries in Australia. It also addresses the problem of working with an industry rather than function-based classification of establishments. For example, the head office of a coal mining firm will be classified as `Coal Mining', whereas its function is to provide services (management, financial, legal, marketing, human resources, etc.) to the firm's business units that actually extract coal from the ground. While it would be possible to devise some sort of functional classification relating to occupations, this would then be difficult to relate to industries' full input-output structures. The housing sector may use one or both of Residential and Commercial land types, as we have population data for each of the mesh blocks from which initial land areas by type are calculated. Mesh blocks are the smallest geographical area defined by the ABS. For simplicity, the provision of housing services is modelled as a Cobb-Douglas aggregation of these land types.

Labour in the SIRCV model is differentiated into 43 occupational groups corresponding to two-digit, Sub-Major Groups in the Australian and New Zealand Standard Classification of Occupations (ANZSCO). Table C-4 in Appendix C presents the occupational groups in the SIRCV model.

Firms' productivity is an increasing function of the effective density of labour force in their location. Total factor productivity is positively influenced by spillovers related to the effective density of all jobs in their vicinity. The elasticity of firms' productivity to effective job density varies between industries (these are documented in the Parameters and Calibration section below). Effective job density is measured by travel distance-weighted job counts using destination zones.

Firms use a composite of non-tradable services from various locations and incur business travel costs. There are two key differences between household consumption trips and business trips. Firstly, the primary motivations for travel differ, at least in emphasis. Whereas most household consumption of non-tradable services is intrinsically an in-person activity, many business inputs are supplied from a distance via telephone, email, data transfers, etc. However, the efficient procurement and use of such inputs almost inevitably requires some level of regular face-to-face contact. Secondly, whereas households incur disutility by travelling to consume, businesses incur monetary costs (including costs of employees' time). However, in both cases, these costs are modelled using an iceberg cost[13] specification for non-tradable inputs.

2.2.3 Land allocation

In general, SCGE frameworks distinguish between two types of land: primary production and non-primary production land within each region. Primary production land is used only by the agricultural and mining industries. Non-primary production land consists of residential land and non-residential (commercial and industrial) land.

The SIRCV model distinguishes the following four major types of land: Residential, Rural, Commercial and Industrial. The initial land areas are based on mesh blocks as specified in the ASGS 2016. These are delineated by the ABS to `broadly reflect land use' and are assigned one of ten categories. With a few exceptions (for example, mesh blocks that include an airport terminal) the model ignores the ABS categories `Parkland', `Transportation', `Water' and `Other'. The model also subsumes the original `Commercial', `Hospital/Medical' and `Education' into our `Commercial' category. The relationship between the four major types and the ABS categories are summarised below:

1. Residential = Residential + any Other or Primary Production deemed to be residential
2. Rural = Primary Production
3. Commercial = Commercial, Education, Hospital/Medical, and Transport (only as corresponds to a major employment facility such as an airport or port)
4. Industrial = Industrial

As an input into the SIRCV model, land resources were classified into these four broad classes exogenously based mainly on ABS data, with supplemental use of Victorian planning data and satellite imagery. Land is endogenously allocated amongst competing uses, for example, commercial and residential, with the allocation responding endogenously to relative land rents. In the SIRCV framework, the allocation of land resources to various permitted uses is modelled in a two-level nested logit specification, in which allocations respond to relative use-specific rental rates. Figure 2-5 represents nested allocation and uses of land with structures in the SIRCV model.

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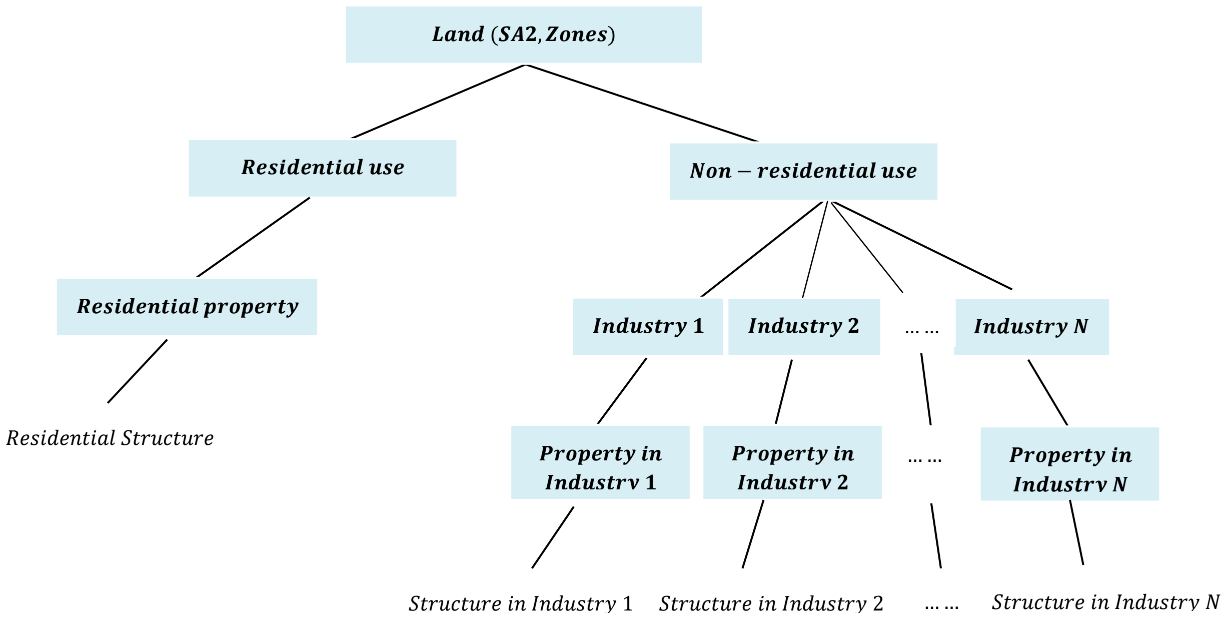
[13] The iceberg cost refers to a constant fraction of the goods which melts away in transit. The iceberg assumption assumes that in order to deliver goods produced in location A to another destination B, one needs to ship goods from location A. Total transport costs equal the cost of producing these melted goods. As a result, per unit transport costs are a destination-specific percentage of the good's producer price in location A.

Figure 2-5. Nested allocation and uses of zoned land



Different industries and housing compete locally for relevant categories of land. Zoned land allocated to each sector is combined with structures to form property specific to that sector using sector-specific technology. In any SA2 regions, each industry sector is identified with a single land category, but housing services provided by a single dwelling may use Residential and/or Commercial land. One household type should consume (services of) only one type of housing. In the SIRCV model, Residential and Commercial property is modelled as a Cobb-Douglas composite of land categories and structures capital. Structures capital is assumed to be elastically supplied at an exogenous rental price. Commercial and Residential categories are not perfect substitutes in housing production. It is assumed that users of Commercial or Residential property are indifferent to zoning of the underlying land, therefore property rents for each use in each location are equalized through no-arbitrage conditions. Local growth in Commercial demand relative to Residential will increase the Commercial use share of Commercial land and will cause conversion of Residential land to Commercial. Local growth in housing demand relative to agricultural and commercial demands will cause conversion of Rural land to (Non-industrial) Urban land[14] and will increase the Residential share (vs Commercial) of (Non-industrial) Urban land.

Within SIRCV, areas of (Non-industrial) Urban land are allocated to Residential and Commercial land types in proportions that respond to changes in relative prices. Rural land can be irreversibly converted to Industrial land or to Urban land. Rural to Urban conversions are practically irreversible. Reasons for this include, but are not limited to, the value of investments made in urban infrastructure when land is developed (for example, new water and sewerage connections), increasing demands for urban land, and the contamination and compaction of soils caused by urbanisation. Furthermore, the costs of reallocating urban land between most urban uses are modest. However, industrial uses are an exception because they tend to generate large negative

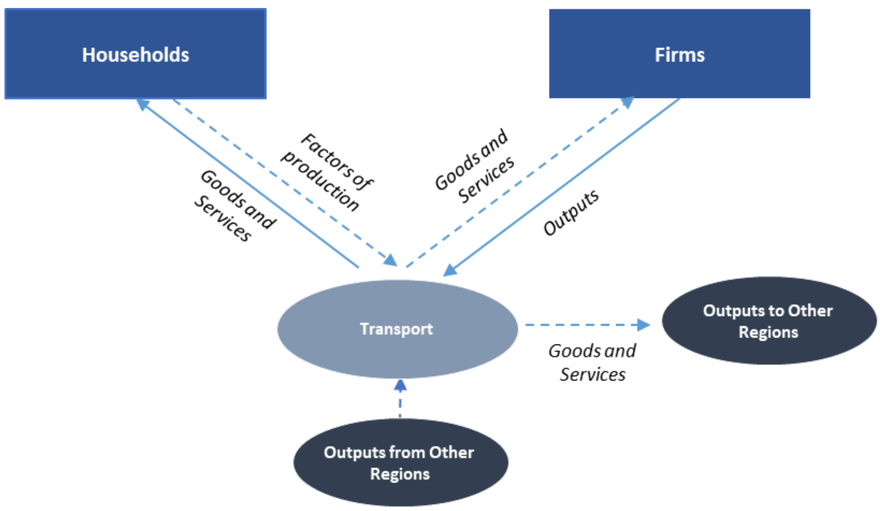
[14] *Urban land defined as land used or expected to be used for urban activities within urban zones. An urban zone is a zone or part of a planning scheme that has been declared an urban zone, under a planning scheme in force under the Planning and Environment Act 1987, by the Governor in Council. These zones change over time.*

externalities such as heavy vehicle traffic, noise, odour, air pollutants, and soil contaminants. For these reasons, new industrial sites are almost always established outside of existing urban areas. Conversely, while the emergence of higher value uses may ultimately lead to the conversion of established industrial sites, this process is typically very slow. In many cases, historic site contamination is a major barrier to redevelopment. A limitation of this account is that it ignores urbanisation of natural areas (such as native grasslands), which is still occurring on a significant scale in Victoria.

2.2.4 Market

In SCGE models all markets for goods and services, and factors of production must clear. Factor markets clear, all supplied factors from households (labour and capital) to each region are used as primary inputs by firms in the same region. A representative firm in each sector produces a single commodity. The output of firm i in region r is either used to satisfy final demand by the households and as intermediate inputs to the firms, or it is used to satisfy export demand from other regions. Figure 2-6 presents the flows of goods and services and factors of production in a SCGE framework.

Figure 2-6. Real flows for a specific sector of a region in a SCGE framework



In the SIRCV model, local sectoral composite goods and services are formed by combining individual varieties sourced from different locations. All services in the model, except housing, are considered to be tradeable. This includes trade by means of travel to consume services in person or, conversely, delivery (for example, restaurant meals). Each variety is sourced from the location that can supply it at the lowest delivered cost. As SIRCV is an open economy model, these locations include an external zone that represents trade with the rest of Australia and with foreign countries.

In the SIRCV model, wages, land rental prices and product prices clear local occupational labour markets, land markets and product markets respectively. There are no re-exports in the model, that is, a region cannot export a product it has imported. In the market equilibrium, aggregate demands for regionally produced non-tradable services (housing services) must equal supply in each local market.

2.2.5 SIRCV model inputs

At a State level, SIRCV makes use of ABS Input-Output Tables to specify firms' production functions and households' consumption functions. The ABS household income & expenditure survey is also used to determine the initial allocation of non-wage income between household types. External trade flows in 2016 by SA2 are taken from the calibration of the Spatial Interactions between Regions and Cities of Australia (SIRCA) model. SIRCA is calibrated to match international import and export flows and imputes trade flows between every SA2 in Australia. The following subsection provide details about spatially disaggregated inputs used in the current version of the model.

Land

In the SIRCV model, initial land areas are based on areas of ASGS Mesh Blocks. These are delineated by the ABS to 'broadly reflect land use' such as Residential and Commercial. With a few exceptions (e.g. mesh blocks that include an airport terminal), the model ignores the ABS categories 'Parkland', 'Transportation', 'Water' and 'Other'. The ABS categories of Commercial, Hospital/Medical and Education are included in the SIRCV Commercial category. Some minor adjustments are also made to address incompatibilities between the data and the model. The most significant of these is that the model does not permit housing supply on Rural land whereas the data show small populations residing in ABS Rural Mesh Blocks (e.g. in farm houses). To resolve this discrepancy, we reallocate small areas of Rural land to Residential so that we may treat Rural land as being used solely for non-housing production. The reallocated areas are based on Rural Mesh Block populations multiplied by population densities of Residential Mesh Blocks within the same SA2.

Employment

ABS Labour Force Survey (LFS) data, the Small Area Labour Markets (SALM) publication[15], and the 2016 Census[16] were used to estimate initial distributions of jobs and of resident workers by occupations. LFS values were taken as definitive counts by place of residence at State/Territory for ANZSCO 2-digit occupations and at SA4 level for 1-digit occupations. SALM data was used to downscale employment to SA2 level. Counts by place of work were constructed using commuting propensities estimated from Census data. The model also distinguishes non-working households - sole persons and single parent households not in the labour force, and couple households with neither member working. Counts of non-working households are based on Census data alone.

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[15] *Published by the Commonwealth Department of Education, Skills and Employment.*

[16] *2016 Census data was retrieved using ABS TableBuilder Pro.*

Transport costs

Within the SIRCV model, people travel to work and to purchase goods and services (including education). Goods are transported between firms, and from firms to households. Travel and freight transport costs are an input to SIRCV. These are obtained as composite generalized costs from VITM.

The SIRCV model uses gravity cost coefficients to convert the shipping cost between two locations to an iceberg cost for transport of goods and services. These coefficient values were calibrated in the SIRCA model to compute national mean transport costs for each good. The latter were estimated from ABS tables of road, rail, water, air and pipeline margins on intermediate and final uses of goods (sector-specific only for freight).[17] These same gravity coefficients were applied in SIRCV after a common rescaling to account for the different source of transport costs in SIRCV.

The model assumes that all direct uses of transportation services by industries are related to business travel. To estimate the cost share, the total expenditure is divided by the total value of intermediate services used in the economy. The estimated cost share is around 0.041. This value was doubled to reflect the costs to firms of business travel time. For retail and other services that are predominantly consumed by households, a higher but arbitrary cost share of 0.33 that reflects combined monetary and time costs of private consumption travel was adopted in the model.

Commuting costs enter the household indirect utility function. Utility in the model depends negatively on the local level of prices, the rate of income tax and commuting costs. Commuting costs in the current version of the SIRCV model enter in a negative power exponential form. The two coefficients of this function are calibrated to minimise the root mean squared error of SA3[18] level occupational commuting flows within Victoria.

2.2.6 Parameters and calibration

Estimated and assumed parameter values

Estimating the necessary parameters is vital since it has been recognized that results from SCGE models, in general, are sensitive to the value of parameters. Statistical estimation of required parameters is difficult due to the large number of observations required, as well as their partitioning into price and quantity variables. Economic parameters defining production technologies and consumption preferences in the SIRCV were based on state level data for Victoria sourced from the Victoria University Regional Model (CoPS VURM) database. Some parameters are used as given from other estimations and some are linked to the data by calibrating them in the baseline version.

The way technology is incorporated in the SIRCV model is through the specification of functional forms and parameters for production and utility functions. In the production function, the key parameters are the input cost shares and those parameters determining total factor productivity. In

[17] Transport cost generally consists of operating costs and a margin. The margin component of a commodity is used to facilitate the movement and sale of both imported and domestic commodities within Australia, and of the exported commodities to the point of exportation. Margins are services such as transport, wholesale trade, retail trade that connect producers to users.

[18] ABS Statistical Areas Level 3 (SA3) are geographical areas built from whole Statistical Areas Level 2 (SA2) regions. They have been designed to provide a regional breakdown of Australia. There are 66 SA3 regions covering Victoria. Whole SA3s aggregate to form Statistical Areas Level 4 (SA4) regions.

the utility function, the key parameters are the household expenditure shares, the transport cost coefficients, and the underlying level of residential amenity of each SA2. While there are other parameters in the model that influence choices about location, occupation and trade, here we present just the key parameters. Table 2-1 presents the key technological and behavioural parameters defining production technologies and consumption preferences in the SIRCV model.

Table 2-1 Estimated, calibrated, and assumed technological and behavioural parameters in the SIRCV model

Parameter	Value	Source
Household choices:		
• Consumption expenditure shares for each household type	β_j^h	ABS 2016 IO tables
• Transport cost coefficient (converts shipping cost to an iceberg cost for transport of good ***j***)	K_j	James Lennox (2020)
• Estimated commuting gravity coefficient • Implied commuting exponent	$\zeta_o \varepsilon_R$ ζ_o	James Lennox (2020)
Firm choices:		
• Labour cost share – cost share for each occupation	α_{or}^i	ABS 2016 IO tables and ABS Labour Force Survey 2016 and Census 2016
• Capital cost share	α_k^i	ABS 2016 IO tables and James Lennox (2020)
• Land cost share	α_D^i	ABS 2016 IO tables and James Lennox (2020)
• Composite of goods and services cost share	α_j^i	ABS 2016 IO tables
Discrete choice parameters:		
• Local choices	$\varepsilon_L = 6.5$	Ahlfeldt et al. (2015) (values rounded)
• SUA choices	$\varepsilon_U = 3.8$	Baum-Snow and Han (2019)
• Occupational choices	$\varepsilon_O = 1.5$	Lee (2020)
Fre'chet parameters for trade:		
• Goods, business services, accommodation:	$\sigma_j = 5$	Caliendo and Parro (2015)
• Urban services:	$\sigma_j = 5$	James Lennox (2020)
• Retail and local consumer services:	$\sigma_j = 10$	James Lennox (2020)
Effective residential density decay rate	$V_a = 0.76$	Ahlfeldt et al. (2015)
Effective job density decay rate	$V_a = 0.36$	Ahlfeldt et al. (2015)
Elasticity of amenity to density	$Q = 0.07$	Ahlfeldt et al. (2015)
Elasticities of productivity to density:		
• Primary production:	$\lambda_i = 0.0$	James Lennox (2020)
• Manufacturing:	$\lambda_i = 0.056$	Mare and Graham (2013)
• Services:	$\lambda_i = 0.047 - 0.18$	Mare and Graham (2013)

The SIRCV model adopted the value estimated for Berlin in Ahlfeldt et al. (2015) for choices of localities, while the upper end of the range in Baum-Snow and Han (2019) for choice between neighbourhoods in the United States was used for choices between cities. For choice between occupations, the model uses a value of 1.5. This is just above the upper end of the range of estimates (1.21 ~ 1.44) in Lee (2020) for occupational choices in the United States conditional on different levels of education.

For trade elasticities, the model uses a value of 5 for goods, business services, accommodation and 'urban' services (e.g. arts, healthcare) and a value of 10 for retail and 'local' services (e.g. school education, personal services). Trade elasticities determine how trade flows react to changes in trade costs. For goods, this is in line with aggregate estimates in the trade literature (e.g. 4.8 in Caliendo and Parro (2015). That and other studies provide sectoral estimates that are in some cases, significantly larger or smaller. However, it is difficult to use such estimates given substantial differences in the definitions/aggregations of sectors and wider variation in sector-specific estimates across studies. For internationally traded services, the value of 5 is also in keeping with the literature (e.g. Costinot and Rodriguez-Clare, 2014); however, these elasticities are rarely estimated because of trade data limitations. There is very little data, or indeed literature, on trade in urban and consumer services. Arguably though, most 'local' services such as schools, supermarkets, and cafes tend to be very close substitutes for similar services provided in different locations. Indeed, many chain stores aim explicitly to provide near-identical services to customers in all of their outlets. For industries providing these types of services, the model adopted an elasticity of 10.

In the SIRCV model, total factor productivity is positively influenced by spillovers related to the effective density of all jobs in their vicinity, that is, urbanisation rather than localisation effects. The elasticity of firms' productivity to effective job density varies between industries. Mare and Graham (2013) estimate spillover elasticities for ANZSIC (the Australian and New Zealand Standard Industrial Classification) Divisions, to which industries in the SIRCV model map exactly. However, some Divisions contain several industries that seem very likely to have much lower or much higher elasticities than average. For these, some ad hoc adjustments were made for the SIRCV model. For example, the estimated elasticity for Education (Division) is 0.107, but the model uses a lower value of 0.06 for school education and higher value of 0.12 for post-school education. These adjustments are only made for services Divisions. For the (single) Division of Manufacturing, the model uses the value of 0.056 to all industries. The model also assumes that local agglomeration effects do not operate at all in primary production sectors including agricultural or mining industries. Productivity of housing service provision is assumed to be uniform. However, on the consumption side, households enjoy residential amenities that are positively affected by spillovers related to the effective density of residents in their vicinity.

Calibration and methodology

Calibration refers to a standard process including estimating and adjusting the technological and behavioural parameters of the model to fit the model to the benchmark data set. Calibration involves compilation of the data values to the model equations. Having specified travel costs, employment, and land uses at the levels required by SIRCV, model parameters are then adjusted to reconcile data with the model equations. If the model is calibrated correctly, it should replicate the base year equilibrium in the absence of any shocks.

The key estimated parameters for household choices consist of share of expenditure on consumption goods and services for each household type, transport cost coefficient, commuting gravity coefficient and commuting cost coefficient. Capital and land cost shares, and composite of goods and services cost shares that are the key parameters for firm choices, are assumed identical across locations because the model is calibrated using a national input-output table. Overall labour cost shares are also location-independent, but the cost shares for each occupation vary by location to match employment data.

As discussed in previous sub-sections, the spatial resolution of the SIRCV model is at ABS SA2 level throughout Victoria. The SIRCV model is calibrated using a set of current year economic and demographic inputs, as well as modelled composite generalised travel costs (GTCs) produced by simulation of the transport model (the rapid VITM, described in section 2.4) with consistent land use inputs. This model database represents the economy in the year 2018. The current version of the SIRCV model was designed to directly match the Small Area Land Use Projections (SALUP)[19] 2018 historic case, travel costs derived from the VITM 2018 reference case, and land uses indicated by the 2016 ABS mesh block categories[20].

Given that the SALUP provides less detail on population distribution than is required by the model calibration, the economic parameters were supplemented by the ABS Census 2016 data to further disaggregate SALUP data by skill and, at place of work, by industry. The inconsistencies in the disaggregated values were eliminated using a proportional adjustment (RAS) algorithm.[21] The model calibration matches composite GTCs derived from the VITM 2018 reference case. These values could be interpreted as the effective travel costs between SA2s given the Victorian transport system in 2018.

When testing future years (such as 2036 or 2051), the initial assumptions surrounding both demographics and the economy are projected from the current year starting point (see section 4 for further details). The calibrated SIRCV model is initially run using the current year GTCs, but is given numbers of resident workers and non-workers by SA2 in the future year. These latter values are derived from the SALUP. This baseline simulation is run through the VLUTI framework in much the same way as a policy simulation. That is, transport costs are adjusted after running Simplified VITM, SIRCV is rerun, and so on and so forth until convergence is achieved. The future year database produced by this baseline simulation then serves as the starting point for policy simulations in that year.

2.2.7 SIRCV model outputs

SIRCV includes a wide range of economic variables. In order to interpret the results from a modelling exercise, it is important to understand what these results are, and what they mean. SIRCV contains many very large multi-dimensional variables. The SIRCV model can produce a wide variety of spatial and macroeconomic (Victorian) outputs ranging from industry-level estimates or activity to headline impacts on gross state product (GSP) and income from any given scenario.

While there is no single correct way to present SCGE results, it is almost always desirable to report relative changes (from the future baselines) rather than absolutes. This is mainly because modelling results are constructed as impacts relative to 'business as usual'. Presenting modelling results in relative changes help audiences to better understand or contextualise the results. However, in some cases it would make sense to ensure results are presented in absolute levels (e.g. headcount variables and possibly land areas).

The model allows us to identify the direct and flow-on benefits of different transport scenarios on the following economic indicators.

[19] Sourced from the SGS Economics and Planning model.

[20] Mesh blocks in the ABS' Other category were recoded the most relevant use category based on manual evaluation of Google Maps™ imagery.

[21] The RAS method is well recognised and widely used method for data reconciliation. Its aim is to achieve consistency between the entries of some nonnegative matrix and pre-specified row and column totals. Mathematically, the method is an iterative scaling method.

Gross State Product (GSP)

GSP is the most commonly used measure of state-level economic activity. At the industry-level, real gross value added is usually used to describe an industry's contribution to growth or GSP. GSP measures the production of final goods and services, that is, domestically produced goods or services purchased by consumers, government, investors and foreigners. SIRCV provides the average (value-weighted) change in productivity as well as the relative contributions of land, labour and capital to changes in GSP, and a breakdown by industry (value added).[22]

Expected Utilities

While GSP is often treated by policy makers as an indicator of welfare, this is not its intended purpose. GSP may be a better or worse proxy measure for welfare, depending on the circumstances and context of its use. In the present context, a major limitation is that GSP does not account for the disutility of commuting travel time.

The SIRCV model uses expected utility as a measure of welfare for each household type. The expected utility for working and for non-working households reflects the contributions of:

- Wages (positive)
- Residential amenity (positive)
- Commuting costs (negative) and
- Housing rental prices and local non-housing consumer prices, which are inclusive of consumption travel costs (negative).

Employment

Employment is another commonly reported measure of economic benefit as jobs provide income as well as other personal benefits (including satisfaction, purpose, social network). Here, employment refers to the total number of people employed (full time and part time). SIRCV can generate the change in employment across different industries from any given transport infrastructure or other type of scenario. Some important economic variables related to employment in the model include:

- Change in average wage rates by place of work or by place of residence (person or wage weights),
- Jobs by ANZSIC Division (place of work),
- Jobs by Occupation or by Skill/Collar (place of work or residence), and
- Change in effective job density.

Additionally, covering both household types:

- Resident workers, retired age population.

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[22] Note that in this context, housing is considered as an industry, its value added generated by the use of land and capital.

Land

For any given transport infrastructure or other type of scenario, SIRCV can simulate changes in land use (for the four types of productive land described in previous sections). Some important economic variables related to land use in the model include:

- Land rental price changes (value-weighted averages of the four types),
- Sqkm of land allocated to Residential, Commercial, Industrial, Rural categories,
- Sqkm of land used for Housing (residential use of Residential as well as Commercial land categories), and
- Change in effective residential density.

2.3 The Victorian Integrated Transport Model (VITM)

VITM is a statewide strategic transport demand model owned and maintained by the Victorian DoT. VITM is a conventional four-step travel model including trip generation, trip distribution, mode choice, and trip assignment, and can be used to:

1) assess transport policies and strategies
2) estimate future demands on the transport network
3) analyse the potential impacts of road, public transport and land-use planning projects, and
4) identify the quantum and location of congestion.

This model has been used by different Victorian 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-time period, multi-trip purpose and multi-modal strategic level transport demand model which considers car, public transport and active transport modes[23] and estimates demand for an average school day. VITM uses population, employment and enrolment forecasts to examine the future impacts of changes to the road and public transport networks in Victoria. The version of VITM employed by Infrastructure Victoria as part of VLUTI to support the development of *Victoria's infrastructure strategy* incorporated[24]:

- 6973 transport zones, representing travel within the state of Victoria,
- 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 buses,
- Constrained public transport capacity, and
- Integration of the Freight Movement Model (FMM) to forecast truck movements and volumes.

2.3.1 VITM Regions

VITM utilises a detailed zone structure which covers the entire state of Victoria. 6973 transport zones are used to represent population, employment and enrolment data spatially (as shown in Figure 2-7). Of these zones, 3544 are located within the Greater Capital City Statistical Division (GCCSA), and 3429 zones are located outside of Melbourne, covering regional centres and rural areas. Zones are generally more detailed in the inner and middle suburbs and along major transport corridors. However, VITM is designed to aggregate these 6973 zones to approximately 3000 zones during the model process. This assists in keeping model run time manageable and care is taken to retain detail in study areas under investigation. For the purposes of reporting and analysis, these zones can then be aggregated further to reflect more common standards such as

[23] *VITM only models active transport to the extent that its contribution to overall trip demand at a high level is understood. Active transport is not considered as part of the assignment process.*

[24] *The VITM version number is VITM19_v2_02.*

ASGS Local Government Areas (LGA) and SA2. Figure 2-8 and Figure 2-9 present Melbourne GCCSA, Inner Melbourne and transport zones.

Figure 2-7. Victoria and transport zones

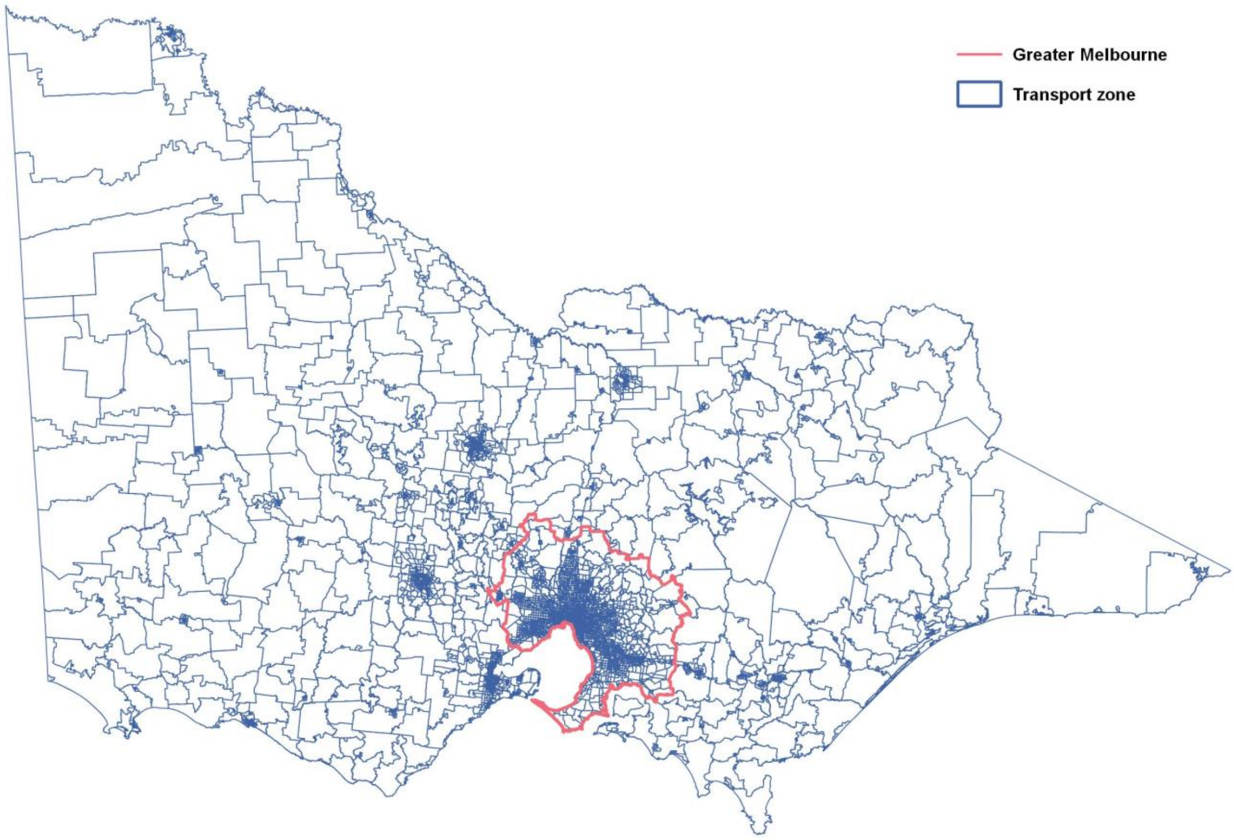


Figure 2-8. Melbourne GCCSA and transport zones

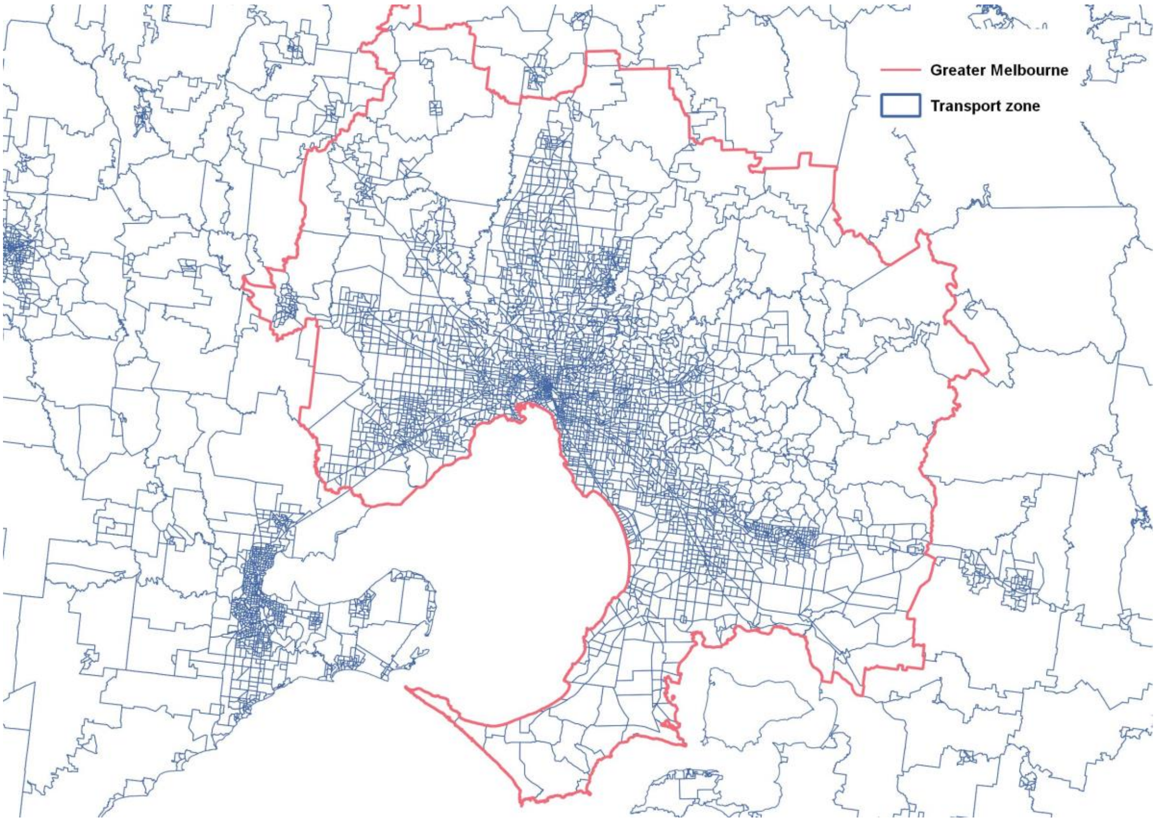
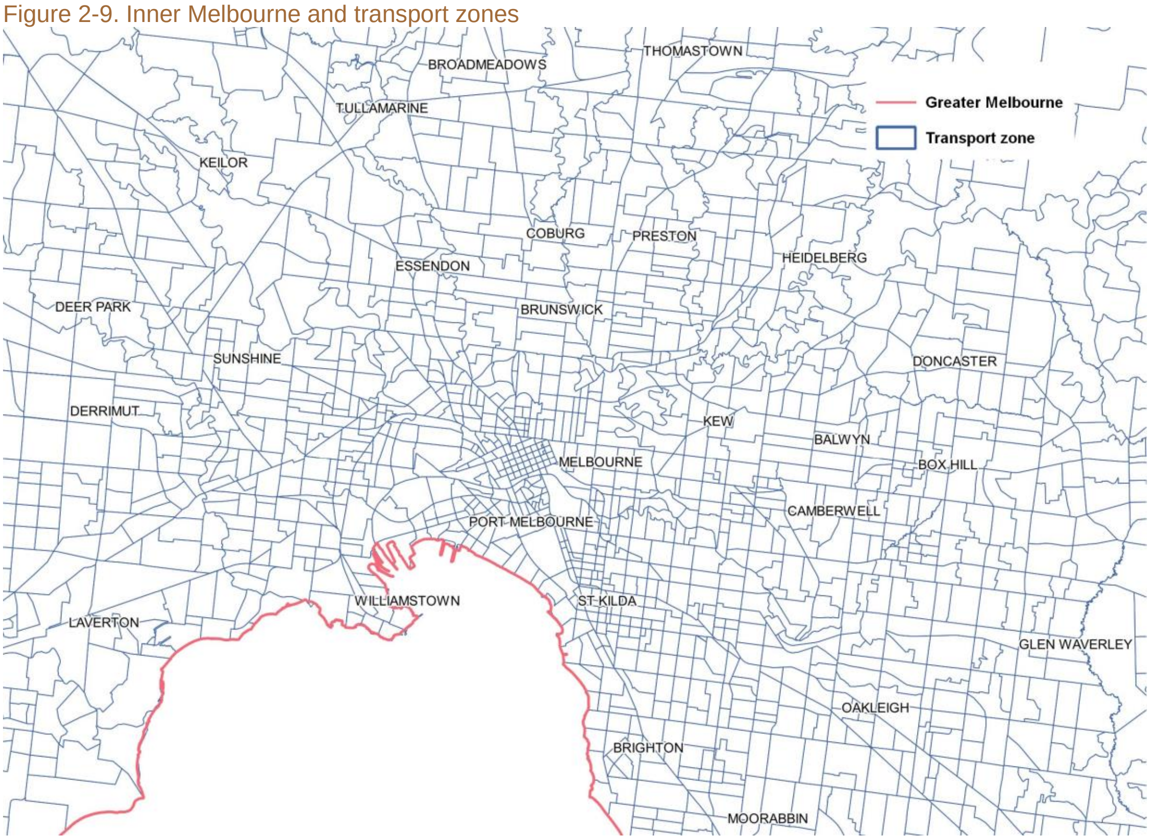


Figure 2-9. Inner Melbourne and transport zones



2.3.2 VITM Model inputs

The primary inputs to VITM include model parameters, road and public transport networks, and zonal population, employment and enrolment data.

VITM is calibrated using the Victorian Integrated Survey of Travel and Activity (VISTA) data. VISTA is an ongoing cross-sectional household travel and activity survey conducted on behalf of the Victorian Government to understand the complex travel behaviour of individuals. VISTA collects data from across Greater Melbourne, Ballarat, Bendigo, Geelong, Latrobe and Shepparton, and provides detailed information about how individuals travel including the walk between services. VISTA includes detailed demographic information on both an individual and household level, as well as comprehensive information on individuals' travel behaviours, such as the length of travel by different modes (car, bus, walking etc.), or the time of day the journey was made. Travel data includes trip origins and destinations and the amount of time spent on each trip undertaken on the survey day by travel mode. The latest year of survey data available is 2018. VITM is periodically recalibrated using the latest VISTA data in order to properly calibrate the trip generation, trip distribution and mode choice modules.

Table 2-2 presents the population, employment and enrolment inputs used by VITM. A variety of datasets are used during model calibration including VISTA, SALUP demographic data (the composition and attributes of people residing in a zone), the 2016 ABS Census data (population and employment levels and distribution) and other demographic, economic forecasts, future land use change, and travel data (such as school enrolments, car ownership levels, household income, public transport usage and traffic counts).

Table 2-2. VITM population, employment and enrolment inputs

POP	Population
HH	Households
AGE0_4	Population aged 0-4 years
AGE5_11	Population aged 5-11 years
AGE12_17	Population aged 12-17 years
AGE18_25	Population aged 18-25 years
AGE26_64	Population aged 26-64 years
AGE65PLUS	Population aged 65 years and over
DEP0_4	Dependents (non-workers) aged 0-4 years
DEP5_11	Dependents (non-workers) aged 5-11 years
DEP12_17	Dependents (non-workers) aged 12-17 years
DEP18_25	Dependents (non-workers) aged 18-25 years
DEP26_64	Dependents (non-workers) aged 26-64 years
DEP65PLUS	Dependents (non-workers) aged 65 years and over
EMP_RETAIL	Retail jobs
EMP_TOTAL	Total jobs
EMP_IND	Employment by ANZSIC 1-digit level (19 aggregated industries)
ENROL_PR	Primary school enrolments
ENROL_SEC	Secondary school enrolments
ENROL_TER	Tertiary school enrolments

The following subsections provide details regarding VITM's four-step process.

2.3.3 VITM Internal Structure

VITM contains four basic steps:

1. trip generation: estimates the number of trips originating from and travelling to each zone,
2. trip distribution: distributes trips to specific origins and destinations based on land use and activities within each area,
3. mode choice: allocates motorised trips to the available motorised modes based on discrete choice,
4. trip assignment: assigns trips to available road and public transport routes.

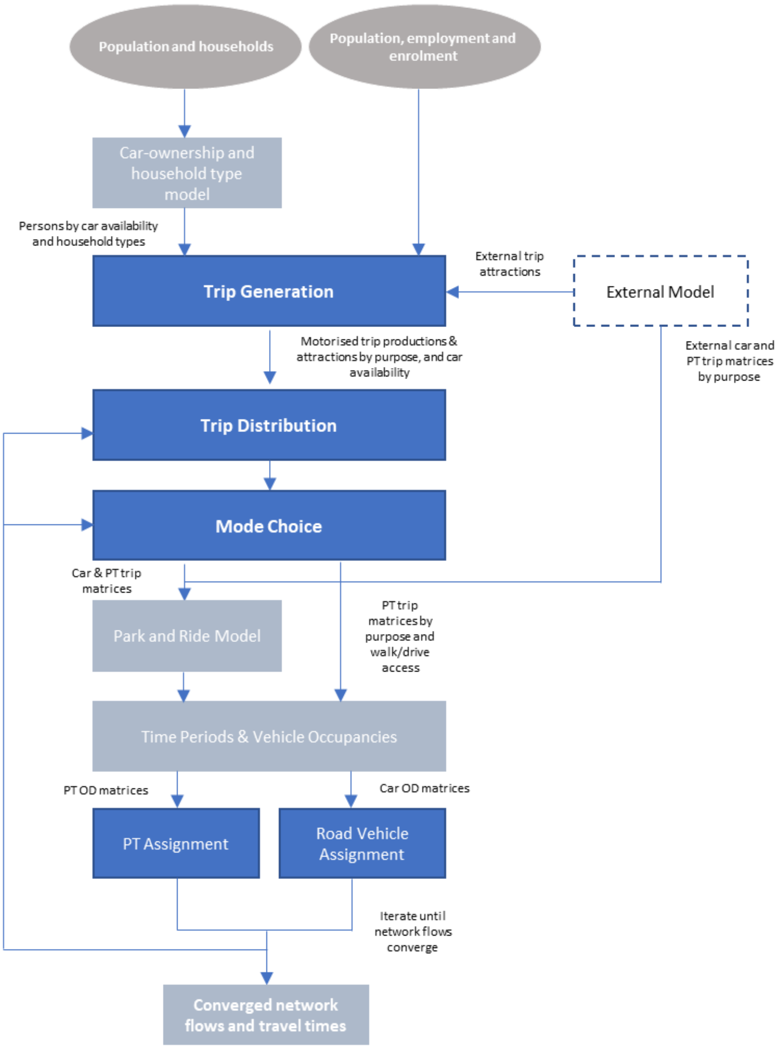
In the trip generation phase, VITM generates the total number of average school day trips by all modes and the total by active modes. Active mode trips (walking and cycling) are then subtracted from the total of all mode trips to derive motorised trips (car and public transport), which are passed to the trip distribution step. Active trips are not used beyond trip generation. Trips are produced for each transport zone and travel purpose. At this stage the destination of these trips is not known. Only the trip productions (the number of home-based trips from a particular area) and attractions (the number of trips generated by particular activities such as work, education, shopping or leisure) are calculated.

The trip distribution step (commonly calculated in other strategic models using a ‘gravity model’) connects the trip productions and attractions to derive trip patterns for each trip purpose by origin/destination pairs. The result is a set of motorised mode trip matrices. In VITM, the trip distribution and mode choice phases sit within the same module. The mode choice component separates the total motorised trip demand into daily production to attraction matrices for car and public transport modes. The mode split utilises a logit choice model with the utility of travel for both car and public transport trips between zones being the key input. Once the trip distribution and mode choice phases are completed, time period factors are used to convert the daily production to attraction trips into trips by origin and destination for each of the four modelled time periods (AM peak (7AM – 9AM), interpeak (9AM – 3PM), PM peak (3PM – 6PM) and off-peak (6PM – 7AM)). The time period factors vary by trip purpose, mode and location.

Finally, the trip assignment step assigns trips to routes/services. Due to the different characteristics of the road and public transport systems, separate assignment algorithms are employed for each in VITM.

Figure 2-10 shows a simplified structure of VITM.

Figure 2-10. The internal structure of VITM



The following sections detail each stage in more detail.

Trip generation

VITM's trip generation module estimates the number of trips, by purpose, generated by and attracted to each transport zone. The module consists of two core components - a trip production model and a trip attraction model. These components estimate typical school day trips for a 24-hour period. The trip production model calculates the number of home-based trips from each transport zone using household type, person type and car availability data. The trip attraction model calculates the number of home-based trips to each transport zone using population, worker and enrolment data by transport zone. At this stage, the attraction and production trip estimates are not linked and are referred to as 'trip ends'. Trip ends are produced for seven home-based and two non-home-based trip purposes:

- home-based work (further split into white-collar and blue-collar trips),
- home-based primary education,

- home-based secondary education,
- home-based tertiary education,
- home-based shopping,
- home-based social,
- home-based other,
- employer's business, and
- non-home-based other

In the trip production model, the population of each transport zone is categorised into household types and car availability categories. Eight person-type segmentations are defined on the basis of age and employment status as shown in Table 2-3.

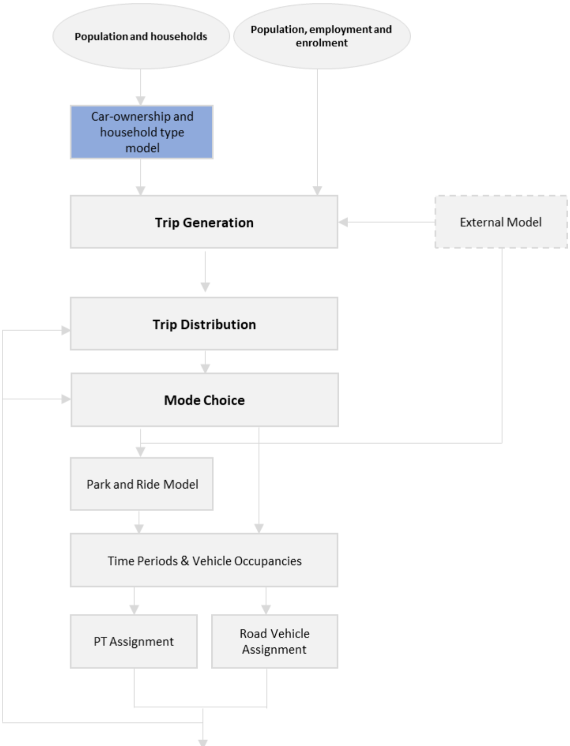
Table 2-3. Person-type segmentations

Person Type	Age	Employment Status
1	0-4	All
2	5-11	All
3	12-17	All
4	18-25	Worker
5	18-25	Non-worker
6	26-64	Worker
7	26-64	Non-worker
8	65+	All

These segmentations were derived by analysing the trip-making characteristics of different demographic groupings in the VISTA data set.

The model also incorporates eight household types and four levels of car ownership identified using VISTA data. The eight household types used in VITM are based on the number of employed adults and the total number of adults (both employed and not employed) in each household:

1) 1 adult 0 worker,
2) 1 adult 1 worker,
3) 2 adults 0 worker
4) 2 adults 1 worker
5) 2 adults 2 workers
6) 3+ adults 0-1 worker
7) 3+ adults 2 workers
8) 3+ adults 3+ workers



The car ownership model further categorises households by the number of vehicles in the household. Car availability is a measure of each person's access to a private vehicle. For a given household, the availability will depend on the number of drivers in the household and the number of vehicles. For trip production, the trip purposes are further disaggregated to low (Captive/Competition[25]) and high (Choice[26]) car ownership households. Table 2-4 shows how the car-availability status of person within each household is determined by the number of vehicles and the household type.

Table 2-4. Car-ownership level segmentations by household-type segment

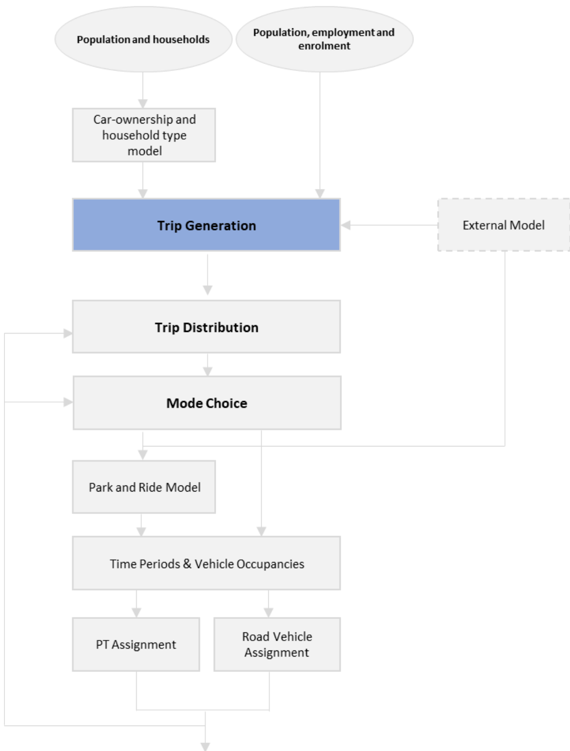
Household Type (h)	Adults	Employed Adults	Number of Household Vehicles (c)			
			0	1	2	3+
1	1	0	$cars\ 0$	$cars \geq 1$		
2	1	1	$cars\ 0$	$cars \geq 1$		
3	2	0	$cars\ 0$	$cars\ 1$	$cars \geq 2$	
4	2	1	$cars\ 0$	$cars\ 1$	$cars \geq 2$	
5	2	2	$cars\ 0$	$cars\ 1$	$cars \geq 2$	
6	≥3	≤1	$cars\ 0$	$cars\ 1$	$cars\ 2$	$cars \geq 3$
7	≥3	2	$cars\ 0$	$cars\ 1$	$cars\ 2$	$cars \geq 3$
8	≥3	≥3	$cars\ 0$	$cars\ 1$	$cars\ 2$	$cars \geq 3$

Captive/Competition
Choice

The trip attraction model estimates the number of trips to each transport zone during a school day by using inputs including population distribution by transport zone, total workers by transport zone and the total enrolments (primary, secondary and tertiary education) by transport zone. Motorised trip productions are determined by calculating the trip productions for all trips, both motorised and non-motorised, then subtracting the trip productions for non-motorised trips. Trip attractions are only calculated for motorised modes (car and public transport).

The trip generation module produces trips for an average 24-hour school day for seven home-based trip purposes based on VISTA data analysis:

- Work
- Shopping
- Social / recreational
- Primary education
- Secondary education
- Tertiary education, and
- Other.



Home-based work trips in the trip generation process are further disaggregated into white-collar and blue-collar trips using a percentage split applied separately to each production zone and each attraction zone. Non-home-based trip generation, which is implemented as part of the mode choice

[25] The number of household vehicles is less than the number of adults in the household.

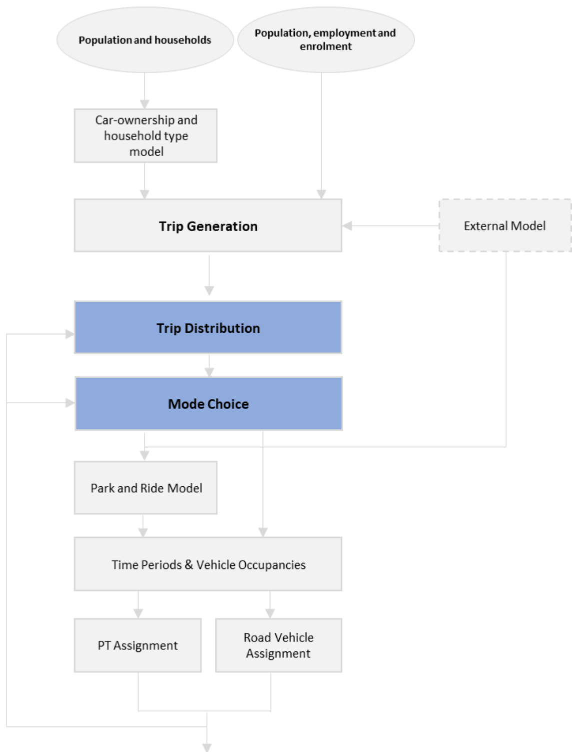
[26] The number of household vehicles is greater than or equal to the number of adults in the household.

and destination choice process (see the following sections), produces two additional trip purposes (employer's business and non-home-based other).

The total trip ends forecast by the trip production and attraction components are not equal as different explanatory variables are used to calculate trip productions and attractions. Matching total trip productions and attractions is the final step in the trip generation module. For this purpose, scale factors, calculated as the ratio of total productions to total attractions for each trip purpose, are applied to the total number of attractions in each zone so they match total trip productions (it is assumed trip production rates are known with more certainty than trip attraction rates).

Trip distribution and combined mode choice

The trip distribution and mode choice process within VITM forecasts the distribution of car and public transport trips across Victoria. The trip ends derived from the trip generation step are the primary inputs.

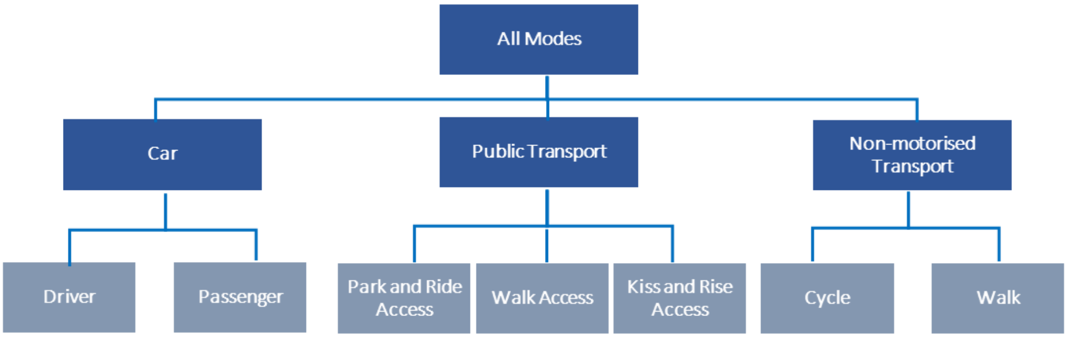


In the current version of VITM, trip distribution and mode choice are considered in the context of discrete choice theory and are expressed in the form of nested logit models. The discrete choice approach offers greater flexibility than traditional approaches by considering the interaction between a traveler's choice of destination (i.e. trip distribution) and choice of mode. VITM's calibration sets mode choice prior or simultaneous to destination choice for all trip purposes. For ease of implementation, mode choice occurs prior to destination choice for all home-based trip purposes.

Inputs to mode choice models are stratified based on the characteristics of people undertaking the travel (age, employment status, current education status, whether they are licensed), the observed mode choice (from survey data), and the characteristics of the travel modes (availability, frequency, price, reliability). Trips are assigned to available travel modes by trip purpose, giving consideration to the characteristics of the trip maker (income, car ownership, age), and the characteristics of the travel mode (fares, vehicle operating costs, travel time, parking availability and cost, reliability).

Nested logit models are used to estimate mode choice. The logit model incorporates three broad modes of travel: car, public transport and non-motorised transport. Figure 2-11 below shows the structure of a nested logit model. The car mode comprises car driver and car passenger. Public transport mode comprises three sub-modes, depending on the mode taken to access public transport. Thus, public transport is split into Park and Ride Access, Walk Access, and Kiss and Ride Access. Non-motorised transport comprises bicycle and pedestrian- modes.

Figure 2-11. Structure of a nested logit mode choice model



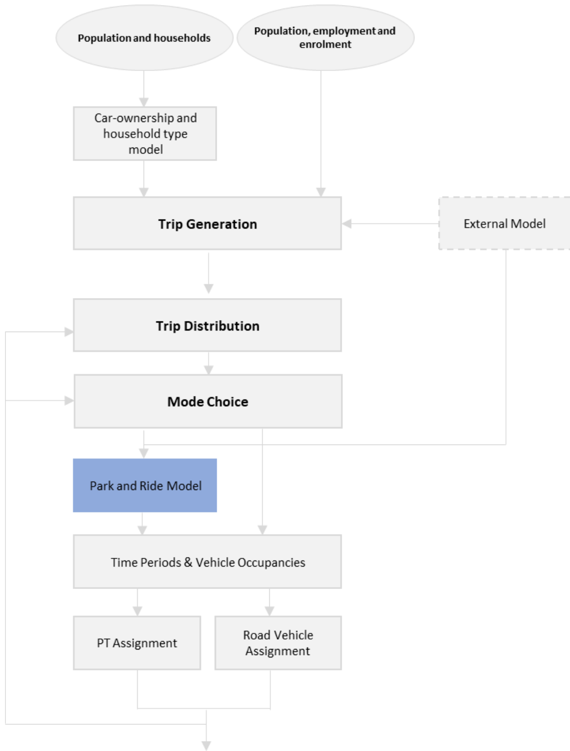
Each choice represented in the hierarchical model has an associated utility. The utility measures the level of satisfaction that an individual traveller perceives with each choice. A traveller is assumed to make a choice that maximises their utility. The logit model assumes that travellers' perceptions of utility vary across the population, resulting in a spread of choices for a given set of alternatives. Within VITM, the utility of travel is closely related to the generalised cost of travel but with the opposite sign. Therefore, utility increases as the generalised cost decreases.

There are different formulations for calculating the generalised cost of travel for different modes. For car trips, the generalised cost is calculated using the travel time, travel distance, tolls and parking charges. Calculating the generalised cost for public transport trips is based on:

- the access time to reach the public transport service,
- the waiting time for the service to arrive,
- the in-vehicle time on public transport,
- the egress time to get from the public transport service to a destination,
- fares,
- discomfort due to crowding, and
- inconvenience and uncertainty of transferring between services.

Generalised costs are calculated in units of time (minutes). For the calculation of generalised costs for mode choice and distribution, the model uses the value of time (VOT) costs to convert the vehicle operating cost, parking costs and public transport fares into generalised time. It is worth noting that the values of time used in the highway assignment are different, as they are derived from a lognormal distribution. VOTs are per person and separated into business trips and all other purposes. The vehicle operating cost (VOC) for business trips is higher than for other trips, and VOC increases over time due to anticipated increases in real fuel costs.

Within the four-step process of VITM and prior to the assignment phase, the 'Park and Ride Choice Model' is implemented. The Park and Ride Model is used to estimate the mode used to access rail services at train stations. The model uses a binary logit model to estimate the two public transport access modes: park and ride access and walk access. The model estimates the probability of choosing a mode, based on the relative costs (or disutility) of each mode. The disutility of the park and ride mode includes driving time to the station, vehicle operating costs, parking costs, wait time, train in-vehicle time, fare, and egress time. The walk access mode disutility includes the walk time to the station plus wait time, train in-vehicle time, fare and egress time. A mode specific constant is used to capture the non-measurable utility (for example, comfort, ride quality, etc.).



Also prior to the assignment phase, Time Period Factors (TPFs) and Vehicle Occupancy Factors (VOFs) are used to split the daily production-attraction (PA) trip matrices produced by the mode choice and distribution models into origin-destination (OD) matrices for each time period. TPFs are defined as the fraction of daily trips that occur in a given time period. With four time periods adopted in VITM, each set of four TPFs for a given category sum to 1.0. Sets of time period factors are defined for each mode, purpose and, for home-based trips, the direction of travel (to home or from home). These factors capture the differences in the directionality and volume of trips in each time period for each trip purpose.

When the TPFs are applied to the daily matrices, the resulting time period matrices represent trips carried out over the entire duration of each time period. Each time period has a different duration, so each raw matrix represents a different number of hours.

Table 2-5 presents VITM time periods with two-hour time period scaling factors. VITM's network capacities and assignments operate over a two-hour period. Each raw time period matrix is therefore scaled to represent an average two-hour block over the time period. The model calculates traffic and public transport forecasts based on these two-hour intervals. To convert the two-hourly flows back to total time period and daily flows, the scale factors will need to be applied in reverse (i.e. to obtain the total flow in the PM peak, multiply the two-hour PM peak flow by 3/2).

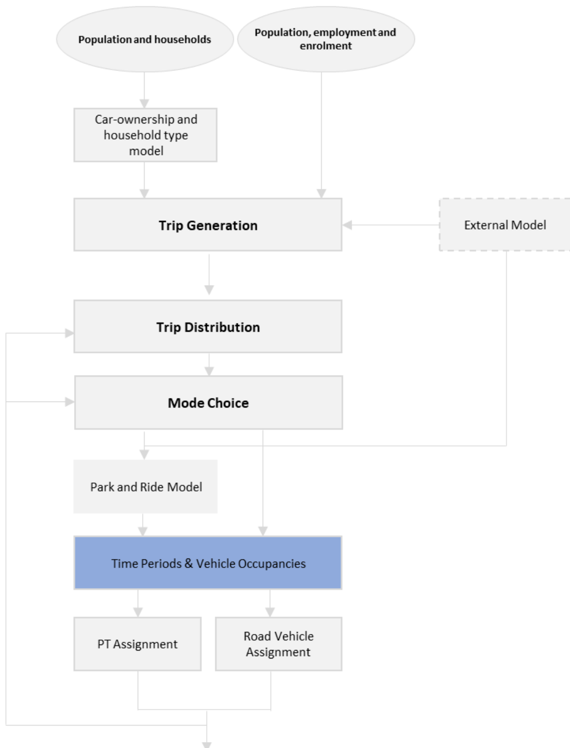


Table 2-5. Two-hour time period scaling factors

	Start	End	Duration	Scale Factor
AM Peak	07:00	09:00	2 hours	**1**
Inter Peak	09:00	15:00	6 hours	**1/3**
PM Peak	15:00	18:00	3 hours	**2/3**
Off Peak	18:00	07:00	13 hours	**1/3***

In addition to TPFs, the model uses VOFs to convert the car-based person OD matrices into vehicle matrices (to account for vehicles carrying more than one person). Public transport trips are left as person trips; no vehicle occupancy calculation is required. Once vehicle and person matrices have been determined for each trip purpose and time period, the individual trip purpose matrices are combined to provide a final aggregate demand to assign to the road and public transport networks – for each time period.

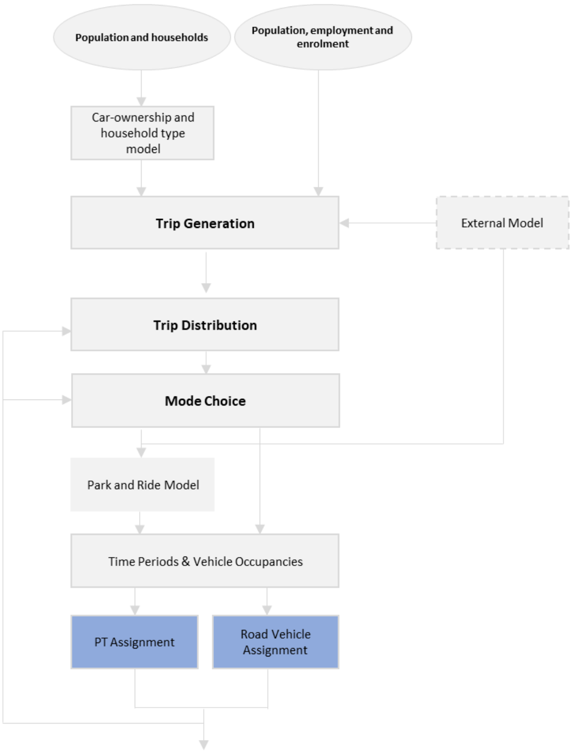
Trip Assignment

VITM's trip assignment module consists of road vehicle assignment and public transport assignment. Once the distribution and mode choice modules derive the mode-based travel demand matrices for each trip purpose, and for each of the modelled time periods, the resulting demand matrices are assigned to the public transport network and the highway network respectively. The assignments include highway characteristics such as capacity and highway classification, and public transport service characteristics. This allows VITM to model the changes in travel conditions across the transport network.

The changes in highway travel conditions are modelled in VITM using speed-flow curves for various highway classifications (freeways, undivided arterials, local roads). The speed-flow curves describe the change in speed, and consequently travel time, on a section of highway based on the assigned volume and the capacity of the highway section. The designation of capacity in VITM is not an absolute measure but describes a characteristic of the highway section, for planning purposes. It links travel conditions to traffic volumes and considers:

– the cross-section of the road (e.g. number of lanes, divided or undivided),
– operational characteristics of the road (parking bans, presence of trams),
– intersection spacing and configuration,
– abutting land uses, and
– pedestrian movements.

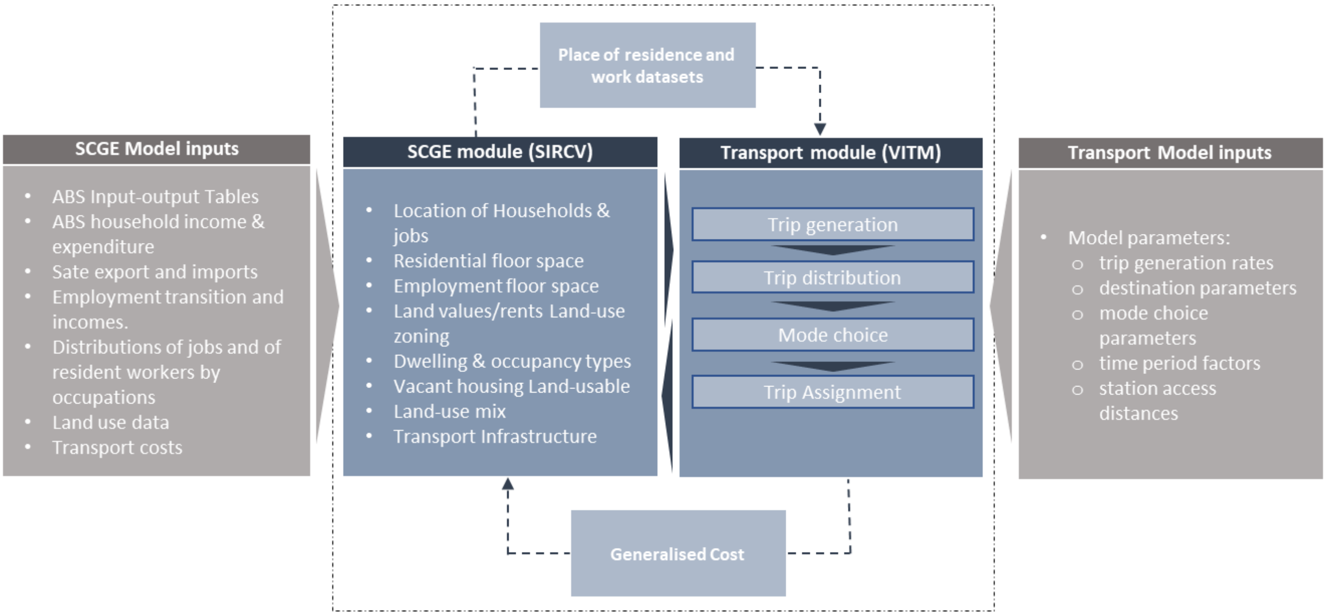
Public Transport demand is calculated for walk access and for park and ride access. While park and ride access trips will involve a train, they may also involve bus or tram as part of a linked trip. Walk access trips may involve any combination of train, tram and bus. The route and mode used in a public transport trip is determined by the generalised cost of travel. For bus and tram services, the travel times are calculated from link speeds that are a function of the speeds produced in the highway assignment. The on-road public transport services (tram and bus) generally operate at a lower speed than the general vehicle traffic. For train services the travel speeds are derived from rail timetables, which are coded into the network as fixed speeds on each rail link.



2.4 VLUTI Model Internal Structure

This section describes the internal structure of the VLUTI model and how the two main components - the SIRCV model and VITM (described in sections 2.2 and 2.3) - are combined into an integrated process. The VLUTI model comprises an SCGE module (SIRCV) and a transport module (VITM) which are run in sequence as part of a single, integrated and iterative process, providing a mechanism for the model outputs to be converged, and a more realistic assessment outcome. The integrated model provides iterative modelling of land use and transport impacts to understand the feedback mechanisms between infrastructure provision and land use changes. Figure 2-12 presents the internal structure of the VLUTI model.

Figure 2-12. The internal structure of the VLUTI model



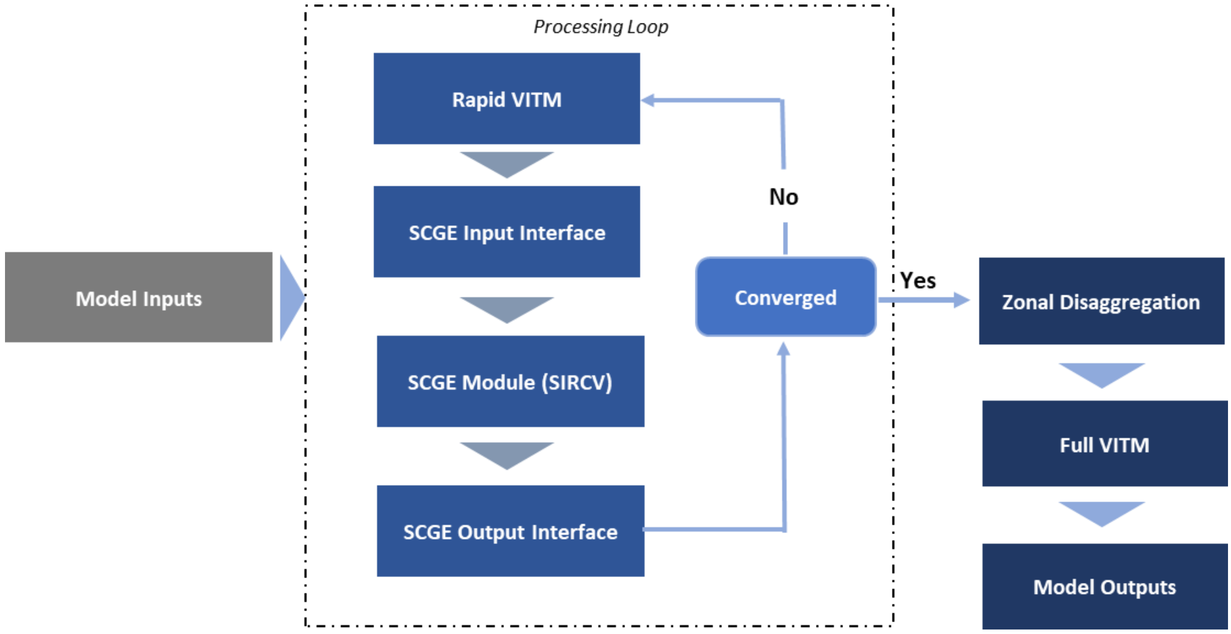
As shown in Figure 2-12, employment and consumption of goods in the SCGE module generate place of residence and work datasets which form inputs for the transport module. The transport module then undertakes trip generation, determines mode split and assigns trips to the transport network, returning expected travel costs to the SCGE module.

The VLUTI model is comprised of the following seven individual components largely executed in a controlled loop:

1. Rapid VITM
2. SCGE Input Interface
3. SCGE Module (SIRCV model)
4. SCGE Output Interface
5. Convergence Testing and back to Step 1 for six loops,
6. Zonal Disaggregation
7. Full VITM

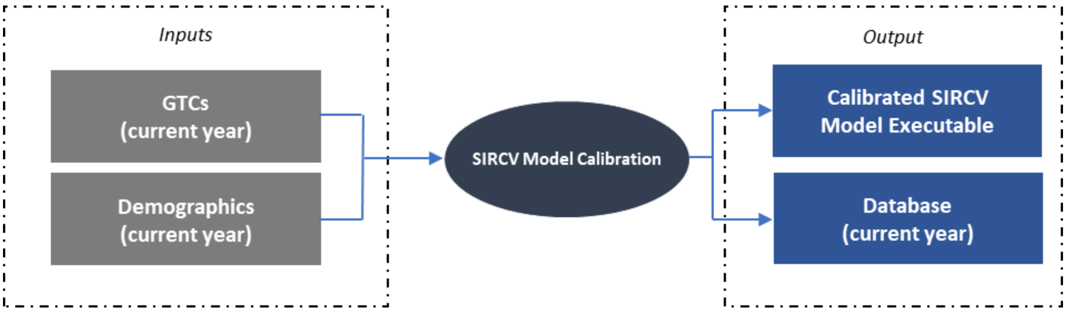
The first five components of the VLUTI process are executed in a loop six times. A full VLUTI scenario takes approximately five days to run, including the processing loop and final VITM assignment phase. Figure 2-13 presents the internal structure of the VLUTI model. Details regarding each individual component can be found in the following subsections.

Figure 2-13. VLUTI model internal structure



The SIRCV model must be calibrated as part of the preparation for the VLUTI process. The required inputs in the SIRCV calibration process include current year demographic inputs (2018, as of writing) as well as modelled GTCs produced by a (single) simulation of rapid VITM.[27] The calibration process produces both a calibrated SIRCV model executable (used in subsequent VLUTI stages) and a current year SIRCV database representing the economy for the current year. Unless changes are made to the current year demographic assumptions, calibration only needs to be conducted once. Figure 2-14 shows this process schematically.

Figure 2-14. SIRCV model calibration process



[27] *Appendix B provides more information regarding the calibration process for the current version of VLUTI.*

2.4.1 Rapid VITM

Rapid VITM is a modified version of VITM that was specifically developed to generate Generalised Travel Costs (GTCs) with a shorter running time (10 hours). Utilising the full VITM for executing a transport infrastructure scenario can take over three days depending on settings and hardware.

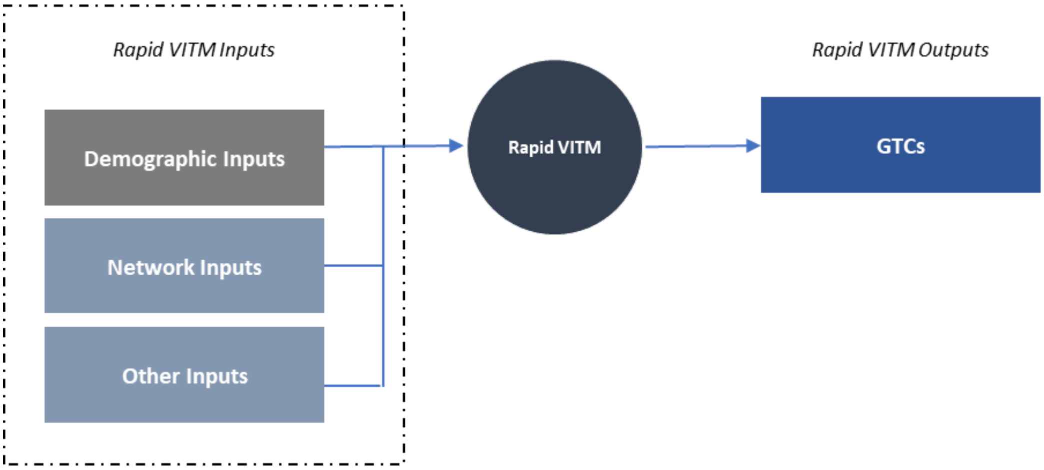
The Rapid VITM is used to generate GTCs as an input into the SCGE module to inform the SCGE module's simulation of the economy. The Rapid VITM aggregates the master set of 6973 zones to approximately 499 zones to match the detail of the SA2 system (458 primary SA2 zones and external connections). The less zones used during assignment, the faster VITM is able to execute a scenario. However, this results in a loss of detail as to where simulated trips can originate and terminate. However, at this stage in the process, GTCs are only required at an SA2 level as the SCGE module uses an SA2-based region system (with only 458 zones). This aggregated zoning system in the Rapid VITM results in much faster running times and means outcomes can be more readily converted into a form for the SCGE module without further spatial manipulation. The loss of accuracy is not a concern as assignment-specific outcomes from the Rapid VITM are not directly used during analysis.

The full VITM contains a bespoke simulation of freight within its highway assignment process known as the Freight Movement Model (FMM). This component is computationally taxing, considering network performance, economic assumptions and several other factors to generate freight demand. During the processing loop, the Rapid VITM runs internally for six loops, to achieve a convergence of mode share. The FMM is only used during the first internal iteration of the Rapid VITM. In subsequent Rapid VITM runs, the FMM is run again but only once during the first internal iteration of the rapid VITM. Changes predicted by the SCGE module mainly concern private travel and it is assumed that land use redistribution will have little impact on specific freight movement patterns. Therefore, the setting to run the FMM once in the Rapid VITM was to save substantial running time. The FMM is still set to run at every iteration where the full VITM is employed.

As shown in Figure 2-15, Rapid VITM uses demographic inputs, network and other inputs to generate GTCs. Depending on the iteration, demographic inputs to the Rapid VITM change. On the first iteration of the processing loop, the specific demographic inputs will be used depending on the modelled year being tested. On subsequent iterations, the demographic inputs provided for the Rapid VITM come from the SCGE module. Network inputs remain unchanged through all iterations.

The Rapid VITM is primarily used to produce a combined car and public transport GTC matrix. These values act as a primary input to the SCGE module, governing how the workforce and their jobs are redistributed throughout the state. VITM's assignment process (and correspondingly that of the Rapid VITM) produces a set of 24-hour composite travel cost matrices for each trip purpose and mode (car and public transport). These are the primary inputs used to derive the combined GTC matrix.

Figure 2-15. Rapid VITM inputs and outputs



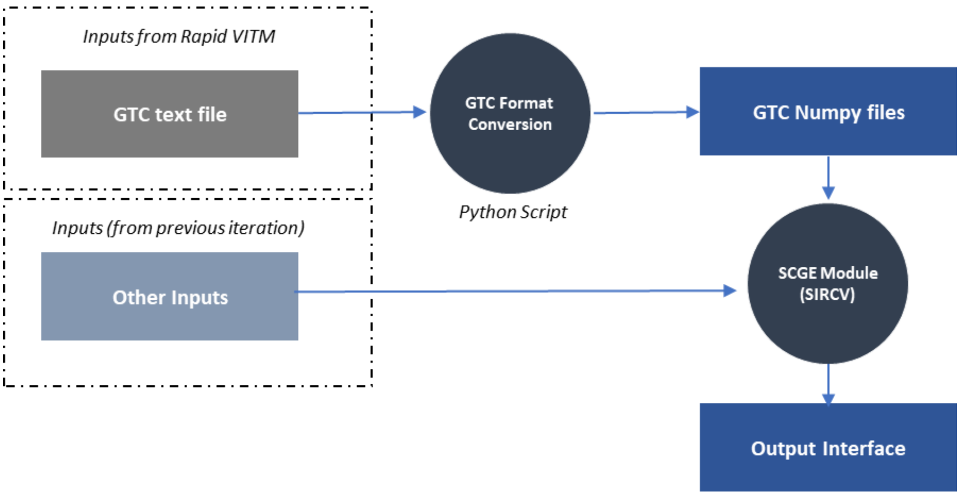
2.4.2 SCGE Input Interface

The GTC outputs produced by the Rapid VITM need to be converted into a form directly compatible with the SCGE module (the SIRCV model): Numpy files. This conversion is achieved using a Python script run automatically within the Cube modelling environment.

In addition to the GTCs, the SIRCV model also requires additional inputs in the form of an initial model database. For the initial iteration of VLUTI, the model inputs must be provided exogenously. On subsequent iterations, the input database originates from the execution of the SIRCV model in the previous iteration.

Figure 2-16 shows the necessary inputs schematically.

Figure 2-16. SCGE module required inputs



This database, together with the GTC file, represent the only inputs necessary for the land use simulation to run.

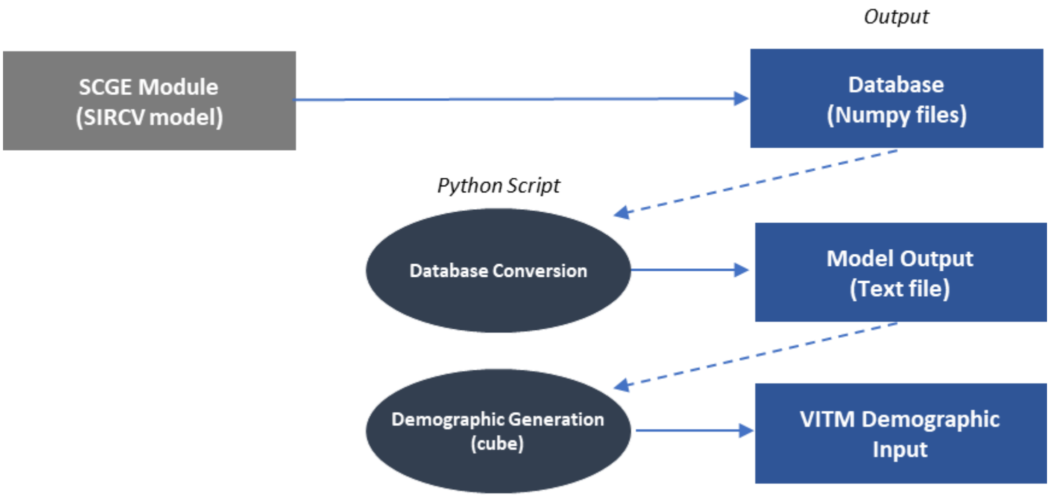
2.4.3 SCGE Module

The SCGE module in the current version of VLUTI is the SIRCV model. The SIRCV model is provided inputs from the previous step and is run to determine how changes in transport costs (and potentially other inputs) affect location choices and economic activities. Places of residence and place of work are provided as outputs to inform the transport module. See section 2.2 for more details on the SIRCV model.

2.4.4 SCGE Output Interface

The SIRCV model (or SCGE component of the VLUTI model) uses the provided GTCs from the Rapid VITM and generates output representing the state of the economy. The output file contains the new distribution of resident workers and employment throughout Victoria. The contents of the database must be converted back into a format suitable for checking model convergence progress (see Sub-section 2.4.5) and executing the Rapid VITM again (if necessary for a subsequent iteration). Figure 2-17 represents the specific sequence of steps used to achieve this.

Figure 2-17. SCGE module output interface



After running the SIRCV model, there is a process that takes model's outputs and generates a corresponding VITM demographic input. The database produced by the SIRCV model cannot be directly interrogated using traditional tools. A Python script is used to automatically extract the relevant resident worker and employment data from this file into a text format. A new aggregated demographic input file containing population, households and employment information is generated using a process implemented in Cube. VITM (and similarly the Rapid VITM) requires a single consolidated demographic input file containing a superset of the attributes produced by the SIRCV model and extracted during the preceding database conversion step. This includes but is not limited to population split into age group, as well as employment by specific industry classes. The assumptions and process employed to generate the required VITM attributes from the SIRCV database are described in section 2.4.6.

Those attributes not produced directly by the SIRCV model are inferred using a proportioning and migration process. As workers are moved between locations, as simulated by the SIRCV model, the demographic characteristics of their households from their original locations are retained and transferred to their new places of residence. It should be noted that both the SIRCV and Rapid VITM use the same zoning system, thus no spatial disaggregation is applied at this stage of the process. This is only necessary when preparing for the final full VITM run.

2.4.5 Convergence

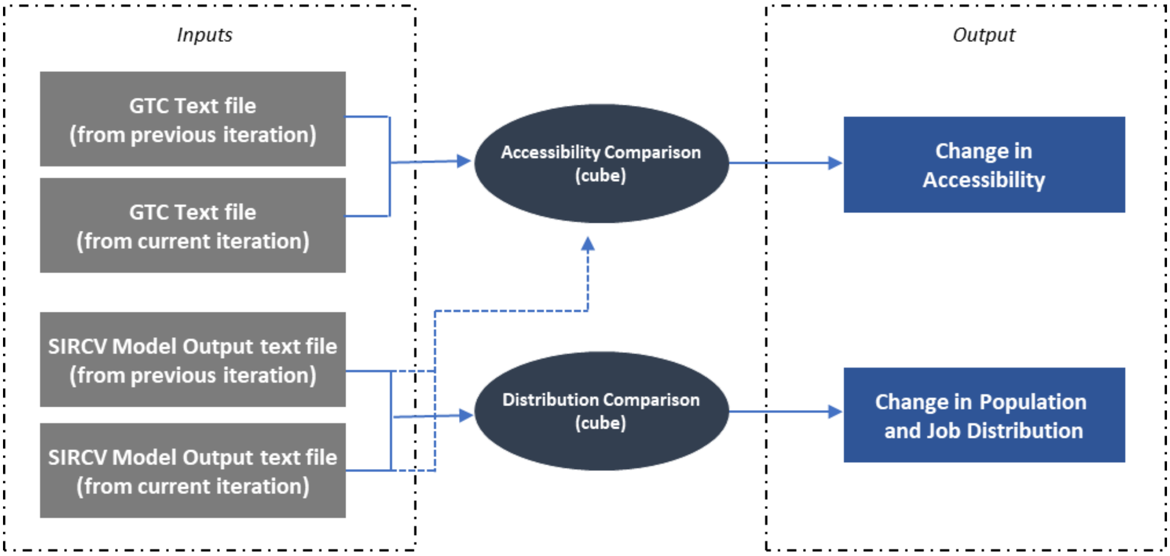
In the processing loop within VLUTI (as shown in Figure 2-13), both SCGE (SIRCV) and transport (VITM) modules are run iteratively until an equilibrium is found. Once the model has reached a stable combination of demographic distribution and network performance, it can be said to have converged. The SIRCV and VITM models need to reach their own respective equilibrium status and these respective equilibriums need to be aligned for convergence to be achieved. Several different variables produced by both the Rapid VITM and the SIRCV Model have been selected to monitor this process during scenario testing. These variables have been determined, through testing, to provide the clearest indicators that the model is converging.

Change in population distribution and accessibility to employment are the main two components in the convergence monitoring process. The processing loop is run between three to six times – if the value of change for both these metrics falls below specific thresholds in this window, no further iterations are undertaken. Figure 2-18 shows the convergence monitoring process within the VLUTI framework.

The SIRCV model produces new distributions of jobs and resident workers throughout Victoria. As the VLUTI model is run, it is expected that the difference between the current and previous iteration’s distributions approach zero as the model converges. To test whether this is occurring, the model compares the previous and current iteration’s outputs and calculates the absolute proportional change in both jobs and resident workers for each zone. An overall weighted average absolute proportional change value is then generated, aggregating the results of all zones simultaneously. To test the convergence, the model adopted the following thresholds for weighted average change in jobs and resident workers to signal an early termination of the model:

- Change in jobs: less than 0.1% between iterations.
- Change in resident workers: less than 0.2% between iterations.

Figure 2-18. Convergence monitoring process



In addition to distribution comparison, the model uses an accessibility to employment index as the second test of convergence between iterations. This accessibility index is first calculated at a zonal level for home-based white and blue-collar work trips. As the model converges, there should be net improvement in access as people are moved closer to their jobs. To test the convergence, the model adopted a threshold of 0.1 units of change in weighted average accessibility between iterations to signal the early termination of the model.

It is observed that the VLUTI model was able to achieve a convergence based on the above criteria after four iterations. The model was therefore set to run arbitrarily at six iterations for all projects to ensure convergence and consistency between base and project cases.

2.4.6 Zonal Disaggregation

The zonal disaggregation process concerns upscaling the 458-zone based demographic inputs derived from the SCGE to the 6973 zones required by the full VITM. After running through iterations and achieving the convergence criteria in the processing loop, the final distribution of jobs and resident workers must be converted into a format suitable for running the full VITM through a final simulation. This process is required to create inputs at the level of granularity required by VITM (as both the Rapid VITM and the SGCE model operate at a more aggregated zonal level). This process involves the generation of a VITM demographic input file. This subsection first outlines the assumptions and process employed to generate the required VITM attributes from the SCGE database, and then describes the zonal disaggregation process which is necessary for the full VITM.

Attribute disaggregation

The SCGE module's outputs do not provide all the information required to create a demographic input dataset compatible with VITM. Table 2-6 outlines the attributes extracted from the database generated by the SCGE module and the required VITM attributes by zone.

Table 2-6. SCGE outputs and demographic attributes required by VITM

<table>
<tr><th>Resident (origin)</th><th colspan="2">Employment (destination)</th></tr>
<tr><td colspan="3">SCGE Database</td></tr>
<tr><td>Resident workers by occupation</td><td>Jobs by industry group</td><td>Jobs by occupation</td></tr>
<tr><td>43 occupational groups – ANZSCO 2-digit</td><td>100 industries:
• 10 produce primary products,
• 40 produce manufactures,
• 5 provide utilities,
• 4 undertake construction activities and
41 produce non-housing services. Each corresponds to one or several ABS Input-Output Industry Groups (IOIG).</td><td>43 occupational groups – ANZSCO 2-digit</td></tr>
<tr><td colspan="3">Required VITM attributes</td></tr>
<tr><td>Resident workers</td><td>Jobs by industry class</td><td>Blue collar proportion by class</td></tr>
<tr><td>Population
Households
Population by age group:
• Population (0-4 years)
• Population (5-11 years)
• Population (12-17 years)
• Population (18-25 years)
• Population (26-64 years)
• Population (65+ years)
Dependents by age group:
• Dependents (0-4 years)
• Dependents (5-11 years)
• Dependents (12-17 years)
• Dependents (18-25 years)
• Dependents (26-64 years)
• Dependents (65+ years)
Enrolments:
• Primary
• Secondary
• Tertiary</td><td>Employment by 19 industry classes (correspond to ANZSIC industry classification groups):
1. Agriculture, Forestry and Fishing
2. Mining
3. Manufacturing
4. Electricity, Gas, Water and Waste Services
5. Construction
6. Wholesale Trade
7. Retail Trade
8. Accommodation and Food Services
9. Transport, Postal and Warehousing
10. Information Media and Telecommunications
11. Financial and Insurance Services
12. Rental, Hiring and Real Estate Services
13. Professional, Scientific and Technical Services
14. Administrative and Support Services
15. Public Administration and Safety
16. Education and Training
17. Health Care and Social Assistance
18. Arts and Recreation Services
19. Other Services</td><td>BC Proportion by 19 industry classes (correspond to ANZSIC industry classification groups):
1. Agriculture, Forestry and Fishing
2. Mining
3. Manufacturing
4. Electricity, Gas, Water and Waste Services
5. Construction
6. Wholesale Trade
7. Retail Trade
8. Accommodation and Food Services
9. Transport, Postal and Warehousing
10. Information Media and Telecommunications
11. Financial and Insurance Services
12. Rental, Hiring and Real Estate Services
13. Professional, Scientific and Technical Services
14. Administrative and Support Services
15. Public Administration and Safety
16. Education and Training
17. Health Care and Social Assistance
18. Arts and Recreation Services
19. Other Services</td></tr>
</table>

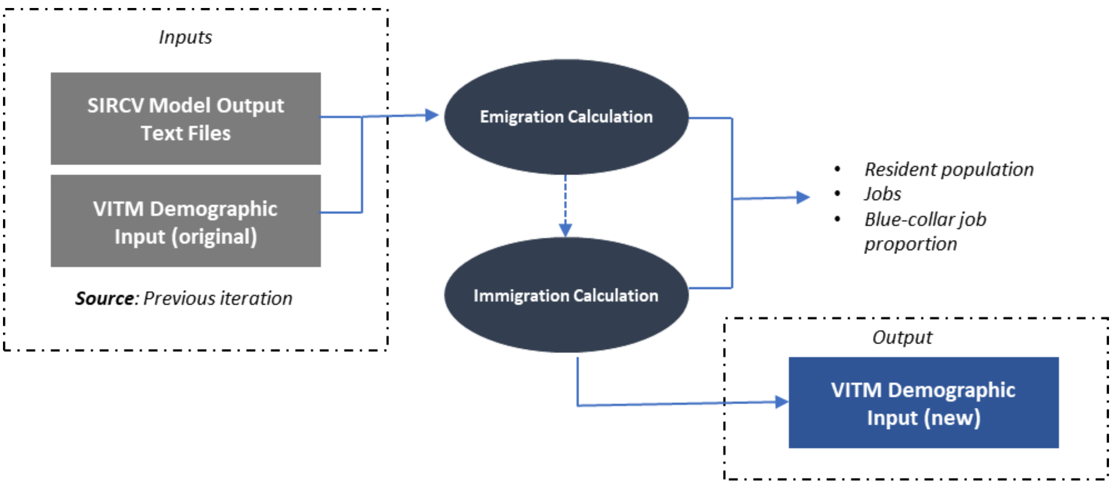
The SCGE model produces only change of resident workers, but not other attributes of VITM such as population, and dependents by age group. The process of attribute disaggregation involves the following steps:

1. Estimating the relocated population by age group and dependents for each VITM zone by using VITM proportion of population over worker timed the relocated resident workers (estimated by SCGE),
2. Summing up the total relocated population and their dependents to form a relocated pool,
3. Distribute the pool of relocated population and dependents to where the resident workers are relocating to.

Zonal disaggregation process

Zonal disaggregation is required to disaggregate the SCGE 458-zone output (SA2 regions) into the complete 6973 zones necessary for the full VITM. Each SCGE zone is associated with a number of VITM zones (as SCGE zones are larger). Disaggregation is then achieved by distributing the contents of each larger zone from the 458-zone system across the smaller 6973 zones required by the full VITM. This process uses corresponding year SALUP data as a template to perform the expansion. Figure 2-19 shows the zonal disaggregation process in the VLUTI framework.

Figure 2-19. Zonal disaggregation process



Zonal disaggregation is achieved through three separate phases:

1. *Generation of Production Variables* - each VITM zone has a profile of production-related attributes derived from SALUP demographic data (i.e. the composition and attributes of people residing in a zone). This profile is used to split the demographic composition of the larger SCGE zone across multiple underlying VITM zones, whilst maintaining the correct total number of people across each attribute.

2. *Generation of Attraction Variables* - attraction variables within VITM's demographic input relate largely to the amount of employment opportunities present within each zone split by industry class. The 458-zone attraction attributes are disaggregated to the 6973-zone system using the same process as that used for the production variables. SALUP data is used to calculate the

proportion of employment by industry class occurring within a smaller VITM zone relative to its enclosing SCGE zone. These proportions are then used to distribute employment opportunities by industry across all the smaller 6973 zones.

3. *Balancing Blue and White-Collar Split* - VITM also requires the blue and white-collar split of employment by industry class for each zone. The disaggregation of this attribute cannot be calculated in the same manner described for the production and attraction variables. Blue and white-collar split is a direct output of the SCGE model, and thus has no direct relationship with equivalent SALUP values. Naively applying SALUP proportions of blue and white-collar splits to model outputs may result in situations where there are more blue-collar workers assigned to a zone than there are total employment opportunities. Thus, SALUP data is used to calculate only initial proportions of blue and white-collar splits by zone in a similar manner to the production and attraction values. These initial proportions are used to split the SCGE outputs of blue-collar employments into zones, calculate total blue-collar employments by zone and industry class, and balance the total blue-collar employments to ensure they do not exceed the total zonal employment. Following this balancing process, total employment by industry and zone remains consistent with the proportions of blue and white-collar employment assigned within them.

The above three phases in the zonal disaggregation process ensure that the demographic distribution produced by the processing loop across the SCGE 458-zone system remains consistent in totals and general profile to the resulting 6973 zone version used for the final VITM assignment.

2.4.7 Full VITM

Once the zonal disaggregation is done, the full VITM will be used to assign demand against a more typical disaggregated zoning system. The full VITM model will be used to run a final iteration against disaggregated demographic inputs, producing final modelled outcomes.

2.5 VLUTI Model Outputs

The internal structure of the VLUTI model and its components – the SCGE model (SIRCV) and transport model (VITM) - were described in the previous sections. This section provides details about different types of outputs that the current version of the VLUTI model can provide from different transport infrastructure and urban form scenarios.

The model can produce a wide variety of spatial and macroeconomic (Victorian) outputs from any given scenario. At the end of modelling and output processing for each scenario testing, the VLUTI model provides an outputs package. This package will contain a standard set of outputs generated by the model runs. For the sake of completeness, different types of outputs from the VLUTI model are categorised into three broad groups: 1) demographic outputs, 2) transport infrastructure related outputs, and 3) land use changes and macroeconomic outputs. The following subsections provide details regarding these three broad groups of the VLUTI outputs.

2.5.1 Demographic outputs

The transport-zone level demographic output file generated by the VLUTI model contains the total number of persons living in a region (by age group), total number of households living in a region, total number of jobs in a region, and total number of primary, secondary and tertiary enrolments in a region. Fundamentally, the model provides the demographic output at the 6973 transport-zone level. These zones can then be aggregated further to reflect more common standards such as Australian Statistical Geography Standard (ASGS), Local Government Areas (LGA), Statistical Areas Level 2 (SA2) and specific regions.

2.5.2 Transport infrastructure related outputs

The VLUTI model outcome reporting framework provided by Arup/AECOM to support the development of *Victoria's infrastructure strategy* consists of four transport infrastructure related metric categories:

1. Infrastructure Changes - describes the infrastructure changes from transport infrastructure scenarios.
2. Travel Patterns - describes changes in trip patterns and volumes across the state and by specific destination. This will build directly on the infrastructure and population change categories, providing evidence that the scenario's travel patterns are a direct and natural result of changes in model inputs.
3. Network Impacts - describes changes that travellers will be experiencing first-hand on the network. This includes measures of congestion, delays and crowding for example.
4. Wider Impacts - Describes broader aggregated changes in travel trends and associated measures across the state because of first-order network impacts.

The model can produce a wide variety of other outputs such as trip purpose outputs that can be accessed by writing scripts. Table 2-7 outlines the VLUTI transport infrastructure related outputs that are consistent with VITM outputs.

Table 2-7. VLUTI transport infrastructure related outputs

Metric categories	Transport infrastructure related outputs
Infrastructure Changes	– *Road Supply Summary* - reporting Road Length, Lane Length. – Metropolitan Melbourne Road Supply - reporting Road Length, Lane Length.

	– *Regions Summary* - reporting Road Length, Lane Length. – *Public Transport Service Kilometres Summary* - reporting Train, Tram, Bus (all variants combined), V/Line.
Travel Patterns	– *Person Trip Summary* - reporting Private Vehicle, Public Transport (Walk Access, Park and Ride Access), Public Transport Mode Share. – *Vehicle Trip Summary* - reporting Private Vehicle, Heavy Vehicle (Rigid, Articulated), Heavy Vehicle Share. – *Kilometres and Hours Travelled* - reporting VKT, VHT, PKT, PHT – *Public Transport Boardings Summary* - reporting Train, Tram, Bus (combine all variants), V/Line. – *Private Vehicle Person Trips by Region (Originating)* – *Public Transport Person Trips by Region (Originating)* – *Private Vehicle Person Trips by Region (Terminating) Public Transport Person Trips by Region (Terminating)*
Network Impacts	– *Congested Road Kilometres* for different time periods. – *Congested Road Kilometres Travelled* for different time periods. – *Congested Freight Kilometres Travelled* – *Road Delay Hours (ratio between modelled VHT and equivalent free-flow or posted VHT)* - for different time periods. – *Crowded Kilometres (proportion of the public transport network that is crowded)* - for different time periods. – *Crowded Passenger Kilometres (proportion of crowded PHT against total PHT)* - for different time periods. – *Freight Terminal Travel Times (average travel times between selected freight terminals)* - for selected freight terminal pairs & for different time periods.
Wider Impacts	– *Congested Road Kilometres* - for different time periods. – *Congested Road Kilometres Travelled* - for different time periods. – *Congested Freight Kilometres Travelled* - for different time periods. – *Road Delay Hours (ratio between modelled VHT and equivalent free-flow or posted VHT)* - for different time periods. – *Crowded Kilometres (proportion of the public transport network that is crowded)* - for different time periods. – *Crowded Passenger Kilometres (proportion of crowded PHT against total PHT)* - for different time periods. – *Freight Terminal Travel Times (average travel times between selected freight terminals)* - for selected freight terminal pairs & for different time periods.

2.5.3 Land use changes and macroeconomic outputs

The VLUTI model allows identification of the direction of trends and potential benefits (both direct and flow-on benefits) of different urban form scenarios on:

- Land use for different purposes (Residential, Commercial, Industrial, Rural),
- Jobs and value-added in sectors that are directly or indirectly dependent on the land use and infrastructure interventions in Victoria,
- Industry activity across the broader economy (value-added, jobs), and
- GSP, employment and labour productivity, capital and land returns, household and job locations, and generalised travel cost.

Land use changes and macroeconomic outputs that can be generated by the model are outlined in Table 2-8 below.

Table 2-8. Land use changes and macroeconomic outputs

Metrics	Outputs
Land	– Land rental price changes (value-weighted averages of the four land categories). – Sqkm of land allocated to Residential, Commercial, Industrial, Rural categories.

	– Sqkm of land used for Housing (Residential land because of mixed uses). – Change in effective residential density.
Employment	– Average wage rates by place of work or by place of residence (person or wage weights). – Jobs and output prices and quantity indices by ANZSIC Division (Place of Work). – Jobs by Occupation or by Skill/Collar (Place of Work and Residence), – Resident workers, Retired age population, Total population (Place of Residence). – Change in effective job density.
Prices	– Local CPI - Prices are not reported in levels.
Gross State Product (GSP)	– The relative contributions of land, labour and capital to changes in GSP, and a breakdown by industry. – Average (value-weighted) change in productivity.

Project Assessment and Scenario Testing

3. Project Assessment and Scenario Testing

In general, land use and transport interaction models can be used to examine the magnitude and distribution of both direct and wider economic impacts of land use and transport investments, and can estimate variations in the location of population and employment in an urban system impacted by any transport infrastructure-related changes. The VLUTI model developed by Infrastructure Victoria is an innovative tool able to assess land use changes, transport sector network performance and broader economic impacts derived from major transport infrastructure interventions and reforms. Using the VLUTI model for assessing short, medium, and long-term land use and transport infrastructure implications of any given transport infrastructure interventions requires both a preparation and a scenario testing phase. The following two subsections provide details of both the preparation and scenario testing phases.

3.1 Preparation

The calibration of the SIRCV model and the generation of inputs for future year baselines (2036 or 2051) are the two distinct tasks in the preparation phase. This phase begins with the generation of a calibrated SIRCV model using a combination of current year (2018) observed demographic data and modelled GTCs (described in section 2.4).

The generation of future year baseline inputs is a further key phase in the preparation stage. When testing the future years of 2036 and 2051, the initial assumptions surrounding both demography and the economy must be generated. These values are taken from the SALUP datasets. Expected changes in land allocation also act as an input to the SIRCV model.

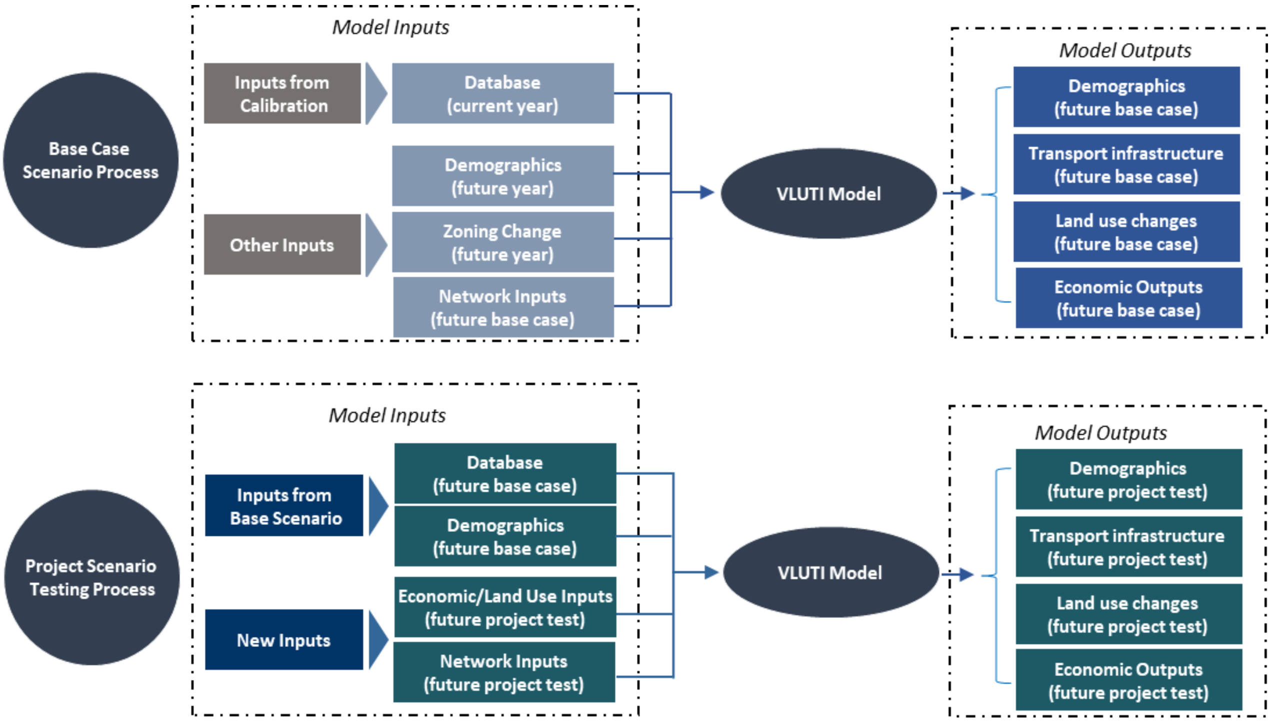
3.2 Scenario testing

For scenario testing, the VLUTI model utilises both inputs generated during the preparation phase, and external data and assumptions such as network assumptions and new zoning policies. There are two distinct tasks within scenario testing:

- *Base case* - refers to generating a baseline future year scenario against which the outcomes of all corresponding project tests will be compared.
- *Project testing* - refers to a future year scenario that, when compared against the corresponding base case, incorporates some combination of infrastructure and policy intervention being assessed.

Both base case and project scenario testing processes are shown in Figure 3-1.

Figure 3-1. Base and Project scenario testing processes



3.3 Potential VLUTI model applications

The VLUTI model provides the basis to explore a wide range of policy issues. Potential questions include:

- *Land-use, economic and infrastructure implications of behaviour changes* – such as examining the economic, spatial and infrastructure impacts of behaviour changes associated with the COVID-19 pandemic including increased Working from Home (WFH) or changes in transport mode preferences (shift to private motor vehicle travel and active transport) .
- *Land-use change and economic implications from infrastructure enhancement* – such as understanding the city shaping and land use change potential and wider economic impacts of major transport infrastructure programs such as the Melbourne Metro Two and Direct Geelong Rail Line project[28] (linking the Mernda and Werribee rail lines).
- *Land-use change implications from policy reform* – such as understanding city shaping and land use change implications of policy reform from land use or zoning policy changes, for example, enabling increased density in locations with good public transport infrastructure, and land tax reforms.

Each of the above example applications have been used as part of the Major Transport Program Strategic Assessment undertaken to support the development of *Victoria's infrastructure strategy* (see the Infrastructure Victoria Major Transport Program Strategic Assessment Report and the Arup Strategic Modelling Outcomes Report[29]).

[28] The Melbourne Metro Two and Direct Geelong Rail Line project includes the construction of a new rail tunnel connecting Newport to Clifton Hill, to support additional train services on Hurstbridge, Mernda, and Werribee/Williamstown services and support direct electrified train services to Geelong. This project was one of the projects assessed in the major transport program strategic assessment undertaken to inform Victoria's infrastructure strategy.

[29] Both reports are available from www.infrastructurevictoria.com.au

VLUTI Model Strengths and Limitations

4. VLUTI Model Strengths and Limitations

The key features of the VLUTI model and how transport and land use interact within the VLUTI framework were discussed in the previous sections of this report. The VLUTI model is a spatially disaggregated model incorporating many individual zones. Within the VLUTI framework, the location of population and jobs respond to changes in transport conditions, while transport, including the main traveller flows between the different zones, responds to changes in land use conditions.

This section discusses the main strengths and limitations of the current version of the VLUTI model.

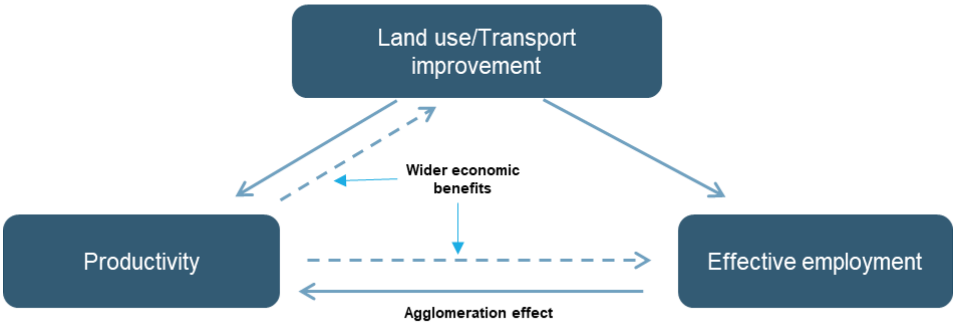
4.1 Strengths of the VLUTI model

The VLUTI uses two existing models: the SIRCV model (an SCGE model) and VITM. VITM is well established and accepted by key government agencies such as DTF, DoT and DJPR as a tool to assess transport infrastructure projects. The SIRCV model was developed by the Centre for Policy Studies (CoPS) at Victoria University who are well regarded in the development of CGE and SCGE models.

The SCGE modelling approach can be seen as an evolution of the modelling method of comparative static CGE models that are well-established tools for estimating the wider economic impacts of policy changes. SCGE models use utility and production functions with substitution between inputs, while also allowing for both the geographical distribution and overall level of activity to be influenced by spatial policies and changes in transport costs. SCGE models are considered by many to provide the most comprehensive framework for modelling the local or regional impacts of an intervention in the infrastructure and transport sector (Robson et al (2018), Bröcker (2004), Tavasszy et al (2011), Koike et al (2009), Hansen and Johansen (2017), Oosterhaven and Knaap (2017), Lennox and Sheard (2019), Chen (2019)).

The VLUTI modelling framework is a powerful tool to develop land use and transport infrastructure related scenarios. The model can provide valuable insights into the economic impacts of transport infrastructure proposals – particularly at the regional and subregional level (e.g. SA2 and LGA). The model can be used to assess different types of transport infrastructure investments (such as significant improvements in public transport services or major new road and rail infrastructure) and captures potential land use changes, broad level traffic and travel patterns and changes, and both direct productivity and wider economic impacts. The land use component within the VLUTI framework is an appropriate tool to build the long-term relationship between transport, agglomeration and productivity (as shown in Figure 4-1).

Figure 4-1. Wider Economic Impacts – Agglomeration effects



The VLUTI model comprises both an economic model (that incorporates land use) and a transport model integrated and run together to a convergence. The integrated model provides a better understanding of transport and land use interactions for the purpose of developing policies and therefore, provides more insight to policy makers. Another strength of the VLUTI model is its capability to represent internally consistent visions of the future, or different scenarios. The use of different scenarios helps the decision maker understand the factors that cause pressure for development or stress in the transport systems and how these relate.

The model provides an explanation of the counterfactual - how a transport infrastructure intervention affects the labour supply and consequently how this contributes to higher levels of productivity and economic growth. Another positive is that the VLUTI model can be employed to strategically assess planning policies such as broad land use allocations and the general impacts of land use decisions on transportation. The model allows for both the geographical distribution and overall level of activity to be influenced by spatial policies and changes in transport costs. The model uses existing and future population, and employment forecasts to predict future impacts of changes to the road and public transport networks.

The model is a multi-modal transport model that focuses on the motorised modes of car and public transport. The model is capable of generating daily road trips that can be used to capture the preferences of individuals regarding where they live and work, the associated daily activity travel patterns, and transport mode and route choice, given network performance and other factors.

The model can be used to support transport infrastructure Cost Benefit Assessments (CBAs), as it considers land use impacts as a result of infrastructure projects and models the future with and without infrastructure investment. While the model provides the impacts on key metrics (described in section 2.5), it also provides some social and environmental indicators from any given transport infrastructure scenario. The model can identify potential indirect impacts or disbenefits from infrastructure projects or policies (e.g. increased congestion resulting from induced demand or increases in local population).

4.2 Limitations of the VLUTI model

All models have limitations and constraints on appropriate application. Similar to other LUTI models, the VLUTI model developed by Infrastructure Victoria is complex. The theoretical structure of the SIRCV model is relatively simple and transparent: a small number of equations describe the choices and behaviour of households and the behaviour of firms. However, with many elements in each dimension — space, industries, occupations—there are millions of individual variables in the model. Moreover, all of these elements are tightly coupled through trade and travel flows, and industry and household demand functions.

The SIRCV model's outputs do not provide all the information required to create a demographic input dataset compatible with VITM. Therefore, some assumptions and processes need to be employed to generate VITM's input dataset from the database generated by the land use model.

Specialist expertise is required to prepare VLUTI for scenario testing and to interpret the results. Given the time required to solve each of the component models and the necessity of iterating between them, executing a scenario using the VLUTI model is computationally intensive and can take over a week, depending on the zoning system in the final VLUTI iteration. This makes it difficult to examine a large number of scenarios in a short period of time.

Furthermore, it is noted that the VLUTI model is a new development of an overall, unified approach to LUTI modelling. Increasing confidence in its outcomes and a deeper understanding of how to interpret its results will be gained incrementally with further use of the model across a diverse range of applications. Another constraint to a wider application of the VLUTI model is the level of resources and expertise required to use and maintain such a model.

The following subsections provide details regarding the main limitations of the two VLUTI model components – the SCGE (SIRCV) model and the transport (VITM) model.

4.2.1 SCGE model (SIRCV) limitations

In general, it is difficult to be precise around the SCGE (SIRCV) model limitations as these depend on what type of analysis is intended to be used. Key, general limitations of the SIRCV model include:

- *Input data and assumptions:*
  - Similar to other SCGE models, the SIRCV model tests changes compared to a baseline or base case. Baseline forecasts rely upon complex sets of input data and assumptions and are only an indication of scenarios that might plausibly transpire.
  - Very often, key modelling parameters will be difficult to estimate. Most SCGE models borrow elasticities from other sources. There is currently limited empirical evidence to support the value of these parameters. For this reason, it is useful to test how sensitive the model results are to key parameter changes.
- *Land use changes* - Land use changes and impacts can only be modelled at a point in time.
  - The current version of the model is comparative static, and there is no explicit treatment of time. Rather, the model compares one equilibrium state with another by applying a shock to the model and comparing the original economy with an alternative one. That is, the "changes" are between alternative future states under assessment relative to an assumed base case.

- Since we model discrete choices in a comparative static framework, every individual chooses their location in a given future scenario based on common information (price/price-like variables).[30]

- For an individual, there is no correlation between their current choices (e.g. where they live now) and their future choices. Nor is there an explicit account of demographic processes of ageing, deaths and births. Therefore, like any comparative static SCGE model, there is no way to correlate people's current location with their future locations in any scenario.

- Total population and total employment were held constant in the simulations. Thus, infrastructure and policy changes can only redistribute population and jobs within Victoria. This modelling assumption was made to remove complicating factors related to migration when testing different transport scenarios.

- Within the SIRCV model, firms do not explicitly choose their locations. Implicitly, the number and/or sizes of firms adjusts in response to demand for their outputs and supply of inputs such as useable land, labour, and intermediates. In reality, managers and directors of firms do make discrete choices regarding the location of new establishments and factors including scale economies constrain the range of viable sizes of individual establishments.

- Residential and commercial development densities are assumed to be smoothly adjustable in the model. This disregards the fact that buildings are very long-lived and existing structures are associated with significant "lock-in" effects. In reality, significantly increasing or reducing density in areas that are already developed usually requires demolishing existing buildings to construct new ones. This limitation is partly mitigated by the choice of multi-decadal time horizons for the simulations.

4.2.2 Transport model (VITM) limitations

Key limitations of the transport (VITM) module within the VLUTI model include:

- *Transport demand* - one of the general limitations of the transport (VITM) module within the VLUTI model is how demand is represented across zones. The model splits up Victoria into thousands of small regions, and this acts as the foundational basis for the simulation. This means there is a resolution limit to the level of detail which can sensibly be derived from model outcomes.

- *Land use forecasts* - land use forecasts directly affect the trip generation and distribution behaviour produced by the model. If the timing or intensity of demographic growth at a travel zone level differs from forecasts, travel behaviour will likely differ from modelled results.[31]

- *Future road and public transport* - assumptions around the timing of road and public transport projects will affect modelled mode share and route choice. These shift over time as government expectations around future investments evolve.

[30] *The SIRCV model also includes an uncorrelated random shock in the household utility function.*

[31] *One way to mitigate this limitation is through sensitivity tests that assess outcomes under different assumptions. For example, this was undertaken in the Major Transport Program Strategic Assessment with working from home and electric and autonomous vehicles modelling scenarios and population sensitivity tests of the economic analysis (see Major Transport Program Strategic Assessment Report available from www.infrastructurevictoria.com.au).*

- *Intersections not explicitly modelled:*
  - the model will not fully represent the impacts that significant capacity bottlenecks may cause over wider extents of the network. It also presents limitations in assessing projects that involve intersection improvements.
  - A key assumption inherent in the modelling approach is that upgrade projects will incorporate intersection improvements that are compatible with the changed traffic patterns in the project corridor.
- *Commercial vehicles:*
  - VITM contains a bespoke simulation of freight within its highway assignment process known as the Freight Movement Model (FMM). This component is computationally taxing, considering network performance, economic assumptions and several other factors to generate freight demand.
  - There are a series of additional factors that may impact the commercial vehicle demands that are ultimately realised. This includes considerations such as future land use patterns for commercial and industrial centres, changes to vehicle sizes and mass limits, and government policy in relation to these items.
- *Active transport:*
  - VITM is focusing on motorised transport and, whilst it considers active transport trips, it does not explicitly model them.
- *Not agent or activity based:*
  - VITM is not an agent-based model nor is it activity-based. This limits its ability to link individual's activities and travel patterns throughout the day and to incorporate individual household and person-level attributes in travel behaviour. For this reason, Infrastructure Victoria has separately collaborated closely with KPMG and Arup to develop the Melbourne Activity and Agent Based Model (MABM). The MABM is an additional strategic modelling tool to test the impacts of transport policy and projects, specifically looking at the behaviour of travellers. The MABM is capable of simulating the plans of individual 'agents' as they make trip choices throughout the day. Analysis using the MABM can also use the agent-based structure to make assertions on how different demographic groups across age, income and household composition respond to different modelled policy interventions. Previous work by IV utilising the MABM includes research on road pricing, parking and public transport fares[32].

[32] *See Good Move: Fixing Transport Congestion and Fair Move: Better Public Transport Fares for Melbourne both available from www.infrastructurevictoria.com.au.*

Evolution of the VLUTI model

5. Evolution of the VLUTI model

5.1 Developments to date

Earlier versions

Infrastructure Victoria has previously developed two VLUTI model versions in May 2019 and February 2020. The 2019 version of the model used VITM as the transport module with the "VU Cities – Victoria" (VU Cities) model as the SCGE module. In this version, the SCGE and transport modules were not yet integrated, and the two models operated separately. This version of the VLUTI model was calibrated to directly match Infrastructure Victoria's 2051 network development scenario. The spatial resolution of the 2019 version was ABS SA2 level in metropolitan Victoria and Geelong, Ballarat, Bendigo, and Latrobe Valley and SA4 level for the remainder of regional Victoria.

The 2019 version of the model utilised economic parameters and state level data for Victoria sourced from the Victoria University Regional Model (VURM) database to define production technologies and consumption preferences. The VURM database is itself derived from an SA3 level database associated with the VU-TERM model (Horridge, Madden, and Wittwer, 2005), compiled from various datasets produced by the ABS, including the Australian supply and use tables and national and state accounts. These datasets were supplemented by 2016 Census data to further disaggregate SALUP data by skill or industry. The economic database was projected to reflect employment and productivity growth between 2016 and 2051; the former as specified in the SALUP.

The 2019 version used travel costs reflecting VITM's 2051 network development scenario in the form of travel disutilities. The same disutility function was applied in the network development scenario and in policy cases. Semi-elasticities of commuting probabilities to these commuting disutility values were estimated by CoPS for each skill/collar type and applied in the model.

Land resources in the 2019 version of the model were classified into eight broad classes of Rural, Industrial, Special Jobs Zonings (e.g. hospitals, prisons), Commercial, Permissive Mixed Use, Permissive Residential, Restrictive Residential, and Rural Residential, based on Victorian planning zones. The Rural, Industrial, Commercial and Permissive Mixed Use classes are self-explanatory in terms of similarly named classes under Victorian planning laws. Residential zonings are assigned to one of three classes. Permissive Residential concords with the General Residential zoning and similar zonings that were judged to constrain densities only moderately. Restrictive Residential concords with Neighbourhood Residential and similar zonings that place more severe limitations on increased density. Rural residential concords with types requiring large minimum block sizes in peri-urban and some other areas. The Special Jobs Zonings generally relate to zonings for public uses such as hospitals and prisons.

The February 2020 version of the model integrated the VU Cities model (as the SCGE module) with a simplified version of the transport model (Rapid VITM). The February 2020 version differed in two respects. Firstly, it used a November 2019 version of the VU Cities model to consider two additional travel purposes (business travel, tourism) to the two original travel purposes (commuting, consumption trips). Consumption trips are broadly defined to include trips for the purposes of healthcare or education. Secondly, a different approach was taken to calibration and reference scenario development, in part to permit a full coupling of VU Cities with Rapid VITM.

The spatial resolution of the February 2020 version of the VU Cities model was at ABS SA2 level throughout Victoria. Enhanced spatial resolution in regional Victoria facilitated linking of VU Cities with Rapid VITM. The February 2020 version was designed to directly match:

1. SALUP 2018 historic case,
2. Travel costs derived from VITM 2018 reference case, and
3. Current Victorian land use planning maps (with minor adjustments) identical to those used in the May 2019 calibration.

In the February 2020 version, generalised travel costs were developed directly by Arup/AECOM. Arup/AECOM considered this a more theoretically consistent way to aggregate the individual cost components (e.g. for different transport modes) generated by VITM. The more important point in practice is that these values could be interpreted as the actual travel costs characterising the Victorian transport system in 2018.

The main difficulty with the February 2020 calibration concerned the classification of land and its assignment to different economic activities. This version of the model reused the 2051 network development scenario land classification. While this was based on current land use plans, with only very minor adjustments, it was not reflective of current land uses in some areas. Notably, land areas classified as residential in Melbourne's suburban growth areas are much larger than the actual areas of residential use as of 2018. That is, much of the permissible housing is (or was) yet to be built. The main consequence of this choice for model calibration is that unrealistically low densities of residential development imply unrealistically low housing prices. Importantly, this implies unrealistically low levels of calibrated residential amenity. Consequently, in simulating a future reference case, fewer residents will choose to live in these areas than is likely to be realistic. This difficulty was addressed through the November 2020 (or current) version of VLUTI (also see Appendix B).

Current version

In November 2020, Infrastructure Victoria collaborated closely with VU and developed an updated version of the SCGE model - SIRCV (described in section 2.3). The current version of the model yields results that are reflective of current land uses in different areas, particularly in Melbourne's suburban growth areas.[33] The SIRCV model is an enhanced model to VU's previous SCGE model, VU Cities, and has been used for Infrastructure Victoria's transport program modelling that underpins *Victoria's infrastructure strategy*. Compared with earlier versions, the following enhancements are introduced in the SIRCV model:

- Up to 43 occupations (ANZSCO 2 digit),
- Discrete choices of residence, workplace and occupation,
- 100 industries plus housing (based on ABS Input-Output Industry Groups),
- All goods are tradable with freight costs,
- Household consumption of goods is routed via retailer locations,
- All services are tradeable with businesses travel costs for firms or with shopping travel costs for households,
- Flexible SA2-based geography so that versions of SIRCA, the Australia-wide model, can be relatively easily developed for individual or multiple States and Territories.
- There are external zones that play much the same role as the external zones do in VITM.
- Simplified land resources based on ABS mesh blocks grouped as: Rural, Industrial, Commercial (including healthcare and education) and Residential.
- Corresponding sets of composite transport costs for private travel and freight.

The current version of the model can solve in 15-60 minutes depending on computer hardware and required solution accuracy. This speed partly reflects changes to the structure, but also adoption of an iterative solution method, which appears to be much faster for this type of model than solving the non-linear system of equations.

5.2 Potential future improvements

Similar to most, if not all LUTI models, the VLUTI model is still developing. Future improvements to the SCGE model could be supported on the grounds that this provides estimates of the impact of a transport infrastructure scheme throughout the whole economy as firms, consumers and government respond to the whole range of changes in prices and quantities of goods, services and land availability and in the location of producers and households following the implementation of a transport infrastructure scheme or policy intervention.

The long execution time, the huge data requirement, and uncertainties with respect to model outputs have been recognised as main challenges involved in developing and running such disaggregate modelling approaches. Uncertainties about the VLUTI model outputs can result from model misspecification and imperfect input information. Despite the growing improvement in the model for handling uncertainty, the outputs from the model are affected by variations in inputs and parameters. Therefore, it is essential that future improvements focus on, among other things,

[33] *See Appendix B for details on the calibration of the current version of the VLUTI model.*

understanding the growth in predicting uncertainties over time toward a principled way of addressing the problem of uncertainty.

The SIRCV model component of the VLUTI model distinguishes two types of households: working and non-working. Working households are modelled as choosing their occupation, locations to reside and to work, and expenditures on goods and services that maximise their utility (as described in section 2.2.2). However, the model gives no insight into how transport infrastructure investments and land use changes in the economy of regions affect the growth rates of the skill groups that supply each occupation. Therefore, it is desirable to represent multiple skill groups, which would affect occupational choice in the VLUTI model, to evaluate the impact of any transport policy simulations on the growth rates of the skill groups.

In general, key modelling parameters and elasticity values have considerable potential to affect simulation results. Most SCGE models borrow modelling parameters and elasticities from other sources and there is limited evidence to support these. One area for improvement would therefore be to econometrically estimate key parameters for Australia, or even more specifically, Victoria. It is noted that this would likely require the use of unit record statistical or administrative data including SA2 level locational information, access to which is typically heavily restricted.

Another potential future improvement to the VLUTI model could be integrating some behavioural and decision-making components into the VLUTI modelling framework to better understand the behaviour of individuals and different types of households. This includes, but is not limited to, the activity and vehicle allocation behaviour among members of households, the impacts of children and other mobility dependent individuals on adults' activity-travel scheduling and implementation behaviour, and the appropriate timeframe for different types of activities.

Another potential future improvement to the VLUTI model is to convert the software of the SIRCV model to the same software as VITM, i.e. Cube/Voyager. This would provide benefits including:

- Removal of interface programs before and after a SCGE run, hence removal of potential errors due to the interface programs, and speeding up the model run time
- True integration of SIRCV and VITM. This would improve internal consistency, and could remove duplicated processes
- SIRCV becomes transparent and user friendly and could be audited and improved by other agencies.

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Appendix

Appendix A The Structure of SCGE Models

A.1. Background

Analysing and forecasting the major impacts of government policies, such as transport infrastructure schemes, on different socio-economic actors in an economy can be done by applying different modelling approaches. It may be appropriate to use a partial equilibrium framework (i.e. econometric techniques) when the government policy being considered is expected to have relatively small effects on the economy with limited intersectoral repercussions. However, the increasing trade-off between economic sectors, consumers, producers and government has been a cause for concern for inadequacy and inefficiency of partial equilibrium methods. Partial equilibrium methods fail not only to analyse interactions among a number of different markets at the same time, but also fail to answer many questions of economic policy once large policy changes are considered. Therefore, there has been a growing need for a reliable method of assessment to study the socio-economic consequences of major policy changes.

General equilibrium methodology provides an appropriate tool for studying socio-economic issues by concentrating on the whole socio-economic system. General equilibrium analysis attempts to analyse the economy as a system of mutually dependent markets. Once a government's economic policy is implemented in order to accomplish an economic objective, many socio-economic variables other than those directly targeted are likely to be affected. Therefore, the economic results can be different from the direct economic predictions of partial equilibrium techniques and the objective of economic policy.

For the sake of completeness, this Appendix begins with the basic theoretical starting point of CGE modelling, which is the circular flow of goods, services and factors in an economy. This Appendix also provides the theoretical framework of the Spatial Computable General Equilibrium (SCGE) model.

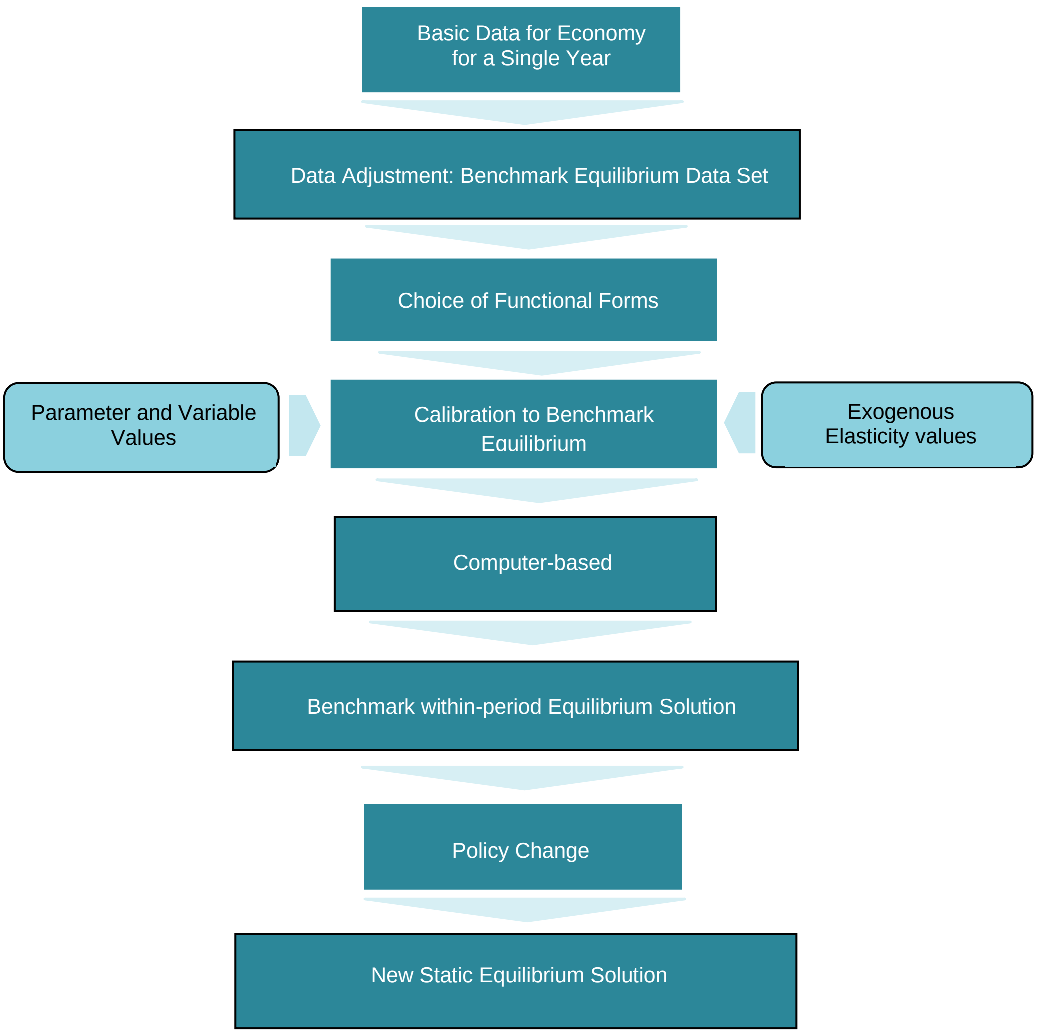
A.2. Computable General Equilibrium (CGE) Models

A CGE model designed for a single region or country encompasses a set of equations and parameters to portray the interrelationships between households, producers, the government, and the rest of the world. Households, on the one hand, are endowed with the factors of production are also the final consumers of produced commodities. On the other side of the model, firms provide goods and services for households, and intermediate inputs and trade, and also employ factors of production supplied by households. The government is assumed to collect taxes and uses these tax revenues to provide services to households. Domestic firms employ factor inputs, such as labour, capital services and natural resources owned by either households or the government, to produce goods and services for households.

CGE models give a complete description of the transactions of domestic households, producing sectors, government and the rest of the world. In general, CGE models incorporate the structural parameters including share parameters (i.e. consumer and government expenditure shares, import and export shares, intermediate input costs and average tax or subsidy rates), and elasticity parameters describing the behaviour of consumers, producers and trade patterns in the model, into the equations of the model. CGE modellers make use of additional data such as micro-survey data and other major statistics for a representative year. The mathematical structure of a CGE model implies that the number of simultaneous and nonlinear equations is balanced by the number of variables in the model. The choice of functional form of the equations in the general equilibrium model is influenced by the policy issue being addressed. The Leontief function, the Cobb-Douglas function, the Constant Elasticity of Substitution (CES) function, the Constant Elasticity of Transformation (CET) function and the Linear Expenditure System (LES) function are the familiar functional forms used to model both preferences of households and production technologies of firms in CGE models.

Figure A-1 presents the steps that need to be taken in CGE modelling. Having made the choice of functional forms as well as dimensions of the model, compilation of an appropriate data set and calibrating the selected functional forms to the initial equilibrium dataset are the crucial steps prior to moving to the implementation of policy change. Calibration refers to a standard process including estimating and adjusting the structural parameters of the model to fit the model to the benchmark dataset. Once the calibration process is done, CGE modellers use a base replication check in order to ensure consistency between the functional forms of the model and the benchmark data set. After this stage, the model is ready to analyse change in exogenous variables or parameters of the model and study a variety of policy scenarios.

Figure A-1. Flow chart outlining steps in CGE modelling



A.3. Spatial Computable General Equilibrium (SCGE) Models

The SCGE modelling approach can be seen as an evolution of the modelling method of CGE models. The spatial dimension is added to the CGE model by specifying locations in which consumption and production activities take place. This then introduces explicit transport costs between locations that will influence the locations of consumption and production. The SCGE modelling approach complements conventional multiregional CGE modelling approaches, such as that of VU-TERM (Horridge, Madden, and Wittwer, 2005). These models use utility and production functions with substitution between inputs, while also allowing for both the geographical distribution and overall level of activity to be influenced by spatial policies and changes in transport costs. SCGE models typically focus on commuting and residence and workplace location choices, with extensions to other travel purposes (e.g. shopping).

The main purpose of developing a SCGE model for a region is to allow quantitative modelling of the long-run regional macroeconomic and spatial impacts of policies and infrastructure investments in order to capture both direct and flow-on impacts of costs of private and business travel within and between urban areas as well as urban land allocation. These models can combine generalised travel costs (GTCs) with demographic and land use datasets to predict the resulting distribution of employment throughout the state. SCGE models are considered to provide the most comprehensive framework for modelling the local or regional impacts of an intervention in the infrastructure and transport sector.

In Victoria, Infrastructure Victoria has collaborated closely with VU to develop a SCGE model of Victoria's economy. This multi-sectoral model has been set up to analyse the impacts of spatial policies such as land use changes and transport schemes on the Victorian economy at the sub-regional level. The SCGE model can be used to test policy impacts, similar to most CGE models, however, with an added spatial and land-use dimension. The latest version of VU's spatial economy model, called the Spatial Interactions within and between Regions and Cities in Victoria (SIRCV) model is being used for modelling to inform *Victoria's infrastructure strategy.*

Appendix B Calibration of the SIRCV model and preparation of baselines

B.1 Calibration of the SIRCV model for the November 2020 version of VLUTI

Earlier versions of VLUTI had identified a number of opportunities to refine the model (see Section 5). In particular, opportunities to improve how existing land use policies were reflected and the scale of forecast population growth in Melbourne's growth areas were identified from the February 2020 version of VLUTI results.

To support the modelling used for the major transport program strategic assessment associated with *Victoria's infrastructure strategy*, changes to the SIRCV inputs and operation were made.

Land categorisation and allocation in SIRCV

The SIRCV model distinguishes four major categories of land: Residential, Rural, Commercial and Industrial. In the SIRCV 2018 database, land resources were initially classified into these four broad classes based mainly on ABS data, with supplemental use of Victorian planning data and satellite imagery.

In the model, land in each of these categories is endogenously allocated amongst relevant competing uses (e.g. commercial and residential). These allocations respond endogenously to competing demands. Furthermore, land areas are endogenously converted between these categories in response to changes in relative rental rates.

Rural land can be converted to Industrial or to (non-Industrial) Urban[34] categories. Such conversions from the Rural land category are modelled as being irreversible (see section 2.2.3). However, Urban land is allocated between the Commercial and Residential categories in a manner that is assumed to be reversible. While SIRCV is not a dynamic model, the concept of irreversibility/reversibility here does relate to the evolution of land allocations over time. For example, land that is Residential in 2018 cannot revert to being Rural in 2036, but could become Commercial land.

All changes in land allocation are responsive to changes in relative land rental prices. Firstly, conversion out of the Rural category increases as land rental prices increase in non-Rural uses relative to Rural uses, and decrease as the remaining quantity of unreserved Rural land goes to zero. Secondly, the share of newly converted land added to the Industrial or Urban categories depends on relative rental prices in these two categories. Thirdly and finally, the share of all Urban land allocated to the Residential versus the Commercial category depends on relative rental prices in those two categories.

[34] *The non-Industrial Urban category subsumes the more specific categories of Commercial and Residential.*

To illustrate this, suppose that the rental price of Residential land in a peri-urban SA2 increased relative to rental prices of Rural, Industrial and Commercial land because housing demand grew more strongly than demand for other types of land use. This would have several consequences:

1. Land would be converted from Rural to non-Rural
2. The ratio of converted land allocated to Urban, relative to that allocated to Industrial, would be higher than the same ratio for the prior land allocation.
3. Of the total new area of Urban land, the share allocated to Residential would be higher than the same share for the prior land allocation.

Restricting residential development in sensitive peri-urban areas

In the February 2020 version of the VLUTI model, rural land was being converted to residential land in sensitive peri-urban areas (i.e. urban development was occurring in these sensitive areas). This development would not be allowed under current planning policy due to the environmental and agricultural impacts. The following SA2s were identified as presenting modelling issues in this regard:

- Yarra Valley
- Koo Wee Rup
- Dandenong Ranges
- Plenty-Yarrambat
- Pt Nepean
- Somerville
- Torquay

Urban Growth Boundary (UGB)

The Urban Growth Boundary (UGB) around Melbourne was established to better manage outward expansion in a coordinated manner.[35] Its purpose is to direct urban growth to areas best able to be supplied with appropriate infrastructure and services and protect other valuable peri-urban land (and environmental features) from urban development pressures.

The UGB is defined using different boundaries to SA2s, which are the spatial unit used in SIRCV and there are SA2s that straddle the UGB. In the February 2020 version of the VLUTI model, some SA2s straddling the UGB had substantially more rural land converted to residential land than the amount of land that fell within the UGB in that SA2. That is, there were large residential population increases occurring on land outside the UGB.

Implementation of land conversion constraints

To better reflect the UGB policy articulated in *Plan Melbourne*, constraints on land use conversion were implemented within SIRCV. Of the 458 SIRCV SA2s, there are 120 SA2s in which a specified area of rural land is reserved and cannot be converted to urban or industrial uses, or in which rural to urban conversions are precluded altogether (see Table B-1). In addition, there are many SA2s, particularly in metropolitan Melbourne, in which there is no rural land area and land areas deemed

[35] The current UGB was reaffirmed as the outer limit for growth in Plan Melbourne 2017-2050 at Policy 2.1.1.

‘environmental’, ‘natural’, etc. are not represented in SIRCV at all. The rural areas that are reserved are estimated by overlaying and intersecting UGB-protected areas on the Mesh Block layer that was originally used in constructing the SIRCV land areas database. As explained above, within SIRCV, rural to urban conversion is driven by the price ratio of urban to rural use and by the area of rural land remaining. Reserved rural land is not included in the area of land remaining used in the conversion calculation. Thus, the rental price differential required to convert each additional hectare becomes increasingly large, as the area of unreserved Rural land goes to zero. Some such land will therefore always remain, and the total Rural land area will always exceed the reserved Rural land area.

Table B-1 SA2s with a rural land conversion constraint

SA2 Code	SA2 Name	Corresponding SA3	Corresponding SA4
201021009	Bacchus Marsh Region	Creswick - Daylesford - Ballan	Ballarat
202021028	Castlemaine Region	Heathcote - Castlemaine - Kyneton	Bendigo
202021029	Heathcote	Heathcote - Castlemaine - Kyneton	Bendigo
202021030	Kyneton	Heathcote - Castlemaine - Kyneton	Bendigo
203021043	Lara	Geelong	Geelong
203031053	Torquay	Surf Coast - Bellarine Peninsula	Geelong
204011055	Euroa	Upper Goulburn Valley	Hume
204011056	Kilmore - Broadford	Upper Goulburn Valley	Hume
204011058	Nagambie	Upper Goulburn Valley	Hume
204011059	Seymour	Upper Goulburn Valley	Hume
204011060	Seymour Region	Upper Goulburn Valley	Hume
204011061	Upper Yarra Valley	Upper Goulburn Valley	Hume
204011062	Yea	Upper Goulburn Valley	Hume
205011076	Drouin	Baw Baw	Latrobe - Gippsland
205031089	Korumburra	Gippsland - South West	Latrobe - Gippsland
205031093	Wonthaggi - Inverloch	Gippsland - South West	Latrobe - Gippsland
208021427	Bentleigh East (South)	Glen Eira	Melbourne - Inner South
208031183	Aspendale Gardens - Waterways	Kingston	Melbourne - Inner South
208031184	Braeside	Kingston	Melbourne - Inner South
208031185	Carrum - Patterson Lakes	Kingston	Melbourne - Inner South
208031187	Chelsea Heights	Kingston	Melbourne - Inner South
208031188	Cheltenham - Highett (East)	Kingston	Melbourne - Inner South
208031190	Mentone	Kingston	Melbourne - Inner South
208031191	Moorabbin - Heatherton	Kingston	Melbourne - Inner South
208031192	Moorabbin Airport	Kingston	Melbourne - Inner South
208031193	Mordialloc - Parkdale	Kingston	Melbourne - Inner South
209031210	Hurstbridge	Nillumbik - Kinglake	Melbourne - North East
209031211	Kinglake	Nillumbik - Kinglake	Melbourne - North East
209031212	Panton Hill - St Andrews	Nillumbik - Kinglake	Melbourne - North East
209031213	Plenty - Yarrambat	Nillumbik - Kinglake	Melbourne - North East
209031214	Research - North Warrandyte	Nillumbik - Kinglake	Melbourne - North East
209031215	Wattle Glen - Diamond Creek	Nillumbik - Kinglake	Melbourne - North East
209041224	Wallan	Whittlesea - Wallan	Melbourne - North East
209041225	Whittlesea	Whittlesea - Wallan	Melbourne - North East
209041430	Doreen	Whittlesea - Wallan	Melbourne - North East
209041434	Mernda	Whittlesea - Wallan	Melbourne - North East
209041435	South Morang (North)	Whittlesea - Wallan	Melbourne - North East
209041437	Wollert	Whittlesea - Wallan	Melbourne - North East
210011228	Keilor	Keilor	Melbourne - North West
210021232	Gisborne	Macedon Ranges	Melbourne - North West
210021234	Riddells Creek	Macedon Ranges	Melbourne - North West
210021235	Romsey	Macedon Ranges	Melbourne - North West
210041240	Sunbury	Sunbury	Melbourne - North West
210041241	Sunbury - South	Sunbury	Melbourne - North West
210051245	Gladstone Park - Westmeadows	Tullamarine - Broadmeadows	Melbourne - North West
210051246	Greenvale - Bulla	Tullamarine - Broadmeadows	Melbourne - North West
210051248	Melbourne Airport	Tullamarine - Broadmeadows	Melbourne - North West

SA2 Code	SA2 Name	Corresponding SA3	Corresponding SA4
210051445	Mickleham - Yuroke	Tullamarine - Broadmeadows	Melbourne - North West
211011255	Lysterfield	Knox	Melbourne - Outer East
211011258	Rowville - South	Knox	Melbourne - Outer East
211011448	Ferntree Gully (South) - Upper Ferntree Gully	Knox	Melbourne - Outer East
211011449	The Basin	Knox	Melbourne - Outer East
211021261	Donvale - Park Orchards	Manningham - East	Melbourne - Outer East
211021262	Warrandyte - Wonga Park	Manningham - East	Melbourne - Outer East
211051274	Belgrave - Selby	Yarra Ranges	Melbourne - Outer East
211051275	Chirnside Park	Yarra Ranges	Melbourne - Outer East
211051276	Healesville - Yarra Glen	Yarra Ranges	Melbourne - Outer East
211051277	Kilsyth	Yarra Ranges	Melbourne - Outer East
211051278	Lilydale - Coldstream	Yarra Ranges	Melbourne - Outer East
211051279	Monbulk - Silvan	Yarra Ranges	Melbourne - Outer East
211051280	Montrose	Yarra Ranges	Melbourne - Outer East
211051281	Mooroolbark	Yarra Ranges	Melbourne - Outer East
211051282	Mount Dandenong - Olinda	Yarra Ranges	Melbourne - Outer East
211051283	Mount Evelyn	Yarra Ranges	Melbourne - Outer East
211051284	Upwey - Tecoma	Yarra Ranges	Melbourne - Outer East
211051285	Wandin - Seville	Yarra Ranges	Melbourne - Outer East
211051286	Yarra Valley	Yarra Ranges	Melbourne - Outer East
212011287	Beaconsfield - Officer	Cardinia	Melbourne - South East
212011288	Bunyip - Garfield	Cardinia	Melbourne - South East
212011289	Emerald - Cockatoo	Cardinia	Melbourne - South East
212011290	Koo Wee Rup	Cardinia	Melbourne - South East
212011291	Pakenham - North	Cardinia	Melbourne - South East
212011292	Pakenham - South	Cardinia	Melbourne - South East
212021293	Berwick - North	Casey - North	Melbourne - South East
212021295	Doveton	Casey - North	Melbourne - South East
212021299	Narre Warren North	Casey - North	Melbourne - South East
212021453	Endeavour Hills - North	Casey - North	Melbourne - South East
212021454	Endeavour Hills - South	Casey - North	Melbourne - South East
212031301	Cranbourne East	Casey - South	Melbourne - South East
212031303	Cranbourne South	Casey - South	Melbourne - South East
212031304	Cranbourne West	Casey - South	Melbourne - South East
212031308	Pearcedale - Tooradin	Casey - South	Melbourne - South East
212041309	Clarinda - Oakleigh South	Dandenong	Melbourne - South East
212041310	Clayton South	Dandenong	Melbourne - South East
212041311	Dandenong	Dandenong	Melbourne - South East
212041312	Dandenong North	Dandenong	Melbourne - South East
212041313	Dingley Village	Dandenong	Melbourne - South East
212041314	Keysborough	Dandenong	Melbourne - South East
212041318	Springvale South	Dandenong	Melbourne - South East
213011340	Taylors Lakes	Brimbank	Melbourne - West
213021341	Altona	Hobsons Bay	Melbourne - West
213021342	Altona Meadows	Hobsons Bay	Melbourne - West
213041353	Bacchus Marsh	Melton - Bacchus Marsh	Melbourne - West
213041355	Hillside	Melton - Bacchus Marsh	Melbourne - West
213041356	Melton	Melton - Bacchus Marsh	Melbourne - West
213041357	Melton South	Melton - Bacchus Marsh	Melbourne - West
213041358	Melton West	Melton - Bacchus Marsh	Melbourne - West
213041359	Rockbank - Mount Cottrell	Melton - Bacchus Marsh	Melbourne - West
213051365	Tarneit	Wyndham	Melbourne - West
213051368	Werribee - South	Wyndham	Melbourne - West
213051369	Wyndham Vale	Wyndham	Melbourne - West
213051464	Point Cook - East	Wyndham	Melbourne - West
213051466	Point Cook - South	Wyndham	Melbourne - West
213051468	Werribee - West	Wyndham	Melbourne - West
214011370	Carrum Downs	Frankston	Mornington Peninsula
214011371	Frankston	Frankston	Mornington Peninsula
214011372	Frankston North	Frankston	Mornington Peninsula
214011373	Frankston South	Frankston	Mornington Peninsula
214011374	Langwarrin	Frankston	Mornington Peninsula

SA2 Code	SA2 Name	Corresponding SA3	Corresponding SA4
214011375	Seaford (Vic.)	Frankston	Mornington Peninsula
214011376	Skye - Sandhurst	Frankston	Mornington Peninsula
214021377	Dromana	Mornington Peninsula	Mornington Peninsula
214021378	Flinders	Mornington Peninsula	Mornington Peninsula
214021379	Hastings - Somers	Mornington Peninsula	Mornington Peninsula
214021380	Mornington	Mornington Peninsula	Mornington Peninsula
214021381	Mount Eliza	Mornington Peninsula	Mornington Peninsula
214021382	Mount Martha	Mornington Peninsula	Mornington Peninsula
214021383	Point Nepean	Mornington Peninsula	Mornington Peninsula
214021384	Rosebud - McCrae	Mornington Peninsula	Mornington Peninsula
214021385	Somerville	Mornington Peninsula	Mornington Peninsula

Industrial land conversion in urban renewal sites

As described above, Industrial land cannot be endogenously converted to Rural or non-industrial urban (i.e. Residential or Commercial) uses. This is because historic site contamination from industrial land uses is a major barrier to redevelopment due to the costs associated with remediation (see section 2.2.3). It also reflects strategic land use policy such as the Melbourne Industrial and Commercial Land Use Plan (MICLUP) which seeks to protect the supply of industrial land and minimise conflict with other sensitive uses, such as housing. However, Arden and Fishermans Bend are significant urban renewal precincts that will be redeveloped for future residential and commercial development on land that was previously used by heavy industry.

To reflect the future development of these precincts, the version of SIRCV used for *Victoria's infrastructure strategy* modelling was modified to allow Industrial land to be exogenously converted to non-industrial urban uses in the North Melbourne SA2, to reflect the Arden precinct, and in the Port Melbourne Industrial SA2, to reflect the Fishermans Bend precinct.

B.2 Preparation of baselines for the 2021 modelling program

A key step in preparing the VLUTI model is to establish a plausible baseline (or base case) from which to test the impact of infrastructure or policy proposals. SALUP were developed by SGS based on available data (including *Victoria in Future*)[36] and provide a plausible long-term forecast of the future distribution of people, households and jobs in Victoria.

To develop the base case for the 2021 VLUTI modelling program (referred to as the Network Development Scenario), the SALUP 2036 and 2051 forecasts were used to anchor inputs in the SIRCV calibration process. This was undertaken to ensure the base cases within VLUTI were plausible. Specifically, SA2 level amenity variables in SIRCV were adjusted to ensure SIRCV resident worker and retired age totals by SA2 matched the equivalent SALUP totals.[37] This process was applied to SIRCV in the initial calibration (or preparation) stage. Through the VLUTI modelling process, these population distributions were subsequently allowed to vary endogenously as the VLUTI model converged.

The resulting VLUTI demographic outputs were compared with SALUP to confirm plausible base cases had been established. Whilst there are differences between the VLUTI and SALUP

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[36] SGS Economics & Planning (2019).

[37] This process also used 2018 GTCs (generated by running the rapid VITM for 2018 using 2018 SALUP population, household and job distribution). 2018 GTCs were only used for the initial SIRCV calibration process. The subsequent VLUTI process to develop the 2036 and 2051 baselines used GTCs that were endogenously calculated.

demographic outputs, these were deemed acceptable given the inherent uncertainty associated with longer term forecasts. A comparison of SALUP and VLUTI results at the FUA level is provided in Table B-2 below. As shown, the distribution of jobs differs more significantly than population and households, as this variable was not targeted in the calibration process.

Table B-2 Comparison of VLUTI and SALUP future population, households and job distributions

Population	2036 SALUP millions	2051 SALUP million	2036 VLUTI NDS millions	2051 VLUTI NDS millions	Comparison VLUTI and SALUP 2036		Comparison VLUTI and SALUP 2051	
FUA	**8.863**	**10.838**	**8.863**	**10.838**	**0**	**0%**	**(0)**	**0%**
Inner Melbourne	1.299	1.607	1.351	1.676	51,559	4%	68,646	4%
Middle Melbourne	2.070	2.518	2.080	2.516	9,298	0%	(1,906)	0%
Outer Melbourne	2.406	2.753	2.367	2.716	(39,573)	-2%	(37,021)	-1%
Melbourne New Growth Areas	1.036	1.551	1.007	1.500	(29,408)	-3%	(50,291)	-3%
Regional Centres and Rural Areas	1.221	1.445	1.204	1.404	(17,057)	-1%	(40,798)	-3%
Regional City	0.830	0.964	0.855	1.026	25,181	3%	61,369	6%

Households	2036 SALUP millions	2051 SALUP millions	2036 VLUTI NDS millions	2051 VLUTI NDS millions	Comparison VLUTI and SALUP 2036		Comparison VLUTI and SALUP 2051	
FUA	**3.486**	**4.312**	**3.486**	**4.312**	**0**	**0%**	**0**	**0%**
Inner Melbourne	0.601	0.756	0.620	0.782	19,248	3%	26,708	4%
Middle Melbourne	0.793	0.975	0.796	0.973	2,472	0%	(1,889)	0%
Outer Melbourne	0.879	1.020	0.866	1.007	(13,411)	-2%	(12,636)	-1%
Melbourne New Growth Areas	0.342	0.534	0.331	0.514	(10,414)	-3%	(20,063)	-4%
Regional Centres and Rural Areas	0.518	0.609	0.512	0.598	(6,358)	-1%	(11,493)	-2%
Regional City	0.353	0.417	0.361	0.437	8,463	2%	19,372	5%

Note: The VLUTI results for the November 2020 version have an established:growth area ratio for new households of 63:37 (2036) and 65:35 (2051) compared to 61:39 (2036 SALUP) and 64:36 (2051 SALUP). Whereas the February 2020 version of VLUTI had 83:17 in 2051. Plan Melbourne includes a target of 70:30.

Jobs	2036 SALUP millions	2051 SALUP millions	2036 VLUTI NDS millions	2051 VLUTI NDS millions	Comparison VLUTI and SALUP 2036		Comparison VLUTI and SALUP 2051	
FUA	**4.553**	**5.549**	**4.553**	**5.549**	**(0)**	**0%**	**0**	**0%**
Inner Melbourne	1.387	1.680	1.362	1.627	(25,360)	-2%	(52,424)	-3%
Middle Melbourne	1.000	1.240	0.995	1.197	(5,760)	-1%	(43,134)	-3%
Outer Melbourne	1.080	1.313	1.088	1.373	7,765	1%	60,532	5%
Melbourne New Growth Areas	0.136	0.198	0.102	0.148	(34,172)	-25%	(49,626)	-25%
Regional Centres and Rural Areas	0.529	0.625	0.554	0.637	25,177	5%	12,464	2%
Regional City	0.420	0.493	0.453	0.565	32,351	8%	72,188	15%

Appendix C Lists of Regions, Industries and Occupations in the SIRCV Model

Table C-1 Regions in Victoria from Statistical Areas Level 2 to Level 4 (SA2, SA3, SA4)

SA4 Code	SA3 Code	SA2 Code	Area Type	Area Name
201	20101	201011001	SA2	Alfredton
201	20101	201011002	SA2	Ballarat
201	20101	201011003	SA2	Ballarat - North
201	20101	201011004	SA2	Ballarat - South
201	20101	201011005	SA2	Buninyong
201	20101	201011006	SA2	Delacombe
201	20101	201011007	SA2	Smythes Creek
201	20101	201011008	SA2	Wendouree - Miners Rest
201	20102	201021009	SA2	Bacchus Marsh Region
201	20102	201021010	SA2	Creswick - Clunes
201	20102	201021011	SA2	Daylesford
201	20102	201021012	SA2	Gordon (Vic.)
201	20103	201031013	SA2	Avoca
201	20103	201031014	SA2	Beaufort
201	20103	201031015	SA2	Golden Plains - North
201	20103	201031016	SA2	Maryborough (Vic.)
201	20103	201031017	SA2	Maryborough Region
202	20201	202011018	SA2	Bendigo
202	20201	202011019	SA2	California Gully - Eaglehawk
202	20201	202011020	SA2	East Bendigo - Kennington
202	20201	202011021	SA2	Flora Hill - Spring Gully
202	20201	202011022	SA2	Kangaroo Flat - Golden Square
202	20201	202011023	SA2	Maiden Gully
202	20201	202011024	SA2	Strathfieldsaye
202	20201	202011025	SA2	White Hills - Ascot
202	20202	202021026	SA2	Bendigo Region - South
202	20202	202021027	SA2	Castlemaine
202	20202	202021028	SA2	Castlemaine Region
202	20202	202021029	SA2	Heathcote
202	20202	202021030	SA2	Kyneton
202	20202	202021031	SA2	Woodend
202	20203	202031032	SA2	Bendigo Region - North
202	20203	202031033	SA2	Loddon
203	20301	203011034	SA2	Bannockburn
203	20301	203011035	SA2	Golden Plains - South
203	20301	203011036	SA2	Winchelsea
203	20302	203021037	SA2	Belmont
203	20302	203021038	SA2	Corio - Norlane
203	20302	203021039	SA2	Geelong
203	20302	203021040	SA2	Geelong West - Hamlyn Heights
203	20302	203021041	SA2	Grovedale
203	20302	203021042	SA2	Highton
203	20302	203021043	SA2	Lara
203	20302	203021044	SA2	Leopold
203	20302	203021045	SA2	Newcomb - Moolap
203	20302	203021046	SA2	Newtown (Vic.)
203	20302	203021047	SA2	North Geelong - Bell Park
203	20303	203031048	SA2	Clifton Springs
203	20303	203031049	SA2	Lorne - Anglesea
203	20303	203031050	SA2	Ocean Grove - Barwon Heads

SA4 Code	**SA3** Code	**SA2** Code	**Area Type**	**Area Name**
203	20303	203031051	SA2	Portarlington
203	20303	203031052	SA2	Point Lonsdale - Queenscliff
203	20303	203031053	SA2	Torquay
204	20401	204011054	SA2	Alexandra
204	20401	204011055	SA2	Euroa
204	20401	204011056	SA2	Kilmore - Broadford
204	20401	204011057	SA2	Mansfield (Vic.)
204	20401	204011058	SA2	Nagambie
204	20401	204011059	SA2	Seymour
204	20401	204011060	SA2	Seymour Region
204	20401	204011061	SA2	Upper Yarra Valley
204	20401	204011062	SA2	Yea
204	20402	204021063	SA2	Benalla
204	20402	204021064	SA2	Benalla Region
204	20402	204021065	SA2	Rutherglen
204	20402	204021066	SA2	Wangaratta
204	20402	204021067	SA2	Wangaratta Region
204	20403	204031068	SA2	Beechworth
204	20403	204031069	SA2	Bright - Mount Beauty
204	20403	204031070	SA2	Chiltern - Indigo Valley
204	20403	204031071	SA2	Myrtleford
204	20403	204031072	SA2	Towong
204	20403	204031073	SA2	West Wodonga
204	20403	204031074	SA2	Wodonga
204	20403	204031075	SA2	Yackandandah
205	20501	205011076	SA2	Drouin
205	20501	205011077	SA2	Mount Baw Baw Region
205	20501	205011078	SA2	Trafalgar (Vic.)
205	20501	205011079	SA2	Warragul
205	20502	205021080	SA2	Alps - East
205	20502	205021081	SA2	Bairnsdale
205	20502	205021082	SA2	Bruthen - Omeo
205	20502	205021083	SA2	Lake King
205	20502	205021084	SA2	Lakes Entrance
205	20502	205021085	SA2	Orbost
205	20502	205021086	SA2	Paynesville
205	20503	205031087	SA2	Foster
205	20503	205031088	SA2	French Island
205	20503	205031089	SA2	Korumburra
205	20503	205031090	SA2	Leongatha
205	20503	205031091	SA2	Phillip Island
205	20503	205031092	SA2	Wilsons Promontory
205	20503	205031093	SA2	Wonthaggi - Inverloch
205	20504	205041094	SA2	Churchill
205	20504	205041095	SA2	Moe - Newborough
205	20504	205041096	SA2	Morwell
205	20504	205041097	SA2	Traralgon
205	20504	205041098	SA2	Yallourn North - Glengarry
205	20505	205051099	SA2	Alps - West
205	20505	205051100	SA2	Longford - Loch Sport
205	20505	205051101	SA2	Maffra
205	20505	205051102	SA2	Rosedale
205	20505	205051103	SA2	Sale
205	20505	205051104	SA2	Yarram
206	20601	206011105	SA2	Brunswick
206	20601	206011106	SA2	Brunswick East
206	20601	206011107	SA2	Brunswick West
206	20601	206011108	SA2	Coburg
206	20601	206011109	SA2	Pascoe Vale South
206	20602	206021110	SA2	Alphington - Fairfield
206	20602	206021111	SA2	Northcote
206	20602	206021112	SA2	Thornbury
206	20603	206031113	SA2	Ascot Vale

SA4 Code	SA3 Code	SA2 Code	Area Type	Area Name
206	20603	206031114	SA2	Essendon - Aberfeldie
206	20603	206031115	SA2	Flemington
206	20603	206031116	SA2	Moonee Ponds
206	20604	206041117	SA2	Carlton
206	20604	206041118	SA2	Docklands
206	20604	206041119	SA2	East Melbourne
206	20604	206041120	SA2	Flemington Racecourse
206	20604	206041121	SA2	Kensington (Vic.)
206	20604	206041122	SA2	Melbourne
206	20604	206041123	SA2	North Melbourne
206	20604	206041124	SA2	Parkville
206	20604	206041125	SA2	South Yarra - West
206	20604	206041126	SA2	Southbank
206	20604	206041127	SA2	West Melbourne
206	20605	206051128	SA2	Albert Park
206	20605	206051129	SA2	Elwood
206	20605	206051130	SA2	Port Melbourne
206	20605	206051131	SA2	Port Melbourne Industrial
206	20605	206051132	SA2	South Melbourne
206	20605	206051133	SA2	St Kilda
206	20605	206051134	SA2	St Kilda East
206	20606	206061135	SA2	Armadale
206	20606	206061136	SA2	Prahran - Windsor
206	20606	206061137	SA2	South Yarra - East
206	20606	206061138	SA2	Toorak
206	20607	206071139	SA2	Abbotsford
206	20607	206071140	SA2	Carlton North - Princes Hill
206	20607	206071141	SA2	Collingwood
206	20607	206071142	SA2	Fitzroy
206	20607	206071143	SA2	Fitzroy North
206	20607	206071144	SA2	Richmond (Vic.)
206	20607	206071145	SA2	Yarra - North
207	20701	207011146	SA2	Ashburton (Vic.)
207	20701	207011147	SA2	Balwyn
207	20701	207011148	SA2	Balwyn North
207	20701	207011149	SA2	Camberwell
207	20701	207011150	SA2	Glen Iris - East
207	20701	207011151	SA2	Hawthorn
207	20701	207011152	SA2	Hawthorn East
207	20701	207011153	SA2	Kew
207	20701	207011154	SA2	Kew East
207	20701	207011155	SA2	Surrey Hills (West) - Canterbury
207	20702	207021156	SA2	Bulleen
207	20702	207021157	SA2	Doncaster
207	20702	207021159	SA2	Templestowe
207	20702	207021160	SA2	Templestowe Lower
207	20702	207021424	SA2	Doncaster East (North)
207	20702	207021425	SA2	Doncaster East (South)
207	20703	207031161	SA2	Blackburn
207	20703	207031162	SA2	Blackburn South
207	20703	207031163	SA2	Box Hill
207	20703	207031164	SA2	Box Hill North
207	20703	207031165	SA2	Burwood
207	20703	207031166	SA2	Burwood East
207	20703	207031167	SA2	Surrey Hills (East) - Mont Albert
208	20801	208011168	SA2	Beaumaris
208	20801	208011169	SA2	Brighton (Vic.)
208	20801	208011170	SA2	Brighton East
208	20801	208011171	SA2	Cheltenham - Highett (West)
208	20801	208011172	SA2	Hampton
208	20801	208011173	SA2	Sandringham - Black Rock
208	20802	208021174	SA2	Bentleigh - McKinnon
208	20802	208021176	SA2	Carnegie

SA4 Code	SA3 Code	SA2 Code	Area Type	Area Name
208	20802	208021177	SA2	Caulfield - North
208	20802	208021178	SA2	Caulfield - South
208	20802	208021179	SA2	Elsternwick
208	20802	208021180	SA2	Hughesdale
208	20802	208021181	SA2	Murrumbeena
208	20802	208021182	SA2	Ormond - Glen Huntly
208	20802	208021426	SA2	Bentleigh East (North)
208	20802	208021427	SA2	Bentleigh East (South)
208	20803	208031183	SA2	Aspendale Gardens - Waterways
208	20803	208031184	SA2	Braeside
208	20803	208031185	SA2	Carrum - Patterson Lakes
208	20803	208031186	SA2	Chelsea - Bonbeach
208	20803	208031187	SA2	Chelsea Heights
208	20803	208031188	SA2	Cheltenham - Highett (East)
208	20803	208031189	SA2	Edithvale - Aspendale
208	20803	208031190	SA2	Mentone
208	20803	208031191	SA2	Moorabbin - Heatherton
208	20803	208031192	SA2	Moorabbin Airport
208	20803	208031193	SA2	Mordialloc - Parkdale
208	20804	208041194	SA2	Malvern - Glen Iris
208	20804	208041195	SA2	Malvern East
209	20901	209011196	SA2	Bundoora - East
209	20901	209011197	SA2	Greensborough
209	20901	209011198	SA2	Heidelberg - Rosanna
209	20901	209011199	SA2	Heidelberg West
209	20901	209011200	SA2	Ivanhoe
209	20901	209011201	SA2	Ivanhoe East - Eaglemont
209	20901	209011202	SA2	Montmorency - Briar Hill
209	20901	209011203	SA2	Viewbank - Yallambie
209	20901	209011204	SA2	Watsonia
209	20902	209021205	SA2	Kingsbury
209	20902	209021207	SA2	Reservoir - East
209	20902	209021208	SA2	Reservoir - West
209	20902	209021428	SA2	Preston - East
209	20902	209021429	SA2	Preston - West
209	20903	209031209	SA2	Eltham
209	20903	209031210	SA2	Hurstbridge
209	20903	209031211	SA2	Kinglake
209	20903	209031212	SA2	Panton Hill - St Andrews
209	20903	209031213	SA2	Plenty - Yarrambat
209	20903	209031214	SA2	Research - North Warrandyte
209	20903	209031215	SA2	Wattle Glen - Diamond Creek
209	20904	209041216	SA2	Bundoora - North
209	20904	209041217	SA2	Bundoora - West
209	20904	209041219	SA2	Lalor
209	20904	209041220	SA2	Mill Park - North
209	20904	209041221	SA2	Mill Park - South
209	20904	209041223	SA2	Thomastown
209	20904	209041224	SA2	Wallan
209	20904	209041225	SA2	Whittlesea
209	20904	209041430	SA2	Doreen
209	20904	209041431	SA2	Epping - East
209	20904	209041432	SA2	Epping - South
209	20904	209041433	SA2	Epping - West
209	20904	209041434	SA2	Mernda
209	20904	209041435	SA2	South Morang (North)
209	20904	209041436	SA2	South Morang (South)
209	20904	209041437	SA2	Wollert
210	21001	210011226	SA2	Airport West
210	21001	210011227	SA2	Essendon Airport
210	21001	210011228	SA2	Keilor
210	21001	210011229	SA2	Keilor East
210	21001	210011230	SA2	Niddrie - Essendon West

SA4 Code	**SA3** Code	**SA2** Code	**Area Type**	**Area Name**
210	21001	210011231	SA2	Strathmore
210	21002	210021232	SA2	Gisborne
210	21002	210021233	SA2	Macedon
210	21002	210021234	SA2	Riddells Creek
210	21002	210021235	SA2	Romsey
210	21003	210031236	SA2	Coburg North
210	21003	210031237	SA2	Fawkner
210	21003	210031239	SA2	Pascoe Vale
210	21003	210031438	SA2	Glenroy
210	21003	210031439	SA2	Gowanbrae
210	21003	210031440	SA2	Hadfield
210	21004	210041240	SA2	Sunbury
210	21004	210041241	SA2	Sunbury - South
210	21005	210051242	SA2	Broadmeadows
210	21005	210051243	SA2	Campbellfield - Coolaroo
210	21005	210051245	SA2	Gladstone Park - Westmeadows
210	21005	210051246	SA2	Greenvale - Bulla
210	21005	210051247	SA2	Meadow Heights
210	21005	210051248	SA2	Melbourne Airport
210	21005	210051249	SA2	Roxburgh Park - Somerton
210	21005	210051250	SA2	Tullamarine
210	21005	210051441	SA2	Craigieburn - Central
210	21005	210051442	SA2	Craigieburn - North
210	21005	210051443	SA2	Craigieburn - South
210	21005	210051444	SA2	Craigieburn - West
210	21005	210051445	SA2	Mickleham - Yuroke
211	21101	211011251	SA2	Bayswater
211	21101	211011254	SA2	Knoxfield - Scoresby
211	21101	211011255	SA2	Lysterfield
211	21101	211011256	SA2	Rowville - Central
211	21101	211011257	SA2	Rowville - North
211	21101	211011258	SA2	Rowville - South
211	21101	211011259	SA2	Wantirna
211	21101	211011260	SA2	Wantirna South
211	21101	211011446	SA2	Boronia
211	21101	211011447	SA2	Ferntree Gully (North)
211	21101	211011448	SA2	Ferntree Gully (South) - Upper Ferntree Gully
211	21101	211011449	SA2	The Basin
211	21102	211021261	SA2	Donvale - Park Orchards
211	21102	211021262	SA2	Warrandyte - Wonga Park
211	21103	211031263	SA2	Bayswater North
211	21103	211031265	SA2	Croydon Hills - Warranwood
211	21103	211031266	SA2	Ringwood
211	21103	211031267	SA2	Ringwood East
211	21103	211031268	SA2	Ringwood North
211	21103	211031450	SA2	Croydon - East
211	21103	211031451	SA2	Croydon - West
211	21103	211031452	SA2	Croydon South
211	21104	211041269	SA2	Forest Hill
211	21104	211041270	SA2	Mitcham (Vic.)
211	21104	211041271	SA2	Nunawading
211	21104	211041272	SA2	Vermont
211	21104	211041273	SA2	Vermont South
211	21105	211051274	SA2	Belgrave - Selby
211	21105	211051275	SA2	Chirnside Park
211	21105	211051276	SA2	Healesville - Yarra Glen
211	21105	211051277	SA2	Kilsyth
211	21105	211051278	SA2	Lilydale - Coldstream
211	21105	211051279	SA2	Monbulk - Silvan
211	21105	211051280	SA2	Montrose
211	21105	211051281	SA2	Mooroolbark
211	21105	211051282	SA2	Mount Dandenong - Olinda
211	21105	211051283	SA2	Mount Evelyn

SA4 Code	SA3 Code	SA2 Code	Area Type	Area Name
211	21105	211051284	SA2	Upwey - Tecoma
211	21105	211051285	SA2	Wandin - Seville
211	21105	211051286	SA2	Yarra Valley
212	21201	212011287	SA2	Beaconsfield - Officer
212	21201	212011288	SA2	Bunyip - Garfield
212	21201	212011289	SA2	Emerald - Cockatoo
212	21201	212011290	SA2	Koo Wee Rup
212	21201	212011291	SA2	Pakenham - North
212	21201	212011292	SA2	Pakenham - South
212	21202	212021293	SA2	Berwick - North
212	21202	212021294	SA2	Berwick - South
212	21202	212021295	SA2	Doveton
212	21202	212021297	SA2	Hallam
212	21202	212021299	SA2	Narre Warren North
212	21202	212021453	SA2	Endeavour Hills - North
212	21202	212021454	SA2	Endeavour Hills - South
212	21202	212021455	SA2	Narre Warren - North East
212	21202	212021456	SA2	Narre Warren - South West
212	21203	212031300	SA2	Cranbourne
212	21203	212031301	SA2	Cranbourne East
212	21203	212031302	SA2	Cranbourne North
212	21203	212031303	SA2	Cranbourne South
212	21203	212031304	SA2	Cranbourne West
212	21203	212031305	SA2	Hampton Park - Lynbrook
212	21203	212031306	SA2	Lynbrook - Lyndhurst
212	21203	212031308	SA2	Pearcedale - Tooradin
212	21203	212031457	SA2	Narre Warren South (East)
212	21203	212031458	SA2	Narre Warren South (West)
212	21204	212041309	SA2	Clarinda - Oakleigh South
212	21204	212041310	SA2	Clayton South
212	21204	212041311	SA2	Dandenong
212	21204	212041312	SA2	Dandenong North
212	21204	212041313	SA2	Dingley Village
212	21204	212041314	SA2	Keysborough
212	21204	212041316	SA2	Noble Park North
212	21204	212041317	SA2	Springvale
212	21204	212041318	SA2	Springvale South
212	21204	212041459	SA2	Noble Park - East
212	21204	212041460	SA2	Noble Park - West
212	21205	212051319	SA2	Ashwood - Chadstone
212	21205	212051320	SA2	Clayton
212	21205	212051321	SA2	Glen Waverley - East
212	21205	212051322	SA2	Glen Waverley - West
212	21205	212051323	SA2	Mount Waverley - North
212	21205	212051324	SA2	Mount Waverley - South
212	21205	212051325	SA2	Mulgrave
212	21205	212051326	SA2	Oakleigh - Huntingdale
212	21205	212051327	SA2	Wheelers Hill
213	21301	213011328	SA2	Ardeer - Albion
213	21301	213011329	SA2	Cairnlea
213	21301	213011330	SA2	Deer Park - Derrimut
213	21301	213011331	SA2	Delahey
213	21301	213011332	SA2	Keilor Downs
213	21301	213011333	SA2	Kings Park (Vic.)
213	21301	213011334	SA2	St Albans - North
213	21301	213011335	SA2	St Albans - South
213	21301	213011336	SA2	Sunshine
213	21301	213011337	SA2	Sunshine North
213	21301	213011338	SA2	Sunshine West
213	21301	213011339	SA2	Sydenham
213	21301	213011340	SA2	Taylors Lakes
213	21302	213021341	SA2	Altona
213	21302	213021342	SA2	Altona Meadows

SA4 Code	SA3 Code	SA2 Code	Area Type	Area Name
213	21302	213021343	SA2	Altona North
213	21302	213021344	SA2	Newport
213	21302	213021345	SA2	Seabrook
213	21302	213021346	SA2	Williamstown
213	21303	213031347	SA2	Braybrook
213	21303	213031348	SA2	Footscray
213	21303	213031349	SA2	Maribyrnong
213	21303	213031350	SA2	Seddon - Kingsville
213	21303	213031351	SA2	West Footscray - Tottenham
213	21303	213031352	SA2	Yarraville
213	21304	213041353	SA2	Bacchus Marsh
213	21304	213041355	SA2	Hillside
213	21304	213041356	SA2	Melton
213	21304	213041357	SA2	Melton South
213	21304	213041358	SA2	Melton West
213	21304	213041359	SA2	Rockbank - Mount Cottrell
213	21304	213041360	SA2	Taylors Hill
213	21304	213041461	SA2	Burnside
213	21304	213041462	SA2	Burnside Heights
213	21304	213041463	SA2	Caroline Springs
213	21305	213051361	SA2	Hoppers Crossing - North
213	21305	213051362	SA2	Hoppers Crossing - South
213	21305	213051363	SA2	Laverton
213	21305	213051365	SA2	Tarneit
213	21305	213051366	SA2	Truganina
213	21305	213051368	SA2	Werribee - South
213	21305	213051369	SA2	Wyndham Vale
213	21305	213051464	SA2	Point Cook - East
213	21305	213051465	SA2	Point Cook - North
213	21305	213051466	SA2	Point Cook - South
213	21305	213051467	SA2	Werribee - East
213	21305	213051468	SA2	Werribee - West
214	21401	214011370	SA2	Carrum Downs
214	21401	214011371	SA2	Frankston
214	21401	214011372	SA2	Frankston North
214	21401	214011373	SA2	Frankston South
214	21401	214011374	SA2	Langwarrin
214	21401	214011375	SA2	Seaford (Vic.)
214	21401	214011376	SA2	Skye - Sandhurst
214	21402	214021377	SA2	Dromana
214	21402	214021378	SA2	Flinders
214	21402	214021379	SA2	Hastings - Somers
214	21402	214021380	SA2	Mornington
214	21402	214021381	SA2	Mount Eliza
214	21402	214021382	SA2	Mount Martha
214	21402	214021383	SA2	Point Nepean
214	21402	214021384	SA2	Rosebud - McCrae
214	21402	214021385	SA2	Somerville
215	21501	215011386	SA2	Ararat
215	21501	215011387	SA2	Ararat Region
215	21501	215011388	SA2	Horsham
215	21501	215011389	SA2	Horsham Region
215	21501	215011390	SA2	Nhill Region
215	21501	215011391	SA2	St Arnaud
215	21501	215011392	SA2	Stawell
215	21501	215011393	SA2	West Wimmera
215	21501	215011394	SA2	Yarriambiack
215	21502	215021395	SA2	Irymple
215	21502	215021396	SA2	Merbein
215	21502	215021398	SA2	Mildura Region
215	21502	215021399	SA2	Red Cliffs
215	21502	215021469	SA2	Mildura - North
215	21502	215021470	SA2	Mildura - South

SA4 Code	SA3 Code	SA2 Code	Area Type	Area Name
215	21503	215031400	SA2	Buloke
215	21503	215031401	SA2	Gannawarra
215	21503	215031402	SA2	Kerang
215	21503	215031403	SA2	Robinvale
215	21503	215031404	SA2	Swan Hill
215	21503	215031405	SA2	Swan Hill Region
216	21601	216011406	SA2	Echuca
216	21601	216011407	SA2	Kyabram
216	21601	216011408	SA2	Lockington - Gunbower
216	21601	216011409	SA2	Rochester
216	21601	216011410	SA2	Rushworth
216	21602	216021411	SA2	Cobram
216	21602	216021412	SA2	Moira
216	21602	216021413	SA2	Numurkah
216	21602	216021414	SA2	Yarrawonga
216	21603	216031415	SA2	Mooroopna
216	21603	216031416	SA2	Shepparton - North
216	21603	216031417	SA2	Shepparton - South
216	21603	216031418	SA2	Shepparton Region - East
216	21603	216031419	SA2	Shepparton Region - West
217	21701	217011420	SA2	Glenelg (Vic.)
217	21701	217011421	SA2	Hamilton (Vic.)
217	21701	217011422	SA2	Portland
217	21701	217011423	SA2	Southern Grampians
217	21703	217031471	SA2	Camperdown
217	21703	217031472	SA2	Colac
217	21703	217031473	SA2	Colac Region
217	21703	217031474	SA2	Corangamite - North
217	21703	217031475	SA2	Corangamite - South
217	21703	217031476	SA2	Otway
217	21704	217041477	SA2	Moyne - East
217	21704	217041478	SA2	Moyne - West
217	21704	217041479	SA2	Warrnambool - North
217	21704	217041480	SA2	Warrnambool - South

Table C-2 Significant Urban Areas and the number of SA2s

SUA name	Number of SA2s
Albury - Wodonga	2
Bacchus Marsh	1
Bairnsdale	1
Ballarat	7
Bendigo	8
Colac	1
Echuca - Moama	1
Geelong	15
Gisborne - Macedon	3
Horsham	1
Melbourne	294
Melton	3
Mildura - Wentworth	4
Moe - Newborough	1
Portland	1
Sale	1
Shepparton - Mooroopna	3
Swan Hill	1
Traralgon - Morwell	2
Wangaratta	1
Warragul - Drouin	2
Warrnambool	2

Table C-3 ABS Input-Output Industry Groups in the SIRCV model

Major Industries	IOIG Business Industry Codes	IOIG Industry Groups
Agriculture, Forestry and Fishing	IND0101	Sheep, Grains, Beef and Dairy Cattle
	IND0102	Poultry and Other Livestock
	IND0103	Other Agriculture
	IND0201	Aquaculture
	IND0301	Forestry and Logging
	IND0401	Fishing, hunting and trapping
	IND0501	Agriculture, Forestry and Fishing Support Services
Mining	IND0601	Coal mining
	IND0701	Oil and gas extraction
	IND08012	Iron Ore Mining and Non-Ferrous Metal Ore Mining
	IND0901	Non-Metallic Mineral Mining
	IND1001	Exploration and Mining Support Services
Manufacturing	IND1101	Meat and Meat product Manufacturing
	IND1102	Processed Seafood Manufacturing
	IND1103	Dairy Product Manufacturing
	IND1104	Fruit and Vegetable Product Manufacturing
	IND1105	Oils and Fats Manufacturing
	IND1106	Grain Mill and Cereal Product Manufacturing
	IND1107	Bakery Product Manufacturing
	IND1108	Sugar and Confectionery Manufacturing
	IND1109	Other Food Product Manufacturing
	IND120125	Soft Drinks, Beer, Wine, Spirits and other Alcoholic Beverages, and Cigarette and Tobacco Product Manufacturing
	IND1301	Textile Manufacturing
	IND1302	Tanned Leather, Dressed Fur and Leather Product Manufacturing
	IND1303	Textile Product Manufacturing
	IND130456	Knitted Product, Clothing, and Footwear Manufacturing
	IND1401	Sawmill Product Manufacturing
	IND1402	Other Wood Product Manufacturing
	IND1501	Pulp, Paper and Paperboard Manufacturing
	IND1502	Paper Stationery and Other Converted Paper Product Manufacturing
	IND1601	Printing (including the reproduction of recorded media)
	IND1701	Petroleum and Coal Product Manufacturing
	IND180124	Human Pharmaceutical and Medicinal Product, Veterinary Pharmaceutical and Medicinal Product, and Cleaning Compounds and Toiletry Preparation Manufacturing
	IND1803	Basic Chemical Manufacturing
	IND19012	Polymer Product and Natural Rubber Product Manufacturing
	IND2001	Glass and Glass Product Manufacturing
	IND2002	Ceramic Product Manufacturing
	IND20034	Cement, Lime and Ready-Mixed Concrete, and Plaster and Concrete Product Manufacturing
	IND2005	Other Non-Metallic Mineral Product Manufacturing
	IND2102	Basic Non-Ferrous Metal Manufacturing
	IND21201	Iron and Steel Manufacturing, and Forged Iron and Steel Product Manufacturing
	IND2202	Structural Metal Product Manufacturing
	IND2203	Metal Containers and Other Sheet Metal Product manufacturing
	IND2204	Other Fabricated Metal Product manufacturing
	IND2301234	Motor Vehicles, Ships and Boat, Railway, and Aircraft Manufacturing
	IND2401	Professional, Scientific, Computer and Electronic Equipment Manufacturing
	IND2403	Electrical Equipment Manufacturing
	IND2404	Domestic Appliance Manufacturing
	IND2405	Specialised and other Machinery and Equipment Manufacturing
	IND2501	Furniture Manufacturing
	IND2502	Other Manufactured Products
Electricity Gas Water and Waste Services	IND2601	Electricity Generation
	IND2605	Electricity Transmission, Distribution, On Selling and Electricity Market Operation
	IND2701	Gas Supply

Major Industries	IOIG Business Industry Codes	IOIG Industry Groups
	IND2801	Water Supply, Sewerage and Drainage Services
	IND2901	Waste Collection, Treatment and Disposal Services
Construction	IND3001	Residential Building Construction
	IND3002	Non-Residential Building Construction
	IND3101	Heavy and Civil Engineering Construction
	IND3201	Construction Services
Wholesale Trade	IND3301	Wholesale Trade
Retail Trade	IND3901	Retail Trade
Accommodation and Food Services	IND4401	Accommodation
	IND4501	Food and Beverage Services
Transport Postal and Warehousing	IND4601	Road Transport
	IND4701	Rail Transport
	IND4801	Water, Pipeline and Other Transport
	IND4901	Air and Space Transport
	IND5101	Postal and Courier Pick-up and Delivery Service
	IND5201	Transport Support services and storage
Information Media and Telecommunications	IND5401	Publishing (except Internet and Music Publishing)
	IND5501	Motion Picture and Sound Recording
	IND5601	Broadcasting (except Internet)
	IND5701	Internet Service Providers, Internet Publishing and Broadcasting, Websearch Portals and Data Processing
	IND5801	Telecommunication Services
	IND6001	Library and Other Information Services
Financial and Insurance Services	IND6201	Finance
	IND6301	Insurance and Superannuation Funds
	IND6401	Auxiliary Finance and Insurance Services
Rental Hiring and Real Estate Services	IND6601	Rental and Hiring Services (except Real Estate)
	IND6702	Ownership of Dwellings, and Non-Residential Property Operators and Real Estate Services
Professional Scientific and Technical Services	IND6901	Professional, Scientific and Technical Services
	IND7001	Computer Systems Design and Related Services
Administrative and Support Services	IND7210	Employment, Travel Agency and Other Administrative Services
	IND7310	Building Cleaning, Pest Control and Other Support Services
Public Administration and Safety	IND7501	Public Administration and Regulatory Services
	IND7601	Defence
	IND7701	Public Order and Safety
Education and Training	IND8010	Primary and Secondary Education Services (incl Pre-Schools and Special Schools)
	IND8110	Technical, Vocational and Tertiary Education Services (incl undergraduate and postgraduate)
	IND8210	Arts, Sports, Adult and Other Education Services (incl community education)
Health Care and Social Assistance	IND8401	Health Care Services
	IND8601	Residential Care and Social Assistance Services
Arts and Recreation Services	IND8901	Heritage, Creative and Performing Arts
	IND9101	Sports and Recreation
	IND9201	Gambling
Other Services	IND9401	Automotive Repair and Maintenance
	IND9402	Other Repair and Maintenance
	IND9501	Personal Services
	IND9502	Other Services

Table C-4 Occupational groups in the SIRCV model

Major Group	ANZSCO 2-digit Codes	Sub-Major Group
Managers	OCC11	Chief Executives, General Managers and Legislators
	OCC12	Farmers and Farm Managers
	OCC13	Specialist Managers
	OCC14	Hospitality, Retail and Service Managers
Professionals	OCC21	Arts and Media Professionals
	OCC22	Business, Human Resource and Marketing Professionals
	OCC23	Design, Engineering, Science and Transport Professionals
	OCC24	Education Professionals
	OCC25	Health Professionals
	OCC26	ICT Professionals
	OCC27	Legal, Social and Welfare Professionals
Technicians and Trades Workers	OCC31	Engineering, ICT and Science Technicians
	OCC32	Automotive and Engineering Trades Workers
	OCC33	Construction Trades Workers
	OCC34	Electrotechnology and Telecommunications Trades Workers
	OCC35	Food Trades Workers
	OCC36	Skilled Animal and Horticultural Workers
	OCC39	Other Technicians and Trades Workers
Community and Personal Service Workers	OCC41	Health and Welfare Support Workers
	OCC42	Carers and Aides
	OCC43	Hospitality Workers
	OCC44	Protective Service Workers
	OCC45	Sports and Personal Service Workers
Clerical and Administrative Workers	OCC51	Office Managers and Program Administrators
	OCC52	Personal Assistants and Secretaries
	OCC53	General Clerical Workers
	OCC54	Inquiry Clerks and Receptionists
	OCC55	Numerical Clerks
	OCC56	Clerical and Office Support Workers
	OCC59	Other Clerical and Administrative Workers
Sales Workers	OCC61	Sales Representatives and Agents
	OCC62	Sales Assistants, Salespersons,
	OCC63	Sales Support Workers
Machinery Operators and Drivers	OCC71	Machine and Stationary Plant Operators
	OCC72	Mobile Plant Operators
	OCC73	Road and Rail Drivers
	OCC74	Storepersons
Labourers	OCC81	Cleaners and Laundry Workers
	OCC82	Construction and Mining Labourers
	OCC83	Factory Process Workers
	OCC84	Farm, Forestry and Garden Workers
	OCC85	Food Preparation Assistants
	OCC89	Other Labourers

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