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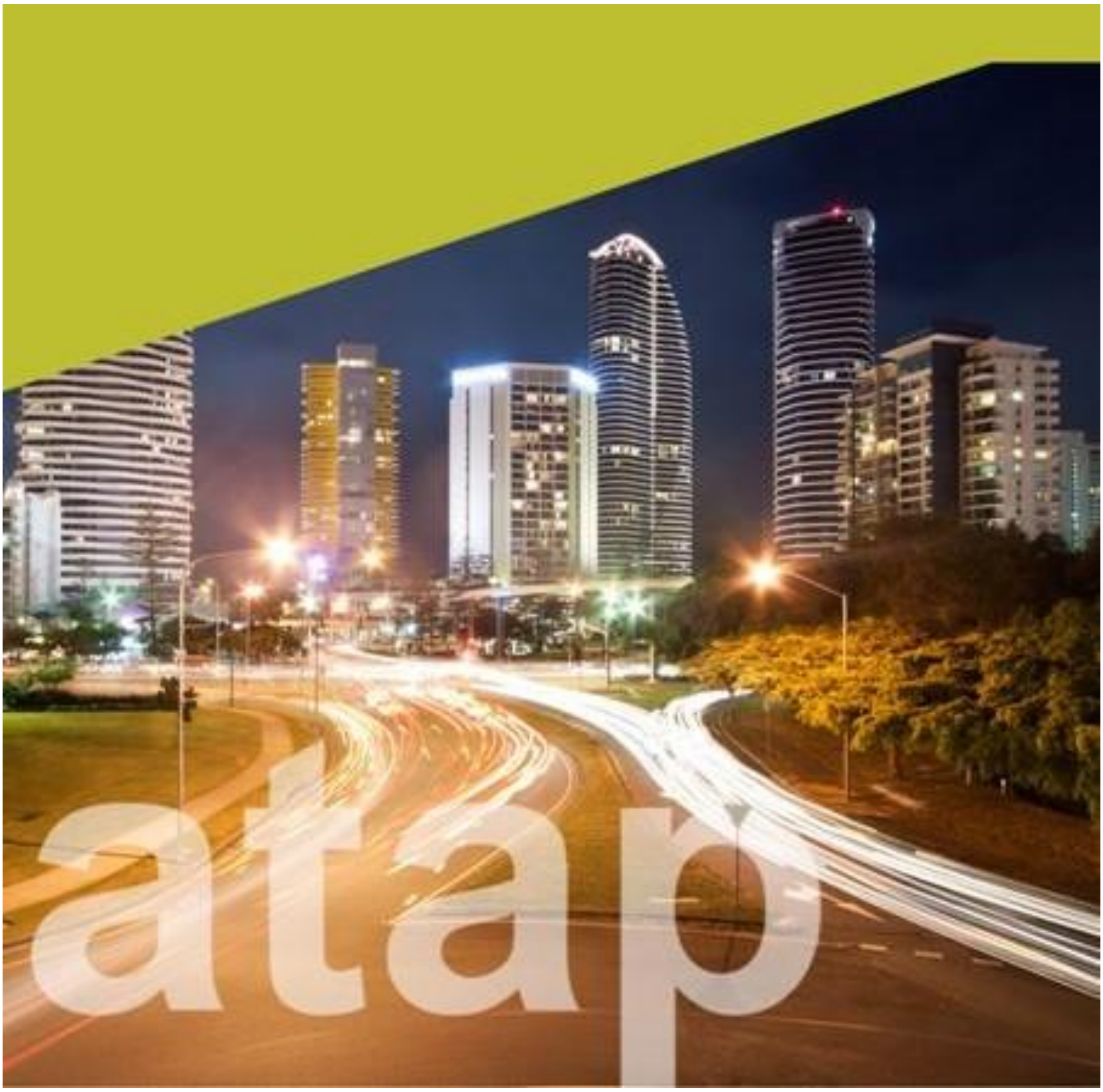
Australian Transport Assessment and Planning Guidelines

N11 Land use transport interaction modelling – Public consultation draft

August 2025



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At a glance

Historically, transport infrastructure has been a key driver of urban development. Australian cities have evolved around the dominant transport technologies of their era, and major infrastructure projects have played a key role in shaping the urban development patterns of Australian cities. The role of transport technology and infrastructure in shaping land use (and vice versa) has been long understood and widely ackowledged by academics, government agencies and their consultants.

There are many examples of major transport investments in Australia that have had a profound impact on the urban development of the cities they are part of. One example includes Melbourne's City Loop, which catalysed and enabled the development of Melbourne CBD, a key driver of Victoria's economic, social and cultural development. Another example is Perth's Mitchell Freeway which, along with the railway in its median strip, has fueled the continuing northward expansion of Perth's greater metropolitan area. There are numerous other examples of transport investments that have shaped land use in all of Australia's major cities.

Historically, evaluation of transport strategies, projects, programs and policies has relied on an assumption of 'fixed land use'. In other words, they have assumed that the intervention being assessed will have no impact on future urban development in its area of influence. While this assumption may be suitable for minor transport interventions, it is widely acknowledged as inappropriate for larger investments.

In recent years, there have been numerous transport proposals made by Australian government agencies which may be characterised as 'megaprojects'. These projects would be expected to have substantial impacts on future urban development. Government agencies have also recently proposed planning reforms which seek to increase densities along major public transport corridors. In some cases – most notably Melbourne's Suburban Rail Loop – major public transport investments and planning reforms have been proposed together as part of the same program.

For these reasons, LUTI modelling has come into increasing focus in recent years. Australian transport and planning agencies have begun to experiment with using LUTI modelling tehniques for a range of purposes, include preparing 'business as usual' land use projections for planning purposes, strategy development, project or program planning and policy analysis. While this is an encouraging trend, the use of LUTI modelling Australian transport and planning agencies remains nascent, and LUTI modelling exercises have varied in sophistication and quality.

The purpose of this report is to enhance stakeholders' understanding of LUTI modelling, its strengths and limitations, and to establish principles of good practice to improve the rigour and consistency of LUTI modelling applications in Australia. The report is structured into four sections, covering theoretical frameworks, the current state of practice, principles of good practice, and case studies to illustrate the application of the principles.

A range of foundational theories have emerged which underpin modern LUTI modelling, including gravity-type models, location choice models, Leontief's input-output models (a special case of Computable General Equilibrium model), Alonso's bid-rent models, Orcutt's microsimulation approach and general equilibrium models.

LUTI modelling approaches vary in nature and complexity. David Simmonds (2024) identified seven groups of approaches: static adjustment models, simpler models, system dynamics models, microsimulation dynamic models, Martin Centre models, multi-level dynamic models and urban SCGE models. This report recommends microsimulation dynamic modelling, multi-level dynamic modelling and urban SCGE modelling approaches be considered best practice, depending on the context of the proposed applications.

To advance LUTI modelling in Australia, it is recommended that academic research and development be funded, and that state agencies invest in developing and maintaining high-quality LUTI models. These efforts will ensure that LUTI modelling can support effective and sustainable integrated transport and land use planning.

This guideline establishes nine principles of good practice LUTI modelling. These principles are characterised as either a ‘must have’ or ‘should have’. Models must be fit for purpose, be transparent in approach and assumptions, and represent accessibility measures. Models should be well calibrated, dynamic, represent economic relationships, represent demand, represent supply constraints, and produce stable, repeatable outcomes.

This report uses three recent examples of LUTI modelling application in Australia to illustrate the application of the principles. These include the Suburban Rail Loop in Victoria, Infrastructure Victoria’s 30 Year Strategy and the ShapingSEQ plan in Queensland.

1. Introduction

1.1 Purpose of this report

Land use transport interaction (LUTI) modelling, as a discipline, first came to prominence in the 1960’s. Various theoretical frameworks and modelling techniques have emerged in that time, but there is no single consensus approach among academics or practitioners.

There have been various policy and infrastructure proposals in Australia in recent years that aim to better integrate transport and land use planning. These include major public transport infrastructure investments and planning policy initiatives aimed at:

- Increasing housing densities along public transport corridors.
- Boosting overall housing supply to improve housing affordability in major Australian cities.

In response, government agencies and their consultants have employed LUTI modelling techniques as part of strategy development, project and program development, and policy analysis. The nature and sophistication of those approaches has varied.

The purpose of these guidelines is to i) improve the understanding that relevant stakeholders have of LUTI modelling and its strengths and limitations; and ii) lay out a set of principles of good practice, with the aim of improving the rigour and consistency of LUTI modelling exercises in Australia. Given LUTI modelling is relatively immature in its application in Australia and globally, this report provides a principles-level good practice instead of seeking to be overly prescriptive in terms of LUTI modelling approaches to allow for future innovations.

1.2 Structure of this report

This document contains four sections, described below.

Section	Summary
How transport shapes land use	This provides a high-level treatment of the context, theory, and application of LUTI modelling and how it has evolved.
The current state of practice	This describes how LUTI modelling is applied in practice to support decision making and when decision makers should consider using LUTI modelling.
Principles of good practice	This provides a set of principles for practitioners and stakeholders to consider when selecting a LUTI modelling approach.
Case studies	This demonstrates application of the above principles on three case studies of Australian LUTI model applications.

2. How transport shapes land use

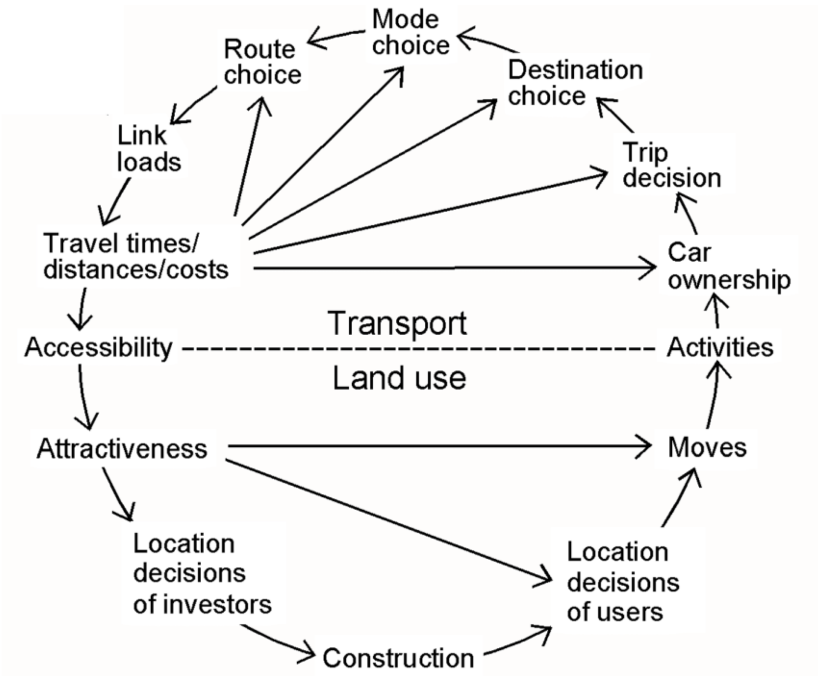
2.1 Historical context

Newman and Kenworthy (1999) identified transport infrastructure and technology as one of the major drivers that have historically shaped cities. Early cities were "Walking Cities," characterised by high-density, mixed land use and narrow streets, allowing residents to reach key centres on foot within approximately half an hour. This form persisted until the mid-19th century. With the advent of the Industrial Revolution and new transport technologies like trains and trams in the 1860s, cities evolved into "Transit Cities," accommodating more people as cities spread outwards along public transport corridors while maintaining access to key centres within around half an hour, which reduced the density of cities compared to the Walking City. The rise of the automobile, particularly post-World War II, led to the development of "Automobile Cities." This era saw cities expanding outward, with low-density housing and segregated residential, commercial and industrial areas, making car travel a necessity. This shift resulted in decentralised, sprawling urban forms, especially prominent in North American and Australian cities that largely developed during the automobile era. The automobile era fostered car dependence, fundamentally altering urban landscapes and community structures.

2.2 Theoretical framework

Wegener and Furst (2004) developed a theoretical framework for representing how transport and land use systems interact with each other. This is depicted in Figure 2-1 and is often referred to as the *Wegener wheel*.

Figure 2-1 The Wegener wheel



Source: Wegener & Furst (2004)

The concept of ‘accessibility’ serves as the cornerstone of LUTI modelling. It represents the interconnection between transport systems and land use. Accessibility relates to how effectively people can use the transport network to access various opportunities that are distributed across a city or region.

Strategic transport models typically capture the elements in the upper half of the Wegener wheel. LUTI modelling approaches expand the framework to address the lower half of the wheel, including how accessibility influences the desirability of locations for households and firms, decisions related to location (such as where to live or work), and how developers respond to demand in the real estate market.

Since the 1960s, numerous LUTI models have been developed, primarily by academic researchers, to address various general and specialised needs. The evolution of these models has been rapid, driven by advancements in modelling techniques, increased computational power, and a wealth of demographic and economic data. Currently, most are based on a few key foundational theories which emerged from academia. Table 2-1 lists these foundational theories and provides references to suggested readings.

Table 2-1 Foundational theories of LUTI models

Theories	Suggested readings
Gravity-type models	Hansen 1959; Lowry 1964
Location choice models	Lerman 1976; McFadden 1978
Leontief's input-output models	Leontief & Strout 1963; Wilson 1970
Alonso's bid-rent models and Ellickson stochastic bid-rent model derivative	Alonso 1960; Ellickson 1981
Orcutt's microsimulation approach	Orcutt 1957

2.3 Impact of major transport interventions

Major transport interventions have the potential to shape cities, influencing accessibility, urban development patterns, and population and economic growth. For example, Cervero (2003) demonstrated that highway upgrades generate significant ‘induced investment’ effects, with real estate developers responding to improved freeways with more residential development along the corridor.

Some illustrative historical examples of how transport interventions have shaped urban development are described below. These examples demonstrate that major transport investments can drive substantial changes in accessibility, urban development and economic growth. Major transport interventions unlock new opportunities for residential and commercial development, drive redistribution of population and employment growth, and can substantially impact overall urban vitality.

City Loop in Melbourne

Melbourne's City Loop, completed in the 1980s, is a prime example of a city-shaping infrastructure project. It transformed Melbourne's central business district (CBD) by addressing critical transport and land use challenges. The City Loop introduced a new underground rail loop, four new stations, and a new viaduct, which improved operational efficiency, reduced congestion and increased the system's maximum capacity. The City Loop catalysed significant urban development, including the relocation of rail stabling yards, redevelopment of Melbourne Central shopping centre and office complex, and the development of the inner-city urban St Kilda Road and Southbank precincts. These changes encouraged higher-value residential and commercial development, increasing the density of employment, and enabling development in the northern parts of the CBD. By enabling CBD development, the City Loop has played an important role in Victoria’s economic, social and cultural development.

Mitchell Freeway in Perth

The Mitchell Freeway in Perth, completed in stages beginning of the 1970s, has played a key role in shaping the city's development. The freeway improved accessibility to the CBD from the middle and outer northern suburbs, leading to significant residential, industrial and commercial growth along its corridor. The freeway facilitated the expansion of Perth's urban footprint and supported the development of new suburbs. The freeway, along with the railway that runs along its median strip, has enabled the low-density, car dependent suburban sprawl that runs along the coast up to 50 km north of Perth’s CBD.

High Speed Two (HS2) in the UK

The High Speed Two (HS2) project in the UK, connecting London and the West Midlands, has catalysed substantial urban development. From the Parliament approval of HS2 to 2024, there had been a 484% increase in the number of new homes planned in its impact zones, with almost 55,000 units planned since 2017 (HS2 2024). This rate of increase is 14 times greater than in the wider West Midlands region. HS2's impact on housing development highlights the transformative potential of major transport investments in reshaping urban areas and stimulating economic growth.

2.4 Australia’s planning context

Australia's urban planning context is distinct from many other developed nations due to its unique combination of rapid population growth, low-density cities and high car dependence. Australia's population growth rate stands at 2.4% annually as of 2023, significantly higher than many other wealthy nations where population growth is relatively stagnant, such as US, UK and some European countries with less than 1% annual growth (World Bank 2024). Much of Australia’s rapid population growth is occurring in greenfield areas on the fringes of major cities, contributing to urban sprawl and increased car dependence.

Australian cities are characterised by their low population densities. The most densely populated city in Australia, Sydney, had a population density of 3,175 people per km^2 in 2023 - considerably lower than many cities in Europe, Asia and older parts of the US and Canada (European Commission 2024). This low-density is coupled with high car ownership rates, with 737 cars per 1,000 people in 2020, placing Australia among the highest in the world for car dependence (International Organisation of Motor Vehicle Manufacturers 2020).

The current pattern of urban development in most Australian cities, characterised by extensive greenfield development, is often criticised. To address this, there is a widely recognised need to enable more infill development supported by public transport investments. Major public transport infrastructure projects such as the Suburban Rail Loop (Victoria), Sydney Metro (NSW), Metro Tunnel Project (Victoria), Cross River Rail (QLD) and Metronet (WA) support the imperative to increase infill development via increased density along key public transport corridors.

At the time of writing, the housing supply and affordability crisis in major Australian cities has become a pressing issue, exacerbated by rapid population growth and supply constraints. The demand for housing has outpaced supply, leading to increasing property prices and rental costs, particularly in major cities. This situation is attributed to a combination of factors, including restrictive zoning rules, limited land release, insufficient investment in social and affordable housing and taxation policy. As a result, many Australians are finding it increasingly difficult to secure affordable housing, pushing them further away from city centres and increasing their reliance on cars for commuting.

Australia's planning and funding processes for major infrastructure typically involve application of a social cost-benefit analysis (CBA) approach. Social CBA seeks to assess the overall value of a policy, project or investment from the perspective of society, rather than from the perspective of any specific group or organisation. The Australian Transport Assessment and Planning (ATAP) Guidelines, influenced by the UK's Transport Analysis Guidance, prescribe this framework, including in ATAP T2 *CBA Guidance* (2022b), ATAP O8 *Land-use Benefit of Transport Initiatives* (2022a) and ATAP T3 *Wider Economic Benefits* (2023) or WEBs. Similarly, State Treasury organisations around Australia and Infrastructure Australia prescribe a social CBA approach.

Representing the land use impacts of proposed transport interventions is key to understanding the true economic costs and benefits. Failing to account for land use impacts is likely to systematically and substantially bias appraisals for major interventions. This was raised in the Victorian Auditor-General Office's 2011 report on the management of Major Road Projects (Victorian Auditor-General 2011), which identified 'relocated trip' as one of the key sources of induced demand for road improvements, see Figure 2-2. It concluded that failing to account for the key sources of induced demand for road improvements 'will significantly underestimate traffic and overestimate the economic benefits'.

Figure 2-2 Induced traffic responses to a road improvement

The ways people and businesses could respond to a road improvement

Changing route—drivers make the same journeys but use the improved route.

Changing destination—drivers decide to travel to more distant destinations because the improvement makes the journey time acceptable.

Changing mode—public transport passengers switch to car because the improvement makes road travel more attractive than rail.

Changing time of travel—drivers decide to travel in the commuting peak period because the improvement reduces journey times to an acceptable level.

Making additional journeys—people are willing to make additional car journeys because of the improvement.

Relocated trip—people and businesses relocate to take advantage of the improvement and so make journeys that are new to the area.

Source: Victorian Auditor-General (2011), Figure 2A

Smaller interventions are likely to have less impact on land use, and may be safely left out of analysis. The use of LUTI models facilitates a better understanding of the potential impacts of interventions and mitigates bias.

2.5 Common application of LUTI models

There are four primary types of applications of LUTI modelling relevant to Australia. These are described below.

Land use projections for planning purposes: LUTI models can be used to produce land use projections that are used for general strategic planning purposes. These projections are widely used for infrastructure planning across various sectors including transport, housing, education, energy and health. State governments typically maintain standard or 'reference' land use projections, such as Victoria's Small Area Land Use Projections (SALUP), New South Wales's Travel Zone Projections (TZP), Queensland's land use projections from Model for Urban Land Use and Transport Interaction (MULTI) and WA's Dwelling and Employment Distribution System (DaEDS). Of these, only MULTI uses a LUTI modelling approach, with the others using simpler rule-based approaches.

Project and program development: LUTI models may be used in project and program development, particularly during the early planning stages or when developing business cases for major infrastructure projects. LUTI models can be used to estimate the expected land use (or 'city-shaping') impact of specific projects or programs, which is usually then used to estimate land use benefits as part of an economic appraisal. LUTI models are particularly relevant when projects combine transport interventions (e.g. a major rail investment) and land use interventions (e.g. upzoning in the station precincts).

Strategy development: LUTI models can be used in long term infrastructure strategy development. Public agencies sometimes produce long-term infrastructure strategies informed by demand and economic modelling. LUTI models may be used to produce land use projections for scenario analysis and to inform demand modelling and economic appraisal, including for infrastructure interventions (e.g. major projects) and non-infrastructure interventions (e.g. transport pricing or planning policy interventions). LUTI models can also estimate the transport and land use impacts of behavioural changes (e.g. work-from-home behaviours) or climate change impacts (e.g. areas impacted by flood, bushfires, cyclones) for scenario analysis.

Policy analysis: LUTI models may be used to assess policy reforms that affect the transport and land use system. For example, LUTI models enable the estimation of the transport and land use impacts of policies relating to transport pricing, building codes, urban planning, car parking, trunk infrastructure (water, sewer, energy, stormwater), social and community infrastructure, taxation, developer contributions and others.

LUTI models can support a vision and validate modelling approach by testing future changes in land use policy, infrastructure investment or behavioural changes on future outcomes. This can be then compared to alternative policy positions to understand the different outcomes and alternative policy and investment settings. LUTI models at their best can provide a valuable tool to support decision makers in evidence-based decision making.

LUTI models are generally designed to represent a greater metropolitan area (e.g. Brisbane Greater Capital City Statistical Area (GCCSA)) or an economic region (e.g. South-East Queensland (SEQ)), though the spatial extent of the study area can vary widely between different model implementations.

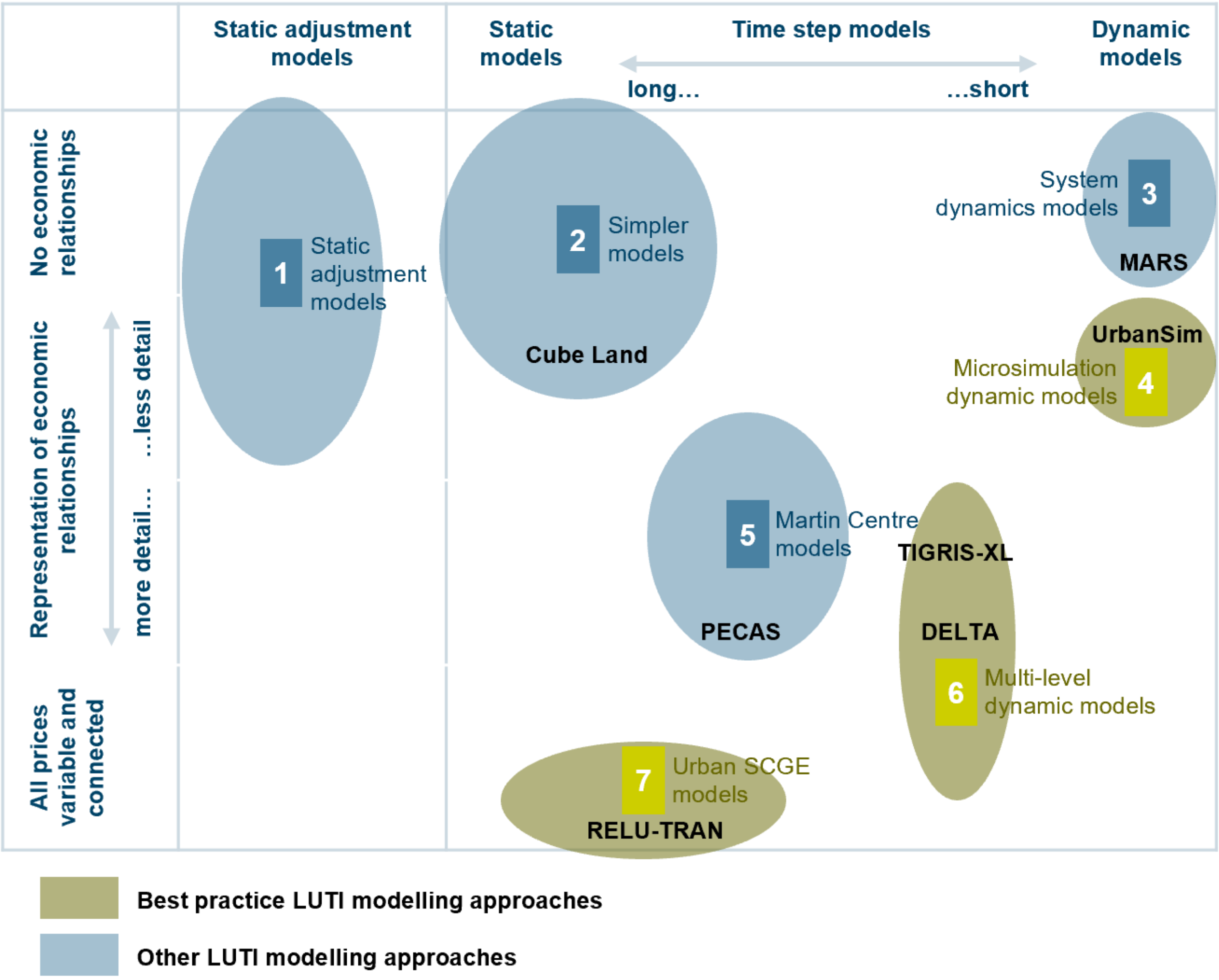
2.6 Types of LUTI models

This section introduces broad approaches to LUTI modelling, describing their strengths and weaknesses, data requirements, and suitability for specific applications. The typology of LUTI modelling approaches discussed in this section are adapted from Simmonds (2024). More detailed discussion of the various LUTI modelling approaches can be found in that paper.

Figure 2-3, adapted from Simmonds' (2024) paper, demonstrates some key distinctions between the model approaches relating to how they represent time and economic relationships. These are broad categorisations, and there exists significant variation in approaches even within the same category. Regardless of the approach taken, any individual model implementation will need to be evaluated on its own merits in the context of its intended purpose.

For the Australian context and the applications described in Section 2.5, Group 4 (microsimulation dynamic models), 6 (multi-level dynamic models) and 7 (urban Spatial Computable General Equilibrium (SCGE) models) are considered best practice. Choosing between these approaches in designing a LUTI model will depend on the aims of the practitioner and the intended applications.

Figure 2-3 LUTI model approaches adapted from Simmonds (2024)



Source: Adapted from Simmonds (2024) Figure 5-1, only select model approaches are named, and the best practice approach designations were added by the author in relation to the purposes set out in Section 2.5 of this report.

Box 1: Australian Bureau of Statistics - Statistical Area Levels

The most commonly used spatial units in Australian LUTI modelling are Australian Bureau of Statistics (ABS) Statistical Area boundaries defined by the Australian Statistical Geography Standard (ASGS). The geographic areas are defined by location of people and communities. The ASGS has a hierarchy of statistical areas starting from Statistical Area Level 1 (SA1) that covers an area with a population of 200 to 800 people, to SA2 which covers an area of approximately suburb level, SA3 with a population of around 30,000 to 130,000, and SA4 with a population of around 100,000 to 500,000.

2.6.1 Group 1: Static adjustment models

Static adjustment models are a special case of LUTI model. They take a set of Base Case land use forecasts and travel costs for a future year as an input along with a set of complementary Project Case travel costs and use those inputs to produce an alternative set of Project Case land use forecasts. These alternative Project Case land use forecasts are usually based on changes in accessibility caused by a transport intervention. In this sense, static adjustment models merely ‘pivot’ off existing forecasts rather than generating their own. This is analogous to an elasticity approach used in transport analysis, for example, an increase in public transport services of 10% may lead to a demand uplift of 5%.

Static adjustment models are straightforward to apply but have significant limitations. They do not represent any economic relationships. They are only able to represent demand changes in the immediate influence area of a transport intervention, while the flow-on impacts to the broader region (e.g. through redistribution of population and employment) is not represented or is based on high level, subjective assumptions. Static adjustment models often do not account for supply-side constraints like planning regulations that limit the type, amount and/or pace of development in a given area.

The data requirements for these models are light, needing only base land use data and travel cost skims from a transport model.

Due to their simplicity, spatial adjustment models are best avoided or used only for sketch planning and early options analysis. They are generally unsuitable for the purposes described in Section 2.5.

2.6.2 Group 2: Simpler models

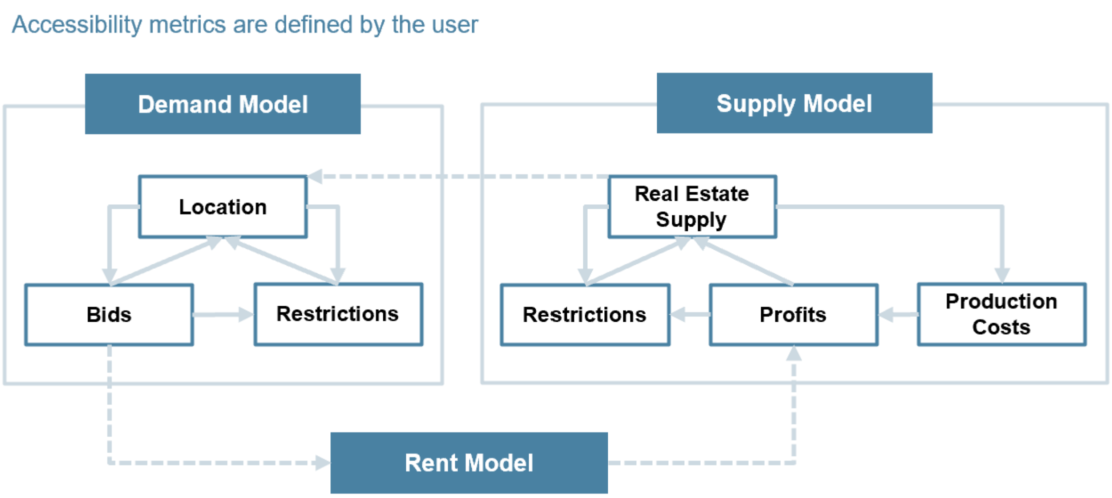
Simpler models are typically static or have limited dynamics (see Section 4.5) and have simplified representations of economic relationships. There are several LUTI model approaches that fall into this group, but the only one considered relevant for this review is Cube Land, based on Francisco Martinez' MUSSA II (Modelo de Uso de Suelos de Santiago or land use model of Santiago) model (see Martinez 1996; Martinez & Donoso 2010). Refer to Figure 2-4 for a schematic of a typical Cube Land model.

While Cube Land represents few economic relationships between relevant actors, it does contain a sophisticated application of bid-choice theory (which combines Alonso's bid-rent theory with random utility theory). This represents an auction-like process where locations are allocated based on the highest bidder, where the bid is a function of the bidder's characteristics. Random utility theory is used to model supply of real estate. Cube Land is a static model, where all actors make location choices to clear the model in each forecast year, with no relationship to the past or future. Supply constraints from planning regulations can be represented, though this is typically at a higher degree of abstraction than Group 4, 5 and 6 approaches.

Cube Land models have relatively intensive data requirements; however, the approach has some flexibility to produce simpler models with lower data requirements.

These models may be useful for early options analysis of land use impacts of transport interventions but are not recommended for detailed transport modelling or economic appraisal.

Figure 2-4 Schematic of a typical Cube Land (MUSSA II) model



Source: Bentley (2024)

2.6.3 Group 3: System dynamics models

System dynamics models incorporate feedback loops and time delays to simulate the dynamic behaviour of complex systems over time, often used to understand long-term policy impacts. Metropolitan Activity Relocation Simulator (MARS) is an example of a system dynamics LUTI model approach (see Pfaffenbichler et al. 2010).

Strengths of the system dynamics models are that they represent changes in stocks and flows and feedback loops over time, especially if the feedback loops include forward-looking relationships. However, these models do not contain explicit economic relationships between agents and often represent location choices at a spatially coarse level. Demand is only represented at a high degree of abstraction, such as at total population level.

Data requirements for system dynamic models are generally light relative to other LUTI model approaches, given that they focus more on the broad dynamics of urban systems than the finer details of urban areas and infrastructure characteristics.

They are useful for exploring relationships between variables and high-level policy analysis but are unlikely to be suitable for detailed transport modelling or economic appraisal.

2.6.4 Group 4: Microsimulation dynamic models

Microsimulation dynamic models simulate the behaviour and interactions of individual agents (households, firms and developers) over time, often representing individual parcels of land and buildings. Microsimulation models are highly disaggregated, allowing the individual characteristics of agents, land and buildings to be represented in the location choice models, which are typically based on random utility theory. UrbanSim is the most well-known and widely applied microsimulation dynamic modelling approach. Refer to Figure 2-5 for a schematic of a typical UrbanSim model.

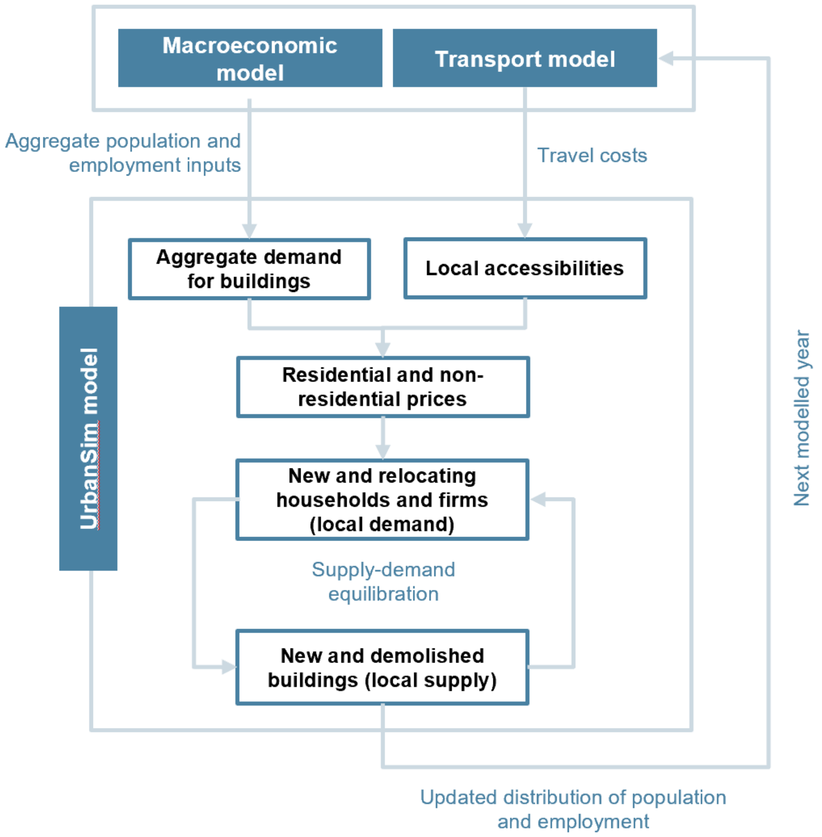
Microsimulation dynamic models assume that land use at a given point in time is influenced by the land use and travel costs at the preceding time step (usually proceeding in one year time steps). They account for the inertia in land use systems and the path dependent nature of urban development - when new buildings are developed, this development is typically ‘locked in’ for a long period of time before redevelopment would be financially feasible.

As microsimulation dynamic models include parcel level detail, they can represent supply constraints in detail, including detailed planning regulations (e.g. permitted uses, maximum densities, coverage, setbacks). This level of detailed representation enables site-level capacity and developer profitability to be estimated and used in location choice models.

Due to the high degree of detail represented in the characteristics of agents, land and buildings, the data requirements for microsimulation dynamic models are relatively intensive.

Microsimulation dynamic models are best suited to reference case land use forecasting, and for estimating the land use impacts of transport interventions for use in project and program development. They are less well suited to strategy development and policy analysis than Group 6 and 7 approaches due to the less detailed representation of economic relationships.

Figure 2-5 Schematic of a typical UrbanSim model



Source: Author's analysis

2.6.5 Group 5: Martin Centre models

Martin Centre models are a grouping of models with origins in research undertaken at the Martin Centre for Architectural and Urban Studies at the University of Cambridge in the UK in the 1970s and further developed by various consulting firms. PECAS is the most well-known and widely applied of the Martin Centre approaches. Refer to Figure 2-6 for a schematic of a typical PECAS model.

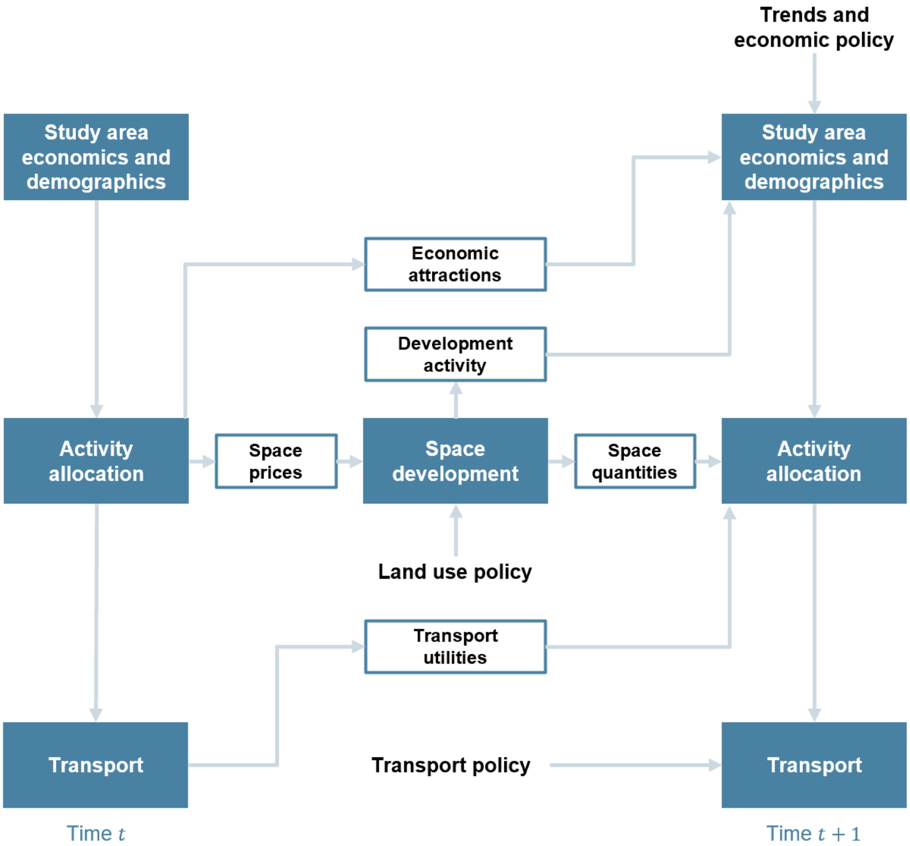
Martin Centre models largely use a static equilibrium framework, although they tend to have some components which account for change over time. Like other static equilibrium approaches (e.g. Group 7 urban SCGE models), their parameters are generally calibrated to a baseline year. Martin Centre models also integrate Alonso-type urban microeconomics theory (similar to Cube Land in Group 2) (Alonso 1960; Alonso 1964).

Martin Centre models are originally based on economic input-output models, though PECAS has been updated to move from fixed input-output coefficients to representing production functions which are characteristics of Group 7 (urban SCGE) models. Martin Centre models were historically aggregate, but PECAS has been updated to include a parcel-level microsimulation floorspace development model characteristic of Group 4 (microsimulation dynamic) models.

Due to the high degree of detail represented in the economic relationships between regions (and in the case of PECAS, the parcel level detail), the data requirements for microsimulation dynamic models are relatively intensive.

While useful for early options analysis of land use impacts of transport interventions, Martin Centre models are generally considered as having been superseded by Group 4 (microsimulation dynamic), Group 6 (multi-level dynamic) and Group 7 (urban SCGE) approaches.

Figure 2-6 Schematic of a typical PECAS model



Source: Adapted from HBA Specto (2023)

2.6.6 Group 6: Multi-level dynamic models

Multi-level dynamic models are characterised by a dynamic approach and a multi-level (hierarchical) spatial structure. TIGRIS-XL, a national model for the Netherlands, and DELTA, which has been widely applied in the UK, are the most well-known examples of multi-level dynamic models. Refer to Figure 2-7 for a schematic of a typical DELTA model.

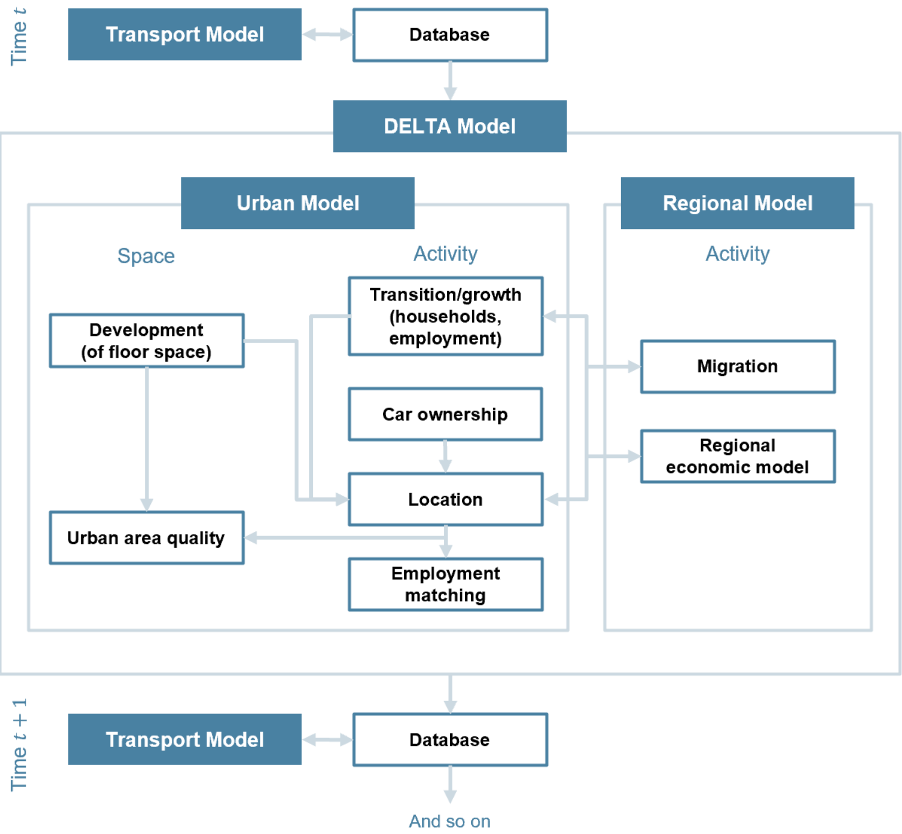
Like Martin Centre models, DELTA uses Alonso-type urban microeconomics theory to clear floorspace markets. However, DELTA only clears the market for the subset of households, firms and floorspace that are active in the market in a given time step (rather than the whole market) – shifting from a static equilibrium approach to a dynamic approach.

Multi-level dynamic models represent a range of economic relationships between actors, albeit less comprehensively than Group 7 (urban SCGE) models. They also represent characteristics of agents (households, firms and developers) and land and buildings, albeit in less detail than Group 4 (microsimulation dynamic) models.

Due to the high degree of detail represented in the economic relationships between regions and the characteristics of households, firms and developers, the data requirements for multi-level dynamic models are relatively intensive.

Multi-level dynamic models are generally suitable for reference case land use forecasting, estimating the land use impacts of transport interventions for use in project and program development, strategy development and policy analysis.

Figure 2-7 Schematic of a typical DELTA model



Source: Adapted from Simmonds (2007)

2.6.7 Group 7: Urban SCGE models

Urban SCGE (Spatial Computable General Equilibrium) models, such as RELU-TRAN have full economic representations of the urban economy. They combine the standard Computable General Equilibrium (CGE) approaches to consumer and producer behaviour with random utility models for location (and other) choices made by households and firms and include a higher spatial resolution in urban areas than standard CGE models. All goods, services and factors in the model have prices which can vary to 'clear' their relevant markets. All market equilibria are solved simultaneously. Refer to Figure 2-8 for a schematic of a typical RELU-TRAN model.

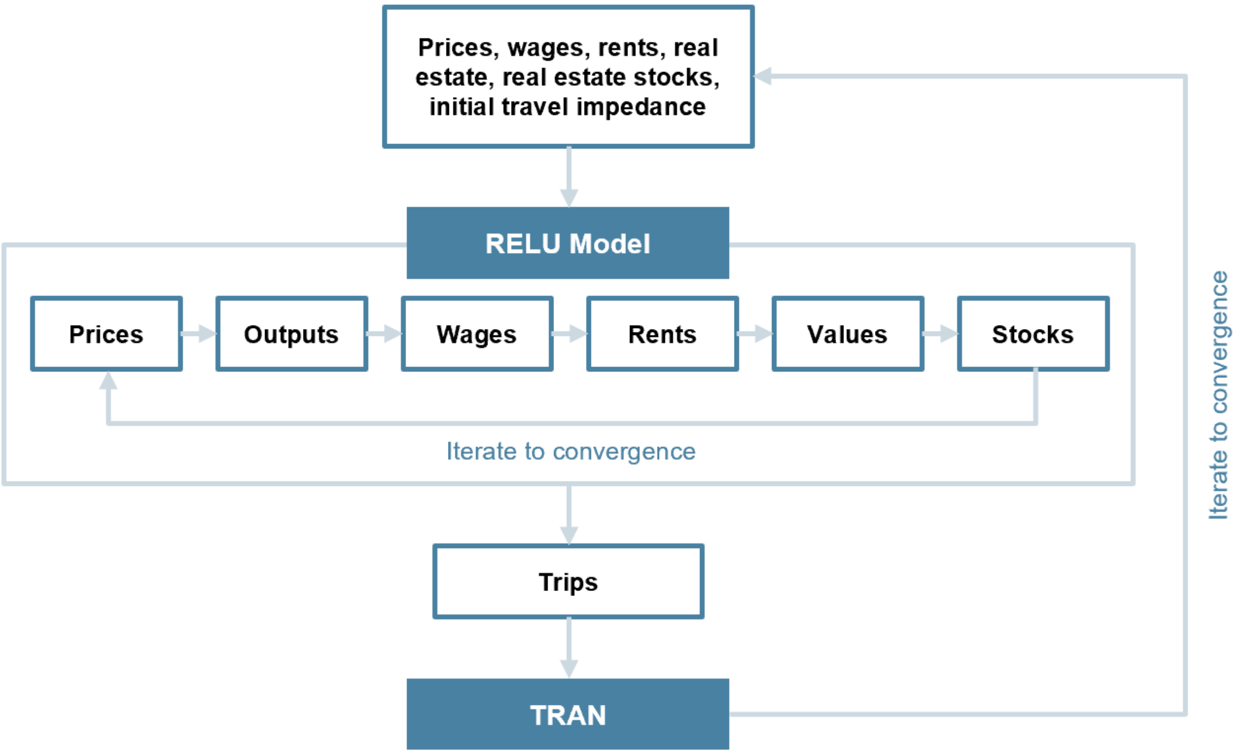
Urban SCGE models typically use a static equilibrium approach and are calibrated to a baseline year (similar to Group 5 models). Lennox (2023) proposes an urban SCGE model approach which incorporates dynamic effects.

Urban SCGE models tend to have a lower spatial resolution and a much more abstract represent of supply constraints (e.g. planning regulations, parcel configurations) than microsimulation dynamic models.

Urban SCGE models have intensive data requirements for the economic data used by the equilibrium models, however, data requirements relating to land use itself (e.g. parcel configurations, planning rules) are light, as those aspects are only represented at a high degree of abstraction.

Urban SCGE models are best suited for strategy development and policy analysis. They are less well suited to reference case land use forecasting and for estimating the land use impacts of transport interventions for use in project and program development, due to their more aggregate representations of parcel configurations, planning regulations and other supply constraints.

Figure 2-8 Schematic of a typical RELU-TRAN model



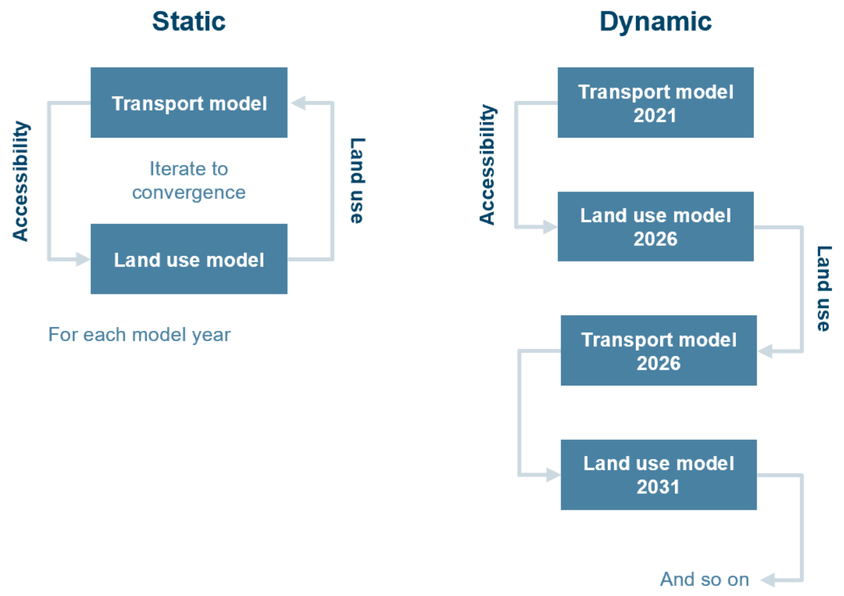
Source: Adapted from Anas & Liu (2007)

2.7 Points of contention

There are several key topics that are central to the discourse on LUTI models. Some of the key points of contention are introduced here and discussed in more detail in Section 4.

Dynamic or static: Dynamic models (e.g. Group 4 and Group 6 models) start with a representation of the built environment, and the modelling process then evolves the built environment through the location and other choices of relevant agents (households, firms, developers, governments) in response to conditions which change over time. Static models (e.g. Group 5 and Group 7 models) represent all choices for all agents in each modelled year, representing a long run equilibrium state. There is a trend towards static model approaches starting to adopt more dynamic components. There is general agreement that dynamic approaches are preferable for the purposes described in Section 2.5 in most cases, though there may be some exceptions. Refer to Section 4.5 for more discussion of this topic and Figure 2-9 for an illustration of the difference between the two.

Figure 2-9 Difference between static and dynamic models



Source: Author's analysis

Calibrated longitudinally or at a single point in time: Dynamic models are usually calibrated longitudinally, by comparing modelled land use change per spatial unit from a past time period (e.g. 2006 to 2021) to observed land use change in that time. Static models are usually calibrated to a baseline year only (e.g. 2021) and then those parameters are carried forward to forecast years. Refer to Section 4.4 for more discussion of this topic.

Calibrated to local conditions or not: Some LUTI models are calibrated specifically to local conditions , allowing them to be sensitive to local consumer preferences, macroeconomic and population drivers, political environment and market conditions, while others use parameters estimated in other cities, or a mix of both. It is generally agreed to be preferable to use models that are calibrated to local conditions where possible. Urban SCGE models model parameters may be more portable between cities than other approaches. Refer to Section 4.4 for more discussion of this topic.

Open city or closed city: LUTI models often represent a single metropolitan area or economic region. Population and economic growth may be defined exogenously and remain fixed between scenarios, so the LUTI model only redistributes population and employment within the region. This is known as a 'closed city' approach. Some LUTI model approaches also account for relationships between regions, meaning that interventions may have an impact on the long-run population and employment of the modelled region in total (e.g. by inducing a higher level of net migration). This is known as an 'open city' approach and is more commonly employed with Group 6 (multi-level dynamic) and Group 7 (urban SCGE) model approaches than other approaches. Refer to Section 4.7 for more discussion of this topic.

Spatial resolution: LUTI model approaches range from having individual parcel-level detail represented (e.g. microsimulation dynamic models) to having suburb-level or coarser spatial units (e.g. urban SCGE models). LUTI models also sometimes have hierarchical spatial units, so different levels of resolution can be applied for different model components. The choice of spatial resolution is largely dependent on the nature of the proposed application. Refer to Section 4.1 and 4.7 for more discussion of this topic.

Market equilibria: LUTI model approaches range from all relevant markets having supply, demand and prices represented and 'cleared' in each time period by converging to an equilibrium state (urban SCGE approaches) to having little or no representation of economic relationships between agents. There is a trend towards LUTI models incorporating more sophisticated representations of supply, demand and prices for relevant markets (e.g. land markets, labour markets, real estate markets). Representations of market processes in LUTI models are generally desirable, but the choice of detail in which economic relationships are represented is largely dependent on the nature of the proposed application. Refer to Section 4.9 for more discussion of this topic.

How accessibility is defined: The way accessibility and travel costs are defined and treated can vary widely between LUTI modelling approaches, and even within categories of LUTI models. The key distinction is between models which use location based or cumulative opportunities approaches and those which use utility-based measures in econometric models. More discussion of accessibility measures is included in Section 2.8.2 and Section 4.3.

2.8 Integration with transport models

2.8.1 Integrated and linked models

Linked LUTI models operate with separate land use and transport sub-models that exchange information at specific intervals, while integrated LUTI models feature a more cohesive structure where the sub-models interact continuously (e.g. FABILUT model, see Ziemke et al. 2022). In practice, most operational LUTI models are linked.

Historically, land use models and transport models have been developed separately, leading to the necessity of linking these models to capture the dynamic interactions between land use and transportation systems. This separation is primarily due to the distinct nature of the data and methodologies employed in each type of model.

Linkage typically involves the use of accessibility measures that connect the transport model's outputs, such as travel times and costs, with the land use model's inputs, such as location choices for households, firms and real estate developers. The feedback loop created by this linkage allows for the simulation of how changes in the transport system can influence land use patterns and vice versa.

Linked models preserve the strengths of the transport and land use models. Combining the two may require different trade-offs to be made for computational reasons.

2.8.2 Accessibility as the mediator between land use and transport

Accessibility is a pivotal concept in urban planning and transport modelling; it serves as a bridge between land use models and transport models. It essentially measures the ease with which people can reach desired opportunities, such as workplaces, schools and recreational facilities.

Accessibility can be defined as the ease of reaching desired opportunities from a given location, considering various factors such as travel time, cost and convenience. It reflects the spatial distribution of opportunities and the efficiency of the transport system in connecting people to these opportunities.

There are several ways to measure accessibility, each with its own advantages and limitations. Geurs & van Wee (2004) identified four key components that should be included in an accessibility measure:

- **Land-use component:** This refers to the spatial distribution and quality of opportunities, such as jobs, schools and healthcare facilities.

- **Transportation component**: This considers the disutility experienced in travelling, including travel time, costs, and perceived inconveniences like transfers.
- **Temporal component:** This accounts for the availability of opportunities at different times of the day and the time available for people to participate in those opportunities.
- **Individual component**: This considers the needs and preferences of different individuals, such as their willingness to travel, car availability and skill levels.

Geurs & van Wee (2004) also categorised accessibility measures into four types:

- **Infrastructure-based measures:** These focus on the performance of specific transport infrastructure, such as average speed and level of service. These measures are straightforward to calculate and are particularly useful for evaluating the performance of transport infrastructure. However, they do not consider the spatial distribution of activities and opportunities, which can limit their effectiveness in comprehensive accessibility analysis.
- **Location-based or cumulative opportunities measures:** These consider the number of opportunities available from a given location, weighted by a deterrence function that reflects the declining value of opportunities as travel impedance increases. These measures are alternatively known as 'effective density' measures. They are widely used in academic literature and practical applications, including UrbanSim implementations and in estimation of agglomeration benefits of transport interventions. They meet all four criteria for a robust accessibility measure (land-use, transportation, temporal and individual components). However, they may oversimplify by assuming all opportunities are equally desired and can be less sensitive to individual variations in accessibility needs. Some location-based measures use trip or destination-weighted average travel times or generalised travel costs.
- **Person-based measures:** These are highly disaggregated and consider the opportunities available to an individual at a given time, accounting for personal constraints and preferences. These measures provide a nuanced understanding of accessibility at the individual level and account for individual variations. However, they are data-intensive and typically applicable only to small regions or populations, making them complex to implement on a larger scale due to the high level of detail required.
- **Utility-based measures:** These assess the economic benefit derived from access to opportunities, often using random utility theory to interpret accessibility. These measures incorporate multiple transport choices and activities, making them useful for economic evaluations and enabling the computation of CBA for transport or land use projects. However, they are complex to calculate and require extensive data on individual preferences and behaviours, which can make them challenging to communicate to non-technical stakeholders due to their complexity.

In practice, operational LUTI models tend to use either location-based (cumulative opportunities) measures or utility-based measures. Section 4.3 provides a more detailed treatment of accessibility measures.

2.8.3 Types of transport models

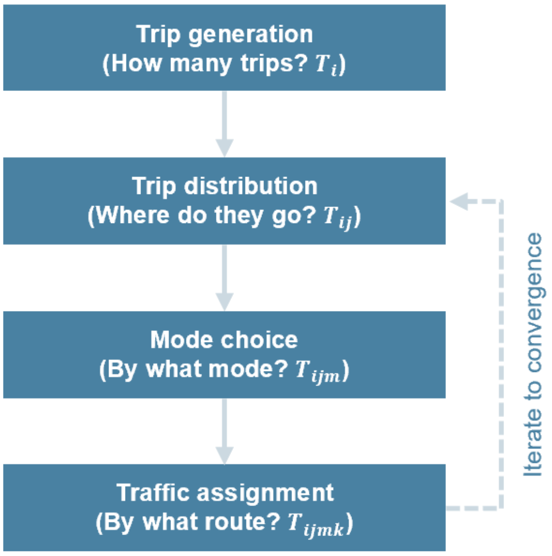
Transport models are used for projecting multi-modal travel demand, volumes, congestion and crowding. These models are broadly classified into two types: operational and strategic transport models, each serving different purposes and operating at varying levels of detail.

Operational transport models provide a detailed representation of transportation systems over smaller geographic areas and shorter time horizons. They are used for operational planning, traffic management and evaluating the performance of specific transport interventions. Operational models focus on the detailed interactions between individual vehicles, traffic signals and road networks to simulate traffic flow, congestion and travel times. Operational transport models include **meso, micro and nano transport models**. Further discussion can be found in ATAP T1 *Travel Demand Modelling*.

Strategic transport models provide a high-level representation of transportation systems over large geographic areas and long time horizons. They are used for policy analysis, long-term planning and evaluating major infrastructure projects. Strategic models represent aggregate relationships between volumes, capacities, crowding and congestion. This is referred to as a macro transport model in ATAP T1 *Travel Demand Modelling* Section 3.6.3.

The most common structure for strategic models is the four-step modelling approach, as per Figure 2-10. Recently, there has been significant efforts for agencies to move to more sophisticated tour-based, activity-based and agent-based strategic modelling approaches, though at the time of writing these are not yet widely used in Australian practice.

Figure 2-10 The four-step strategic transport modelling process



Source: Adapted from Peeta et al. (2011)

LUTI modelling is best suited to estimating the city and region-shaping impacts of major interventions and alternative future scenarios. As such, they are best used with strategic transport models.

Activity and agent based transport models

There is currently a trend in Australia towards adoption of activity-based transport models, particularly using the open-source ActivitySim software and Bentley's AGENT software. These models use agent-based representations of households and persons and simulate their travel choices, including long term decisions like car ownership and workplace choice, and short-term decisions like daily activity patterns, travel mode, time of day, destination and route choices. These agent and activity-based demand models typically iterate with static, aggregate assignment techniques in the same way that traditional trip-based aggregate demand models do (see Section 4.9 for an explanation of how strategic models iterate to an equilibrium state). For this reason, activity-based models can interface with LUTI models in the same way that trip-based models do via the use of origin destination skim matrices[1] that represent generalised travel costs per origin-destination pair.

[1] Skim matrices represent travel impedance between different origin-destination pairs. Travel impedance is usually represented as generalised cost of travel, which can incorporate factors such as travel time, distance, and monetary costs like tolls or fares.

Activity and agent-based models also present the opportunity to more tightly couple land use and transport decisions in a comprehensive integrated LUTI modelling framework at the agent level. This is an area for further academic research and development and is beyond the scope of existing operational LUTI models. An example of an integrated agent-level LUTI model is the FABILUT model developed by academics in Germany (Ziemke et al. 2022).

3. The current state of practice

3.1 How LUTI modelling is used internationally

LUTI models have been applied globally in various contexts to support urban planning and transport planning. This Section includes some examples of how different models, including DELTA, UrbanSim, Cube Land, TIGRIS-XL and PECAS, have been applied.

In the UK, the DELTA land use model, often integrated with the START transport model, has been widely applied. It has been used for transport economic appraisals of significant projects such as Crossrail 2, Silvertown Tunnel and the Trans-Pennine Tunnel. The UK Department for Transport employs LUTI modelling to forecast changes in employment location, dynamic agglomeration calculations, and benefits arising from improved job accessibility.

In North America, several Metropolitan Planning Organisations (MPOs) utilise the UrbanSim microsimulation dynamic model. Notable applications include the San Francisco Bay Area model by the Metropolitan Transportation Commission, the Detroit Metropolitan Area model by the Southeast Michigan Council of Governments and the San Diego model by the San Diego Association of Governments. UrbanSim is also used in Canada. Additionally, Cube Land is employed by a few MPOs in the US for urban planning decision support. PECAS is applied by transport agencies in regions such as Ohio, Oregon, California (Sacramento and San Diego) and the greater Atlanta and Baltimore areas. PECAS is used for forecasting the impacts of urban growth boundaries and other planning scenarios.

In New Zealand, the DELTA model is part of the Auckland Transport Models (ATM2) project, which includes the Auckland Regional Transport Model (ART3) and the Auckland Strategic Planning Model (ASP3). This microsimulation dynamic model was notably applied to appraise the impact of an additional Waitemata harbour crossing in Auckland. ASP3 is currently in the process of being retired.

In France, the Grand Paris Express project, a major urban redevelopment program, employs multiple LUTI models. These include UrbanSim, RELU-TRAN, and a bespoke model called Pirandello. Additionally, David Simmonds developed a DELTA-based model called "Le Modèle interregional pour la France" for the Grand Paris Express rail project.

In Europe, the SustainCity project, funded by the European Union and coordinated by the Technical University of Zurich, addresses modelling and computational issues related to integrating transport models in advanced LUTI models. The project includes case studies in Paris, Zurich and Brussels, using the UrbanSim platform. Although SustainCity is primarily an academic research program, it has significantly contributed to the practical application and popularity of LUTI models in Europe.

The Netherlands employs the TIGRIS-XL model, developed for the Ministry of Infrastructure and Environment. This model complements the national transport model of the Netherlands and is used to evaluate various transport and land use scenarios. Although this model was originally designed for the Netherlands, its generic concept allows for adaptation to other urban regions, such as the development of a Generic Urban Model (GUM) for the UK Department for Transport. In this instance, TIGRIS-XL interacts with the Central Leicestershire Transport Model (RAND Europe 2006).

3.2 How LUTI modelling is used in Australia

There are numerous examples of LUTI analysis being undertaken in Australia, usually in the context of claiming land use impacts and land use benefits of major transport infrastructure programs as part of a business case for submission to a State Treasury agency and/or to Infrastructure Australia. The sophistication of LUTI analysis techniques has varied. There have also been a few attempts by planning agencies to build and calibrate LUTI models to use for the primary purpose of generating land use forecasts for planning purposes. These attempts have not always been successful.

Some select examples of how LUTI models have been applied in Australia are introduced below and discussed in detail in Section 5.

- The Department of Transport and Main Roads (DTMR) in Queensland developed the ‘Model for Urban Land Use and Transport Interaction’ (MULTI). The model was used in the development of ShapingSEQ (2023b) statutory land use targets and Region Shaping Infrastructure list. MULTI was applied to provide an evidence base to inform planning and investment decisions. It was used to provide an initial understanding of the current situation (problem statement) under approved existing land use and infrastructure planning, and for testing the combined impact of land use, infrastructure and transport policy interventions on future population, employment and dwelling growth distribution across the SEQ region.

- The Victorian Government employed the CityPlan model in the Suburban Rail Loop Business and Investment Case to assess the land use impacts of the proposed rail infrastructure and associated planning changes. The model was used to estimate how the SRL would influence urban development patterns, employment distribution, and residential growth around the new and upgraded rail stations and the broader corridor. The modelling was used to support the Business and Investment Case and was incorporated in the economic appraisal (Suburban Rail Loop Authority (SRLA) 2021a).

- Infrastructure Victoria utilised the ‘Spatial Interactions within and between Regions and Cities in Victoria’ (SIRCV) model to inform its 30-year Infrastructure Strategy. SIRCV combined with the Victorian Integrated Transport Model (VITM) was referred to as VLUTI. SIRCV was used to estimate the spatial impacts of a range of alternative infrastructure and policy scenarios (Infrastructure Victoria 2021).

3.3 When to consider LUTI modelling

Proponents considering LUTI modelling should seek expert advice as to the suitability of using LUTI modelling for their application. This section provides some general advice on when it may be appropriate to use LUTI modelling to support a decision or process.

Whether LUTI modelling is appropriate for a given context depends on the extent to which the interaction between land use and transport systems is material to the analysis. In general, LUTI modelling is appropriate for the purposes described in Section 2.5, particularly when scenarios or interventions are expected to materially influence the spatial distribution of population and employment and/or net migration to/from regions or localities due to impacts on road network congestion and/or crowding on public transport services. Scenarios and interventions of this type are often referred to as having 'city-shaping' or 'region-shaping' impacts. These impacts are typically associated with major urban centres. However, smaller and medium-sized cities can also experience substantial impacts, especially when connected with larger cities by major infrastructure interventions (e.g. high-speed rail).

Another factor to consider is whether there is capacity in the land use market to support further development. If an area is considered to have reached its ultimate development capacity, it may not be justified to estimate land use uplift from interventions in that area unless the intervention itself unlocks further development capacity (e.g. through relaxing of zoning restrictions).

The relationship between the size of the initiative and the size of the city is a key consideration. For smaller and medium-sized cities, the scale of the intervention must be substantial enough to warrant the use of a LUTI model. For instance, while a minor road improvement may not justify LUTI modelling, a new rail line connecting multiple urban centres could have region-shaping impacts that do. To test the changes resulting from a specific project, it is essential to assess whether the scale of influence is significant enough to justify the use of LUTI modelling.

Regional and rural areas are unlikely to benefit from LUTI modelling. The expected benefits of infrastructure interventions in these areas are often related to climate resilience, access needs, and supply chain reliability. By contrast, infrastructure interventions in major cities may target road network congestion, crowding on public transport and/or the ability to support ease planning restrictions near public transport nodes. These factors are unlikely to be impacted by infrastructure interventions in areas with a dispersed population and low traffic volumes. In this context, LUTI modelling may not be necessary or appropriate.

3.4 Data requirements for LUTI modelling in Australia

Australia generally has access to high-quality data sources for LUTI modelling. Table 3-1 provides a categorisation of key data requirements and potential data sources. The biggest data gap in Australia generally is access to high-quality, complete and accessible datasets relating to rental and sale price data, particularly for non-residential rents.

All LUTI modelling approaches require transport, land use and demographic data to some extent. The precise data needs vary by modelling approach, but also can vary between model implementations, even between two models that use the same general approach. Generally, LUTI modelling approaches with more economic relationships and that are dynamic (i.e. approaching the bottom right corner of Figure 2-3), require more detailed datasets. The approaches with full economic relationships, such as Group 7 urban SCGE models, require economic data. Dynamic approaches, such as Group 4 microsimulation dynamic models, require time series data including relocation/transition data and more detailed land use, property and developer data than other approaches.

Table 3-1 LUTI model data requirements and potential sources

Category	Data requirement	Potential data sources
Economic data	• Inputs and outputs by sector • Population and employment estimates and forecasts • Economic indicators and forecasts (e.g. GDP, wages, interest rates)	• ABS National Accounts[2] and Business Longitudinal Analysis Data Environment (BLADE)[3] • Reserve Bank of Australia (RBA)[4] • State Treasury agencies • CGE Models maintained by government agencies, universities and consulting firms

[2] ABS National Accounts can be found via this link or go to the ABS website.

[3] ABS BLADE can be found via this link or go to the ABS website.

[4] RBA can be found via this link or go to the RBA website.

Category	Data requirement	Potential data sources
Demographic estimates/projections	• Population by age by small area • Households by type/composition by small area • Employment by sector/collar by small area	• ABS Census[5] • Demographic projection models maintained by state and territory planning agencies • ABS population projections[6]
Relocation/transition data	• Tenure by household type • Household formation data (births/deaths/marriages/divorces) • Migration flows	• Demographic projection models maintained by state and territory planning agencies • Household, Income and Labour Dynamics in Australia (HILDA)[7] owned by University of Melbourne • ABS Census[8] • Regional internal migration estimates from ABS[9] • Medicare change of address data[10]
Transport data	• Travel times/distances/costs by o-d pair by mode • Trips by o-d pair by mode • Measures of accessibility by zone	• Strategic transport models maintained by state and territory planning agencies • Household travel surveys maintained by state and territory planning agencies • ABS Journey to Work and Journey to Education data from Census[11]

[5] ABS Census can be accessed via TableBuilder and Microdata or go to the ABS website.

[6] ABS population projections can be found via this link or go to the ABS website.

[7] HILDA can be found via this link or go to the University of Melbourne's Melbourne Institute of Applied Economic and Social Research website.

[8] ABS Census can be accessed via TableBuilder and Microdata or go to the ABS website.

[9] Regional internal migration estimates can be found via this link or go to the ABS website.

[10] Not publicly available.

[11] ABS Journey to Work and Journey to Education data can be found via TableBuilder or go to the ABS website.

Category	Data requirement	Potential data sources
Land use data	• Planning zones • Heritage/planning overlays • Vacancy rates • Neighbourhood characteristics (e.g. amenity, walkability, education, income, socioeconomic indicators) • Planning policies • Capacity constraints/buildable area • Natural features (e.g. beach, coastline, rivers, hinterland) • Land use composition (e.g. industrial, retail, health, commercial, parks/greenspace)	• Planning scheme layers owned by state/territory and local government agencies. • Land use surveys and censuses (e.g. Census of Land Use and Employment (CLUE) for City of Melbourne[12]) • ABS Census data (including Socio-Economic Indexes for Areas (SEIFA)[13], income, education levels and other socioeconomic indicators)[14] • ABS Mesh Block land use classifications[15] • Non-government data sources like Google Maps and OpenStreetMap.
Property data	• Parcel sizes and configurations • Building characteristics (e.g. footprint, use, height, gross floor area, coverage, number of bedrooms/bathrooms) • Residential prices/rents • Non-residential prices/rents • Unimproved land values • Serviceability (e.g. water, sewer, electricity, telecommunications)	• Parcel and property layers owned by state/territory government agencies • Valuation data owned by local governments and Valuer-General organisations. • Non-government data sources like GeoScape, Corelogic/Cotality
Developer data	• Building applications, approvals and completions • Development costs (e.g. construction cost, civil works cost, statutory cost, development fees, infrastructure charges, financing cost, marketing and sales cost) • Approval pipeline (e.g. development application, development approvals, operational works approval, vacant lot, building approvals)	• ABS building approvals[16], completions[17] • State/territory and local government agencies

Source: Author's analysis

[12] CLUE can be found via this link or go to the City of Melbourne website.
[13] ABS SEIFA can be found via this link or go to the ABS website.
[14] ABS Census can be accessed via TableBuilder and Microdata or go to the ABS website.
[15] ABS Mesh Block land use classifications can be found via this link or go to the ABS website.
[16] ABS Building Approvals can be found via this link or go to the ABS website.
[17] ABS Building Activity, including completions, can be found via this link or go to the ABS website.

3.5 Where to from here?

The following recommendations are made to advance the state of LUTI modelling in Australia.

- Academic research and development into LUTI modelling approaches (including integrated approaches) and land use benefits estimation should be funded.
- State transport and planning agencies should invest in developing and maintaining and continually improving their own high quality LUTI models for the applications described in Section 2.5, rather than relying on consultants developing and applying their own methods.

Agencies that are interested in developing their own LUTI models will have a choice between building their own models, using open-source or custom software or using an off the shelf software package. Software packages often provide a cost-effective and user-friendly solution that can reduce initial costs but may lack the flexibility and specificity required for certain applications, incurring additional expenses for customisation and integration. Developing bespoke models can be expensive and time-consuming, requiring significant resources for initial development and ongoing maintenance, however, it can be better tailored to meet specific and future needs (see Section 2.5 for common applications).

4. Principles of good practice

This section provides a set of principles for practitioners and stakeholders to consider when selecting an appropriate LUTI modelling approach. These nine principles are designed to support government agencies in selecting a model approach that aligns with their unique needs and objectives in the context of the current state of practice.

A LUTI modelling approach does not have to meet all the principles of good practice discussed in this section to be suitable for a given purpose. Different modelling approaches comes with inherent trade-offs, and the strengths and weaknesses of each approach must be evaluated in the context of the proposed applications. In recognition of these inherent trade-offs, principles are characterised as ‘must have’ or ‘should have’ and these are identified in Table 4-1.

Table 4-1 Principles of good practice; ‘must have’ and ‘should have’

‘Must have’ principles	‘Should have’ principles
• Fit for purpose (Section 4.1) • Transparent (Section 4.2) • Represent accessibility (Section 4.3)	• Well calibrated (Section 4.4) • Dynamic (Section 4.5) • Represent economic relationships (Section 4.6) • Represent demand (Section 4.7) • Represent supply constraints (Section 4.8) • Produce stable, repeatable outcomes (Section 4.9)

4.1 Model must be fit for purpose

There is no single correct choice of LUTI modelling approach. The most important consideration is that the selected approach should be suitable for its intended purposes. From a practical perspective, the model run-time, computation/storage costs and data requirements need to be appropriate for the desired application.

Like all models used to support decision making, LUTI models should be parsimonious. This means they should be no more complex than necessary to achieve their intended purpose. Each additional layer of complexity should be justified by a corresponding gain in explanatory power, predictive accuracy or policy relevance.

Different approaches tend to have different levels of spatial aggregation. In general, econometric models (e.g. Group 7 urban SCGE models) tend to have lower spatial resolution (e.g. suburb level), whereas dynamic models (e.g. Group 4 microsimulation dynamic models) tend to have very high spatial resolution (at individual land parcels). This is not always the case, as different model implementations even within a group often have different spatial resolutions depending on their purpose, data availability and other factors. There is no one correct approach, but the spatial resolution should be fit for the desired purpose.

Some considerations for choosing a LUTI model approach against the common applications presented in Section 2.5 are shown in Table 4-2.

Table 4-2 Considerations for choosing LUTI model approaches

Purpose	Model functionality considerations	Run-time and performance considerations	Spatial resolution considerations
Land use projections for planning purposes	Group 4 (microsimulation dynamic) and Group 6 (multi-level dynamic) models are best suited.	Preparation of reference case land use projections is done infrequently, so longer run-times and higher computing costs may be acceptable.	Finer spatial resolution is required for land supply interactions, preferably parcel-level. Demand and supply interaction could occur at a coarser spatial resolution.
Project and program development	Group 4 (microsimulation dynamic), Group 6 (multi-level dynamic) or Group 7 (urban SCGE) models are all suited, depending on the nature and scale project or program.	Run-times should be shorter due to the nature of planning studies and business cases having tight deadlines and dynamic priorities.	Finer spatial resolution is usually required, preferably parcel-level or SA1.
Strategy development			Moderate spatial resolution is usually required, e.g. SA1 or SA2.
Policy analysis			Coarser spatial resolution may be suitable, e.g. SA2.

Source: Author's analysis

4.2 Model approach and assumptions must be transparent

LUTI models are often used to underpin strategic planning and to evaluate proposed infrastructure and policy interventions. Recommendations from planning studies that use the outputs of LUTI models often entail large implementation costs for societies and their taxpayers. These costs may be financial (e.g. through increased taxation to support the investment) or non-financial (e.g. through changes in urban form or new infrastructure which impact amenity). Due to this, the 'burden of proof' lies on the proponent of an intervention. For this reason, any LUTI modelling approach and assumptions must be transparent and clearly documented. The model should be based on accepted modelling principles and in line with academic literature. Where the scale of intervention justifies it (e.g. as part of a major business case, long term strategy or significant policy reform), LUTI modelling approach, assumptions, and results should be peer reviewed by an independent external party.

When results are presented, intermediate indicators that describe the main drivers of an outcome should be included in reporting. For example, if land use impacts of a transport intervention are claimed due to a change in accessibility, the modelled change in accessibility should be presented visually through maps or spatial plots along with the estimated change in households and firms. Similarly, if changes in land use ultimate capacities or development rates are represented, the change between Base and Project Case should be presented spatially. The documentation should clearly outline how they were changed, whether these changes are likely to be accepted by relevant authorities and/or communities and whether they align with state or regional planning policies. This enables a reader or peer reviewer to clearly understand the drivers of modelled outcomes and assess their reasonableness.

Where LUTI models are used to estimate land use benefits as part of economic appraisal, results should be presented with and without land use changes. Refer to ATAP O8 *Land-use Benefits of Transport Initiatives* Section 4.3 for further guidance on how to present land use benefits.

4.3 Model must represent accessibility

By definition, all LUTI models must contain representations of accessibility. Section 2.8.2 contains a detailed definition of accessibility and the different types of measures.

LUTI models take travel costs from a transport model as an input, typically in the form of generalised cost skim matrices, and produce land use/demographic projections as an output to feed back into the transport model. The land use model is usually separate and standalone, as most LUTI models are typically 'linked' rather than 'integrated' (see discussion in Section 2.8.1).

While all LUTI modelling approaches use accessibility measures, the way accessibility is represented can vary. For example, Group 7 urban SCGE models use utility-based accessibility measures, typically representing travel costs as a disutility of commuting, which is combined with the utility of residing in location A and working in location B in a joint residential and workplace location choice model (e.g. dynamic spatial model (DSM), see Lennox 2023). Group 4 microsimulation dynamic models typically incorporate travel costs into location-based (cumulative opportunities) accessibility measures, which are used as explanatory variables in location choice models (e.g. UrbanSim, see Waddell 2011). Group 6 multi-level dynamics models typically use utility-based logsum accessibility measures as explanatory variables in residential and workplace location choice models (e.g. TIGRIS-XL, see Zondag et al. 2015).

It is critical for the way travel costs are represented in the land use model to be consistent with the way travel costs are represented in strategic transport models. Ideally, this should include value of time. This ensures that the land use and travel models are compatible with each other, and model responses are internally consistent within the LUTI model system. Travel cost measures applied in LUTI models should:

- **Incorporate all travel cost components that are relevant for residential and workplace location choices**. These may include weighted travel time (accounting for in-vehicle time and out-of-vehicle time, with weights applied for wait time and access/egress time consistent with the strategic transport model), relevant monetary costs (fares, tolls, vehicle operating costs and parking costs), and any other relevant cost components (e.g. boarding and transfer penalties). The effects of road congestion and public transport crowding should be reflected in the impedance measure.
- **Combine monetary and non-monetary costs into a single measure of 'generalised cost'**. This can be expressed in generalised minutes (with monetary values converted to equivalent minutes based on a value of time) or generalised dollars (with time converted to equivalent monetary value). This requires a value of time to be assumed. Value of time can vary according to various factors; however, it is most common in strategic transport models for value of time to vary most substantially by trip purpose (e.g. commuting, business, leisure). Measures of generalised cost derived from transport models will typically relate to a purpose, mode and time period. For example, for a given origin-destination pair, mode and time period, the commuting generalised cost will differ from the business generalised cost as business values of time are typically much higher than commuting values of time. Commuting generalised costs are usually represented in LUTI models as a key driver of both residential and workplace location choice as commuters seek to mitigate commuting costs. Business generalised costs are also often important as a driver of workplace location choice as firms seek agglomeration economies by locating near their customers and suppliers.
- **Represent all motorised modes (car and public transport).** Some LUTI models include separate travel impedance measures for car and public transport, however, it is considered best practice to use 'combined mode' measures in LUTI models. There are three common ways to achieve this:

- **Logsum of mode choice models**. Strategic transport models typically include a mode choice model based on random utility theory, using generalised travel costs for each mode for each origin-destination pair. Depending on the specifics of the transport model specification, it is usually possible to use the mode choice model to derive a 'logsum' measure that represents the combined disutility of travelling from a given origin to a given destination by all motorised modes (car and public transport). Logsums are expressed in 'utils' which can be used directly by a LUTI model or converted into equivalent generalised dollars or minutes using mode choice model coefficients. Utility values from a transport model should be negative (as travel is represented as a disutility), however logsum utilities can sometimes be positive. If this is the case, it may be appropriate to apply a uniform constant to all travel utilities in producing the measure to ensure all travel utilities have the same sign.
- **Trip-weighted average generalised costs**. A similar measure to the above can be derived by using trip-weighted average generalised costs for each mode to produce a combined mode composite measure of impedance. When an intervention improves travel times for the second fastest mode between an origin and a destination, it can sometimes lead to an increase in trip-weighted travel times, as the model represents people switching from the fastest mode (e.g. car) to the second fastest mode (e.g. train). This can create measures where the accessibility worsens, even though the only thing that has changed is that train travel times have improved. To avoid this, when using trip-weighted average generalised cost measures in comparing two scenarios (e.g. a Base and a Project Case for economic appraisal), it is important to use the sum or average of the Base and Project Case trips as the weight for both Base and Project Case generalised cost measures. An illustrative example of calculating trip-weighted generalised minutes of a given origin-destination pair is provided in Appendix B.
- **Logsum of nested destination-mode choice models.** Some strategic transport models contain a nested destination-mode choice model based on random utility theory. By taking a logsum of the top level of the choice model, it is possible to derive a utility-based accessibility measure for each origin that represents the utility of accessing all destinations in the travel model system by all available (usually motorised) modes. This produces an output expressed in 'utils' which can be used directly by a LUTI model.

4.4 Model should be well calibrated

LUTI models should be calibrated to local conditions using historical information related to the local market. It is acceptable to use parameters from comparable other cities where it is not possible or practical to estimate or calibrate all parameters to local conditions. Which parameters should be locally calibrated and which can be appropriately adopted from other cities should be informed by expert advice. The calibration process and outcomes should be clearly and thoroughly documented, and validation criteria should be specified in advance.

An example five step approach to model calibration is provided below, based on the process that was used for CityPlan for the purpose of estimating the land use impacts of major transport interventions (Department of Transport and Planning (DTP) 2024b). The specifics of the calibration process will vary according to the purpose of modelling.

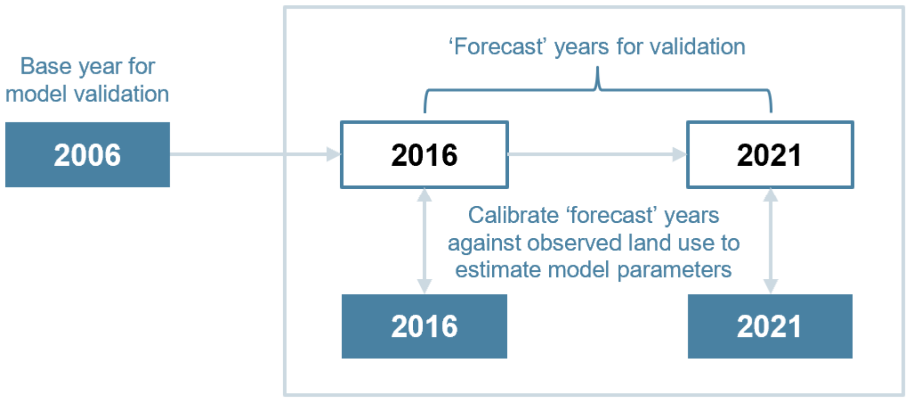
- **Model specification**: The sub-models are designed to best capture the relevant mechanisms of land use transport interaction for the relevant purpose.
- **Model estimation**: The sub-models are statistically robust and adhere to relevant statistical assumptions.
- **Model validation**: The model adequately reproduces historical growth patterns.
- **Model response**: The model's projections reasonably respond to changes in the transport network and planning inputs in a manner that is suitable for the relevant purpose.

- **Model projections**: The model generates reasonable and defensible projections for the spatial distribution of future growth that is suitable for the relevant purpose.

Model validation involves comparing the modelled outcomes with observed historical data. For example, 2006 could be defined as the baseline year, and ‘projections’ could be generated for the later historical years of 2016 and 2021. These projections are then compared with 2016 and 2021 observed historical data to validate if the model adequately reproduces land use changes between the baseline year and the ‘forecast’ year. To the extent that it does not, an iterative approach is undertaken to adjust model parameters to enable the model to achieve a satisfactory validation performance. Figure 4-1Figure 4-1 illustrates this process where the blue blocks represent the observed/historical data, and the white blocks represents the projections. This approach is often described as ‘backcasting’.

The backcasting approach is usually applied to dynamic modelling approaches which represent how land use evolves over time. Static model parameters are typically estimated cross-sectionally to a baseline year or adopted from literature, with the parameters carried forward to forecast years. An example of this type of approach can be found in Infrastructure Victoria (2021b).

Figure 4-1 Example model validation approach



Source: Modified version of Figure 10 from DTP (2024b)

Model validation criteria can identify a quantifiable condition that can be either met or missed with an assigned priority relative to each performance outcome of the model. The validation criteria should be specified in advance of model calibration and should reflect the nature of the desired application. An example set of validation criteria is provided in Table 4-3.

Table 4-3 Example model validation criteria

Element	Geography	Priority	Criteria	Outcome
Change in population	Statistical Area Level 2 (SA2)	High	Prediction accuracy better than 70%	Meets
Change in households	SA2	High	Prediction accuracy better than 70%	Meets
Change in employment	SA2	High	Prediction accuracy better than 70%	Meets

Element	Geography	Priority	Criteria	Outcome
Change in population by age	SA3	Medium	Prediction accuracy better than 70% for at least 60% of elements	Meets
Change in employment by type	SA3	Medium	Prediction accuracy better than 70% for at least 60% of elements	Misses
Change in tertiary enrolments	SA2	Medium	Prediction accuracy better than 70% for at least 60% of elements	Meets

Source: Modified version of Table 74 from DTP (2024b)

The prediction accuracy in Table 4-3 is used to determine whether the change in population (or households or employment) at an SA2-level over the backcasting period (e.g. 15 years) estimated using the LUTI model is predictive of observed change at the target accuracy (e.g. 70%) or greater. If the criteria are met, the outcomes are identified as "Meets", otherwise they are identified as "Misses". Validation criteria targets should be set with consideration to the purpose of the modelling.

Prediction accuracy (R^2) Prediction accuracy, shown in Equation 1, may be used as a measure of how well the model is predicting change in land use over time. Observed and predicted values should relate to the growth or change in the relevant element over the relevant time period (e.g. growth or change between 2006 and 2021), and not to the totals in the final validation year (e.g. 2021). Prediction accuracy is defined as the correlation between the observed and predicted values of the model. A value closer to 1 indicates positive correlation (better fit). A value close to 0 indicates no specific correlation between the observed and predicted values (poor fit). A value closer to -1 indicates a negative correlation.

Equation 1: Prediction accuracy

$$Prediction\ Accuracy\ (X,Y) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2(y-\bar{y})^2}}$$

Response testing can be designed following the below steps (DTP 2024b):

1. **Identify relevant shocks:** Determine the types of shocks the model should respond to, such as changes in accessibility, land use, capacities and other relevant changes.
2. **Prepare alternative (counterfactual) scenarios**: Develop a set of alternative/counterfactual scenarios that highlight the model's sensitivity to different input assumptions. These scenarios do not necessarily need to represent realistic situations but should test the model's responsiveness.
3. **Compare with base validation run:** Use a base validation run, such as historical period, as a benchmark to compare the outcomes of the counterfactual scenarios.
4. **Analyse outcomes**: Access the results of the response testing scenarios to understand how the model behaves under different conditions.
5. **Discuss sensibility:** Evaluate the sensibility of the model's responses to ensure they are reasonable and provide confidence in the model's ability to estimate impacts accurately.

This process helps in understanding the model's behaviour and ensures that its projections can be interpreted correctly when applied for planning purposes.

4.5 Model should be dynamic

Modelling approaches can be broadly defined as 'static' or 'dynamic', which refers to how the model approach treats time. The definitions are provided below.

Static models assume that all relationships are simultaneous, meaning that all actors make all location choices in each modelled year. This is intended to represent a long run equilibrium land use, but does not represent the evolution over time that led to the long run outcome. Most but not all Group 7 urban SCGE models follow this approach. Group 1 (static adjustment models) are also static, but require an exogenous future year land use forecast which is 'adjusted' using the forecast change in travel costs as a basis.

Dynamic models, on the other hand, account for the evolution of land use over time. These models consider land use outcomes at a point in time as functions of conditions at a previous point in time and the change in conditions over a preceding period. Dynamic models incorporate forward-looking decision-making, inertia, and path dependence in the land use system. Group 4 microsimulation dynamic models and Group 6 multi-level dynamic models use this approach. While Group 7 urban SCGE models are generally static, Lennox (2023) proposes a dynamic urban SCGE modelling approach.

Figure 2-9 in Section 2.7 contains a visual representation of the static and dynamic model approaches.

Generally, dynamic approaches are preferred. This is due to the significant 'lock-in' effects of real estate development, where when a building is constructed it is unlikely to be demolished and replaced in the short to medium term. While dynamic approaches are preferred there are typically trade-offs between how well modelling approaches represent urban dynamics and how well they represent economic relationships. Refer to Table 4-4 for further considerations.

Table 4-4 Considerations for choosing between static and dynamic approaches

Purpose	Considerations for choosing static vs dynamic approaches
Land use projections for planning purposes	Dynamic approaches are strongly preferred, as projections tend to be used for shorter and medium term infrastructure planning. Static approaches may include unrealistic changes in certain areas (e.g. overly rapid growth or inappropriate declines).
Project and program development	Dynamic approaches are preferred, as land use impacts from transport interventions tend to be realised gradually over time, and land use impacts and benefits are the most impactful in economic appraisal due to the impact of discounting.
Strategy development	Dynamic approaches are preferred, but static approaches for long range forecasting may be appropriate if the focus of the modelling is on long run outcomes.
Policy analysis	Dynamic approaches are preferred, but static approaches for long range forecasting may be appropriate if the focus of the modelling is on long run outcomes, and especially if policy reforms are best analysed using mechanisms that Group 7 (Urban SCGE) models are best suited to addressing (e.g. taxation reform).

Source: Author's analysis

4.6 Model should represent economic relationships

LUTI modelling approaches have various levels of sophistication in which economic relationships between actors are represented. LUTI modelling approaches vary from models that do not explicitly represent economic relationships at all (e.g. Group 1 static adjustment models and Group 3 system dynamics models) to approaches which explicitly represent revenue and expenditure streams between actors (e.g. real estate developers, governments, households, firms) and supply, demand, and prices in land and property markets. Group 7 urban SCGE models are the most sophisticated in representing economic relationships. Other modelling approaches have varying degrees of sophistication, as represented in Figure 2-3.

Generally, approaches with appropriately sophisticated representations of economic relationships are preferred, though there is usually a trade-off with how well they represent urban dynamics. This also depends heavily on the purpose of modelling. Refer to Table 4-5 for further considerations.

Table 4-5 Considerations for choosing economic relationship representation

Purpose	Considerations for choosing economic relationship representation
Land use projections for planning purposes	Sophisticated representation of economic relationships is desirable but not necessarily required.
Project and program development	Approach should represent economic relationships in at least some detail, especially if used as an input to economic appraisal.
Strategy development	Approach should represent economic relationships in at least some detail, especially if used as an input to economic appraisal. Depending on the nature of the interventions or scenarios being tested, it may be appropriate to have more sophisticated representations of economic relationships (e.g. using Group 6 or Group 7 approaches).
Policy analysis	The choice of approach will depend heavily on the nature of the policy reform being assessed. Group 4, 6 or 7 approaches may be best suited.

Source: Author's analysis

4.7 Model should represent demand appropriately

All LUTI models have some level of representation of the demand for buildings, typically categorised by **building types**. Examples include:

- **Residential dwellings:** These may be classified by type (e.g. separate house, semi-detached, apartment, and non-private dwellings like aged care or boarding homes) and represented as individual dwellings and/or by floorspace.
- **Non-residential buildings:** These may be classified by type (e.g. office, retail, industrial and other), and represented as individual buildings, floorspace and/or 'job spaces' (which have implicit or explicit assumptions about how much floorspace is taken up by each worker).

Vacancy rates are often represented in terms of building occupancy, indicating whether buildings are occupied or vacant.

LUTI models also need to contain representations of the actors that demand buildings, which include households and firms. **Residential buildings** are usually defined as being demanded by households, who may be 'utility-maximising', and **non-residential buildings** are demanded by firms, who may be 'profit-maximising'. Examples of household and firm attributes include:

- **Demographic and socio-economic characteristics** of households and persons, including attributes like age, household composition, income, labour force status, occupation, education and others.

- **Industry and occupation characteristics** of firms, including attributes like industry, occupation, productivity and others.

LUTI models also need to represent the **investment decisions of developers**. Developers are typically assumed to be ‘profit-maximising’ in that they seek to maximise the value of the buildings they produce while minimising the cost of delivering them.

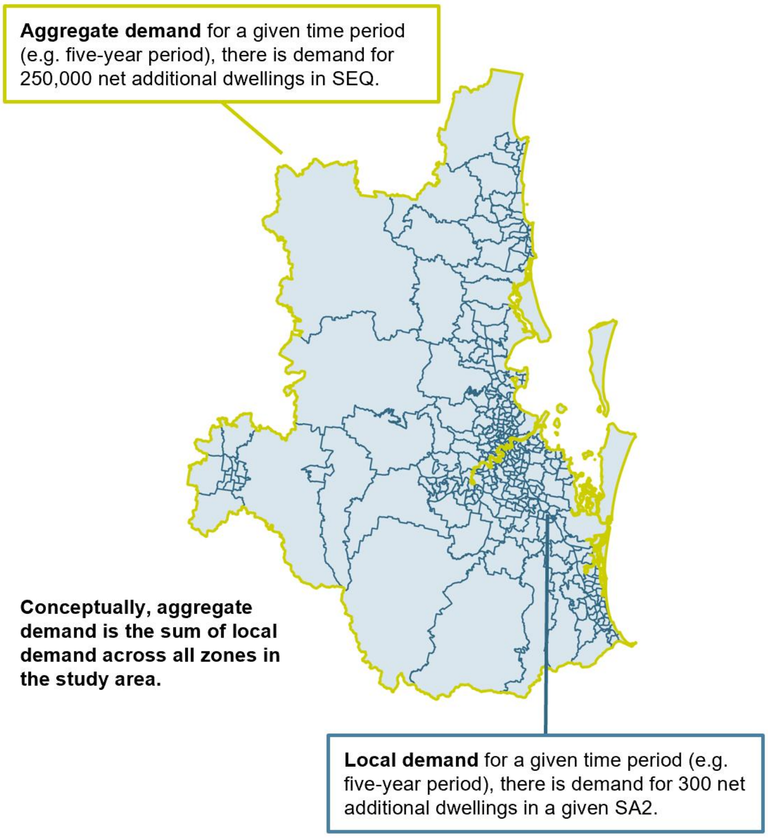
LUTI models are generally designed to represent a greater metropolitan area (e.g. Brisbane Greater Capital City Statistical Area (GCCSA)) or an economic region (e.g. South-East Queensland (SEQ)), though the spatial extent of the study area can vary widely between different model implementations.

There are two types of demand that are relevant:

- **Aggregate demand**: The underlying implied demand for buildings by type at different forecast years for the entire LUTI model study area.
- **Local demand**: The demand for buildings by type at each small area with the model study area.

Figure 4-2 provides a hypothetical example where the LUTI model study area is the SEQ region to illustrate the concepts of aggregate demand and local demand.

Figure 4-2 Example of aggregate demand and local demand



Source: Author’s analysis of ABS ASGS digital boundary data and values presented are hypothetical.

Aggregate demand is most commonly treated as an exogenous input, based on aggregate population and demographic models and economic models, driven by assumptions about future birth rates, death rates, household formation and net migration. When aggregate demand is fixed between alternative scenarios, and therefore only the spatial distribution of population and employment within the study area can vary, this is colloquially known as a '**closed city'** approach.

Some LUTI models include additional (coarse) 'external' zones to the study area, and allow location choices made by households, firms and/or developers to choose between small areas within the study area and larger, more aggregated areas outside of the study area. For example, Lennox (2023) includes 354 regions within SEQ and 100 larger regions in the rest of Australia). When aggregate demand can vary between alternative scenarios (i.e. net inward or outward migration is modelled), this is colloquially known as an '**open city'** approach.

The choice of closed city or open city approach should be based on the nature of the application – if an intervention is expected to impact movement to and from the region, an open city approach might be most appropriate. Where an open city approach is used, the approach should represent variables relevant to the propensity of households to move between regions (e.g. housing availability, housing affordability, wages and amenity). If interventions have more localised impacts, a closed city approach might be best suited.

Local demand relates to the demand for each 'small area' in the study area. The spatial resolution can vary widely between approaches. UrbanSim and PECAS models often represent demand at the level of individual land parcels, of which there may be millions in a major city. Urban SCGE models usually have more aggregate spatial units, at SA2, SA3, or SA4 (refer to Box 1 from Section 2.6 for further information about these spatial units). It is also common for LUTI models to contain hierarchical choices. For example, a household may choose between cities, then choose a suburb within that city, then choose a land parcel within that suburb.

Local demand for residential locations should be influenced positively by accessibility to opportunities and services. Both local accessibility measures (e.g. access to local retail or café strips) and regional accessibility measures (e.g. access to major employment precincts that are further afield, but still within commuting distance) should be represented. Local demand should also be positively impacted by amenity (e.g. access to coastline, rivers or other natural features). There are a range of other factors which influence local demand – including school quality, demographic and socioeconomic characteristics of neighbourhoods, soil quality, views, prestige and many others. These factors can be more difficult to represent in forecasting models, as it is difficult to make assumptions or predictions about how they will change over the forecasting period. These other factors may be represented with dummy variables as time invariant 'constants' in random utility or hedonic models. Local demand should be negatively impacted by higher land and property prices – particularly for lower income groups who are priced out of more expensive areas.

Residential location choices should ideally be represented at a household level, so all persons within a household move together. Dwelling type preferences should also be represented differentially for different types of households – for example families are more likely to prefer detached dwellings than young professional couples. Failure to represent these factors could lead to implausible demographic outcomes from LUTI modelling. For example, if a rail investment is estimated to cause a large number of people to shift from detached houses in a greenfield growth area into apartments in a higher density rail corridor, it could create a situation where many adults are assumed to move into the upgraded rail corridor, but the kids are 'left behind' in the growth areas, which is not a plausible outcome.

Local demand for firm locations should be influenced by firms seeking to locate near other firms (customers, suppliers, partners) in order to seek agglomeration economies – particularly between firms in common industries. Firm location choices may also be influenced by access to workers and consumers and to major economic infrastructure like ports, airports, intermodal terminals, major freeways and passenger and freight rail infrastructure.

There is no right or wrong way to represent demand, however, the way it is represented should be fit for purpose for the desired applications. Table 4-6 presents some considerations.

Table 4-6 Considerations for choosing demand representation

Purpose	Considerations for choosing demand representation
Land use projections for planning purposes	Aggregate demand is likely best estimated exogenously (closed-city) and then allocated to individual parcels or small areas suitable for transport modelling, possibly using a hierarchical spatial allocation process.
Project and program development	An open-city or closed-city approach may be most appropriate, depending on the nature of the project or program. If the scale of impacts is large enough to plausibly impact inbound net migration, it may warrant an open-city approach. Local demand allocated to individual parcels or small areas suitable for transport modelling, possibly using a hierarchical spatial allocation process.
Strategy development	Packages of programs and/or policy interventions tested as part of strategy development are likely to warrant use of an open-city approach. Local demand may be allocated at an SA2 level.
Policy analysis	Depending on the nature of the proposed policy reform, an open-city approach may be warranted. Local demand allocation needs may be SA2 level, but depending on the details may require more granular representation to an SA1 or parcel level.

Source: Author's analysis

4.8 Model should represent supply constraints appropriately

All LUTI models have some level of representation of the supply of buildings, usually broken down into building types (see Section 4.7 for how buildings may be categorised).

The approach to how building supply is represented can vary widely between modelling approaches. For example, Group 1 static adjustment models often model demand in isolation from any supply-side factors, and implicitly assume that buildings will be supplied to meet demand. However, major cities have an array of supply constraints which have a significant bearing on land use outcomes. At the time of writing, major Australian cities are in the midst of a housing affordability crisis, which is primarily caused by supply constraints. For this reason, it is unlikely that LUTI modelling approaches in Australia will be able to capture the dynamics of urban development in Australian cities without appropriately representing supply constraints.

Supply constraints relate to both the amount of development a given area can support (which may be called 'ultimate capacity'), and the pace at which an area can be developed (which may be called 'development rate'). LUTI models should represent supply constraints in a way that is realistic and appropriate for the desired purpose(s).

Generally, LUTI modelling approaches that represent parcel-level detail are best suited to representing supply constraints. UrbanSim and PECAS models usually represent parcel-level detail.

Some relevant supply constraints that apply to LUTI modelling are described below and adapted from DTP (2024c). This list is conceptual, and the level of detail with which constraints are represented may vary, and constraints may be considered either explicitly or implicitly. The way constraints are represented should be fit for purpose for the desired applications.

1. **Physical**

    1.1. Area: All else equal, zones with more area would have more capacity.

    1.2. Topographic: Includes slopes, hills, mountains, other natural features.

    1.3. Hydrographic: Includes rivers, lakes, estuaries, coastline, wetlands, floodplains.

2. **Regulatory**

    2.1. Permitted uses: Permitted uses e.g. residential, industrial, commercial, mixed use, roadways, railways, parks, special uses.

    2.2. Intensity: Permitted density or floor area ratio (FAR), setback, height, parking, lot consolidation/subdivision potential.

    2.3. Overlays: Heritage, environmental, flood, bushfire and other relevant overlays.

    2.4. Building codes: Structural, accessibility, wiring, energy efficiency and other relevant standards.

3. **Community acceptance**

    3.1. Local community: What level of (re)development the local community considers acceptable.

    3.2. Local government: What level of (re)development the local government will support, this is related to 3.1.

    3.3. Recourse for developers: What type and level of recourse do developers have if local community/government opposes (re)development (e.g. relevant courts or tribunals, ministerial interventions), and how likely is it that local government decisions would be upheld.

4. **Infrastructure**

    4.1. Trunk transport: The capacity/availability of trunk transport networks (especially mass transit like rail) to move people in and out of precincts or regions at peak times with time/cost/comfort/ convenience that the community considers acceptable.

    4.2. Local transport: The capacity/availability of local transport networks like roads, footpaths, cycleways, feeder, and coverage public transport services to support (re)development.

    4.3. Energy: The capacity/availability of energy networks (electricity and gas) to support (re)development.

    4.4. Water and sewage: The capacity/availability of water and sewage networks to support (re)development.

    4.5. Social and community: The capacity/availability of social and community infrastructure to support (re)development (e.g. schools, medical facilities, parks, playgrounds).

5. **Market**

    5.1. Industry capacity: Constraints exist within the construction industry relating to labour, materials, supply chains, and capital, which can affect aggregate supply.

    5.2. Existing use, ownership and turnover: How parcels that have potential for (re)development are currently being used, and who owns them. Land use systems are highly path dependent, meaning decisions made at a particular point in time can 'lock in' land use outcomes at the site for decades, especially when parcels are infrequently sold.

    5.3. Coordination: If potential development depends on consolidating parcels, this could require multiple parties to coordinate with each other to enable development, which may be unlikely to occur.

    5.4. Developer returns:

        5.4.1. Minimum return on investment: The minimum level of return on investment developers will require to undertake (re)development. Different types of developers might have different requirements, and requirements can also change over time with broader market conditions and risk appetites.

5.4.2. Expected sale/rental value: The market value developers expect for selling or leasing their products. These expectations can change over time with market conditions (e.g. changes in employment conditions, interest rates).

5.4.3. Nearby developments: Expectations of nearby development (whether private or public sector development) affect developer behaviour due to expectations of spillovers.

5.4.4. (Re)development costs: The cost of (re)development of different building types/intensities affect developer behaviour. Costs can change over time with market conditions, sometimes rapidly (for example due to labour/material shortages, supply chain disruptions, changes in interest rates). Contamination can also affect development costs.

5.4.5. Developer contributions: The financial, in-kind or land contributions developers are required to make to support (re)development.

6. **Other:** There may be unique constraints relevant to a particular policy or project that should be considered on a case-by-case basis.

4.9 Model should produce stable, repeatable outcomes

LUTI models may be categorised as 'deterministic' or 'stochastic'. When a model is deterministic, the same model run with the same inputs will produce the exact same results each time. When a model is stochastic, the model is configured with a random 'seed', and model outcomes may vary according to the sequence of random numbers used by the model. This means the same model run with the same inputs will produce slightly different results when run with a different random seed. This also means that differences in land use between a Base and Project Case run will be partly explained by the intervention (e.g. change in accessibility and/or development capacity) and partly explained by random variation (sometimes referred to as 'noise').

LUTI models should ideally be deterministic to make them practical in an appraisal context. Where models are stochastic, the practitioner will need to demonstrate that the change in land use between scenarios can be confidently attributed to the change in inputs, with minimal influence of 'noise' on the results. This may be achieved by testing the impact of random seeds to ensure the impact is minimal or, if necessary, by running model scenarios multiple times and averaging the results.

Depending on the model approach used, it may also be necessary to ensure that certain components of the land use model, the land use model as a whole, or the entire LUTI model system (between land use and transport model) has reached a 'converged' state. The remainder of this section provides some further information about convergence in a LUTI modelling context.

Joint or global convergence (between land use model and transport model components)

The approach to global convergence varies by LUTI model approach. Static equilibrium models (e.g. Group 5 and Group 7 models) iterate multiple times between the transport model and land use model in a single year until an equilibrium state is reached. Dynamic models (e.g. Group 4 and Group 6 models) do not have a joint equilibrium between the transport and land use model in a given model year, and therefore have no global convergence process. Rather, dynamic models assume that there is no long run equilibrium state between the land use and transport systems (refer to Section 2.7 for further discussion). Land use systems are assumed to be constantly evolving in response to changing conditions. A visual representation of the distinction between static and dynamic approaches is shown in Figure 2-9.

Transport model convergence

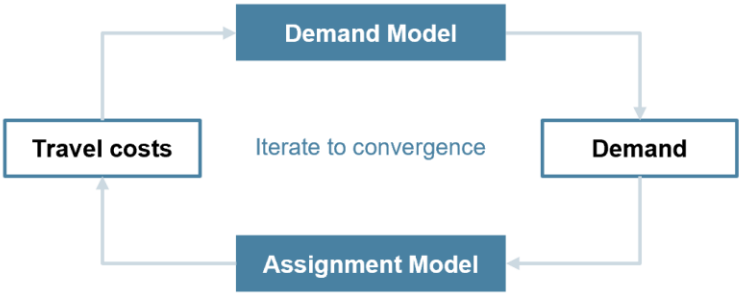
Strategic transport models include:

- **Demand** modules, which estimate the demand for travel.

- **Assignment** modules, which assign the demand to networks and represent the effect on road congestion, public transport crowding and therefore travel costs.

Strategic transport model processes involve iterating between demand and assignment modules until an equilibrium state is achieved. This process is shown in Figure 4-3Figure 4-3.

Figure 4-3 Convergence of a transport model



Source: Author's analysis

Land use model convergence

Static equilibrium approaches contain convergence processes internal to the land use model component. For example, Group 7 (Urban SCGE) models contain iterative processes to simultaneously clear all markets, representing supply curves, demand curves and endogenously variable prices to 'clear' all modelled markets in each year. The same can be true for dynamic models – though they do not seek a long term equilibrium state, they will usually represent supply, demand and prices for some markets within each individual year. Group 4 (Microsimulation dynamic) and Group 6 (Multi-level dynamic) typically contain some equilibration processes, if not to the same level of sophistication as Urban SCGE models.

5. Case studies

This section introduces three case studies where LUTI models have been applied in Australia for a specific infrastructure project and discusses them in the context of the principles introduced in Section 4.

The purpose of these case studies is to illustrate how the principles can be applied in practice by applying them to real Australian examples. The case studies are intended to help practitioners better understand the principles outlined in Section 4. The case studies are not intended to be prescriptive in terms of how practitioners should approach LUTI modelling or use the outputs.

5.1 MULTI for ShapingSEQ and the SEQ Infrastructure Strategy

ShapingSEQ sets planning direction for sustainable growth, global economic competitiveness and high-quality living. The regional plan responds to the region's projected growth, and the opportunities and challenges associated with current and projected trends. It guides the future of the SEQ region, encompassing the 12 local government areas (LGAs) of Brisbane, Gold Coast, Ipswich, Lockyer Valley, Logan, Moreton Bay, Noosa, Redland, Scenic Rim, Somerset, Sunshine Coast and Toowoomba (urban extent).

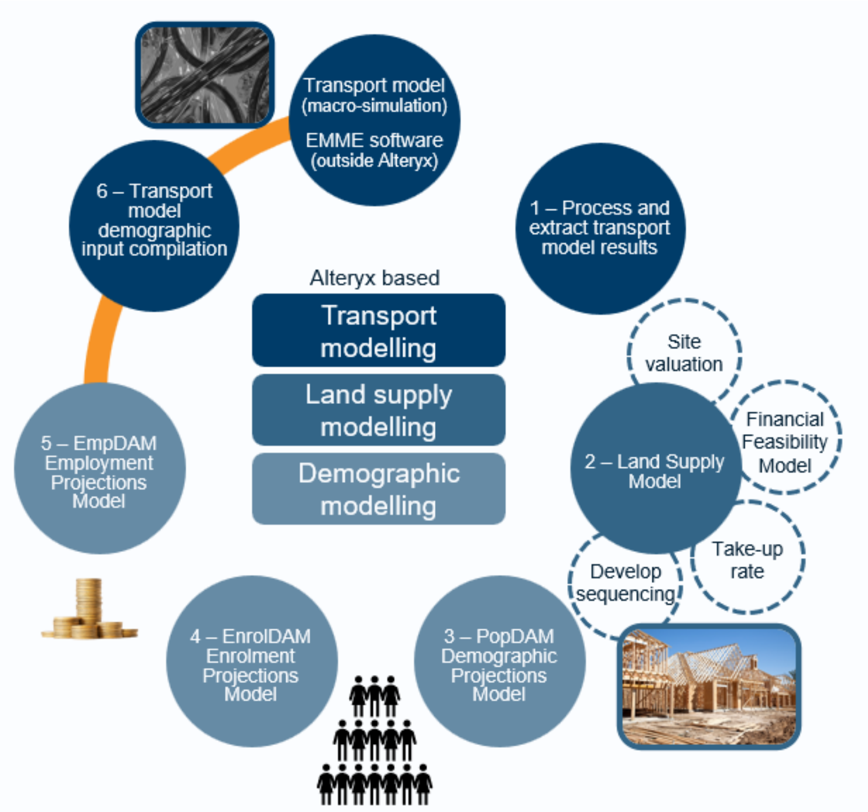
ShapingSEQ 2023 is a part of the Queensland Government's response to the National Housing Accord and National Planning Reform Blueprint. The plan plays a role in setting effective and responsive policies that facilitate the delivery of diverse and well-located homes to meet the housing needs of South East Queenslanders today and into the future (DSDILGP 2023a).

ShapingSEQ used the 'Model for Urban Land Use and Transport Interaction' (MULTI) model. MULTI has elements of Group 4 (microsimulation dynamic) and Group 6 (multi-level dynamic) models. MULTI integrated with the South-East Queensland Strategic Transport Model (SEQSTM) for this application. Refer to Figure 5-1 for the model framework.

The application of MULTI for ShapingSEQ provided analysis of:

- Supply and demand – capacity in planning schemes and demand factors that influence where households would choose to locate.
- Supply and realistic take-up – informed by financial feasibility to deliver development and current and planned infrastructure, including water, sewer, transport, education and other.
- Land use and transport integration – supply for new homes and existing and planned transport infrastructure to provide for more homes closer to transport and infrastructure investment.
- Employment accessibility – future growth in proximity to employment locations across SEQ to support shorter commutes, improved environmental outcomes and thriving businesses.

Figure 5-1 MULTI framework



Source: DSDILGP (2023b) Figure 9

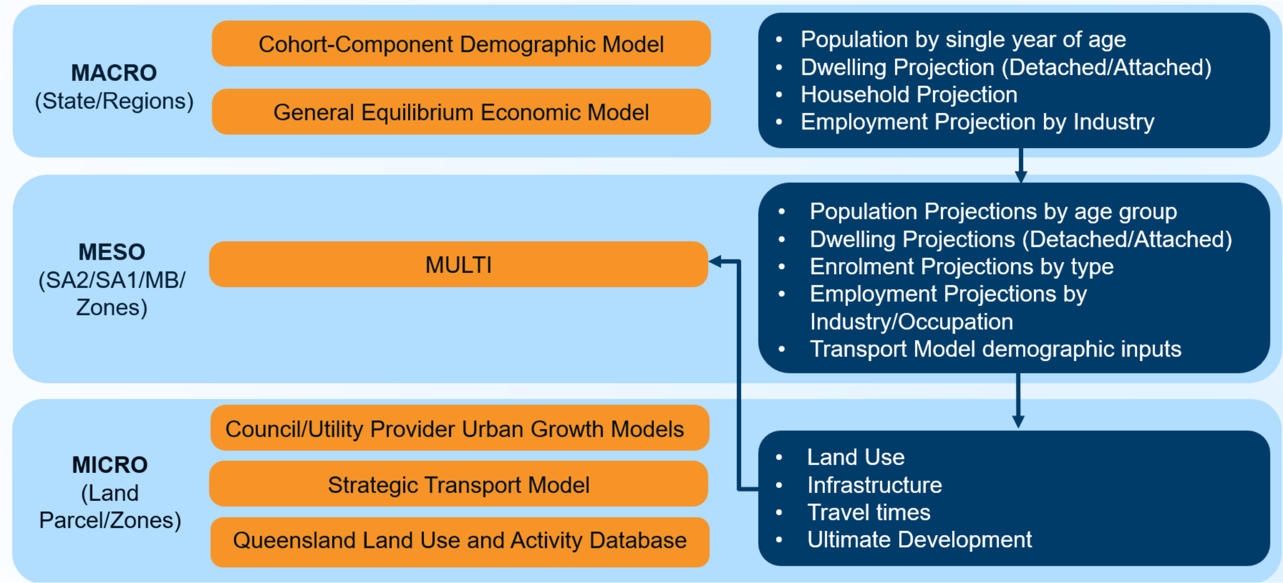
5.1.1 Model must be fit for purpose

Model functionality: MULTI has mechanisms to estimate land use impacts due to changes in accessibility from transport interventions and from changes to planning regulations, among others.

Run-time and performance: MULTI takes about 30 minutes to run per five-year model horizon, and SEQSTM takes about 16 hours to run. A dynamic run which requires individual years to be run in sequence takes about a week to complete.

Spatial resolution: MULTI covers the entire region of SEQ. It has a multi-level hierarchical spatial structure, with the most granular level incorporating parcel-level detail. The higher level geographies act as a benchmark for the proceeding geographic levels to increase the confidence and reliability of the results through a top-down/bottom-up modelling approach. Figure 5-2 illustrates this relationship between geographic levels.

Figure 5-2 MULTI modelling ecosystem



Source: DSDILGP (2023b) Figure 10

5.1.2 Model approach and assumptions must be transparent

MULTI was developed in partnership with University of Queensland under a three-year research and development iMove-CRC partnership with the Department of Transport and Main Roads. As part of this research program extensive testing, development and validation of the modelling framework was undertaken. This included the development of peer reviewed methodology papers and reports. In addition, DTMR maintains detailed methodology documentation for MULTI that covers model specification and calibration (DTMR 2024)[18].

The ShapingSEQ technical background papers (DSDILGP 2023b and DSDILGP 2023c)[19,20] includes detailed information about how MULTI was used to inform ShapingSEQ (2023a)[21].

5.1.3 Model must represent accessibility

MULTI uses trip-weighted average generalised cost measures (by mode, for commuting purposes) as an explanatory variable in the site valuation model. The site valuation model uses machine learning algorithms such as RandomForest to combine travel costs with other geographic and land use factors to estimate the improved site value for every land parcel in SEQ (around 1.2 million properties). This site valuation model is recalculated dynamically every five-year period in response to changes to transport costs, land use and infrastructure changes.

[18] Detailed MULTI methodology documentation (DTMR 2024).

[19] ShapingSEQ Grow Background paper from DSDILGP can be accessed via this link or go to Queensland Government's State Development, Infrastructure and Planning website.

[20] ShapingSEQ Prosper Background paper from DSDILGP can be accessed via this link or go to Queensland Government's State Development, Infrastructure and Planning website.

[21] ShapingSEQ from DSDILGP can be accessed via this link or go to Queensland Government's State Development, Infrastructure and Planning website.

MULTI also uses composite trip-weighted average generalised cost measures (all modes, commuting purpose in AM Peak) as one of the variables used to construct the demand curve in the dwelling allocation module.

MULTI uses a cumulative opportunities accessibility measure (separate measures for car and public transport, working aged population within 30 minutes travel time) as variables in a spatial regression model to estimate local employment by industry (SA2). Employment projections by industry and occupation type are benchmarked to projections developed from an exogenous CGE model at the regional level.

5.1.4 Model should be well calibrated

This section describes validation of the Population and Dwelling Allocation Modelling (POPDAM) component of MULTI. POPDAM is the third of six components in the MULTI model system, as shown in Figure 5-1.

POPDAM has been trained and estimated using data back to 2006. As shown in Pyrohova et al. (2025), several techniques were undertaken to assess the model's performance. These techniques included an in-sample (measure of fit) and two measures for out-of-sample prediction ability, including out-of-sample estimation and a leave-one-out (cross validation) method.

To compute the out-of-sample prediction, the dataset was split into a training (2006 to 2018) and test dataset (2019). The coefficients were estimated using the training dataset and used to compute the predictions for dwellings in 2019. The out-of-sample model performance ranged from approximately 91-98% accuracy across SEQ.

The leave-one-out validation technique was also applied in the validation of the model performance. The steps used to undertake this technique are illustrated below:

- Step 1: Leave all the observations related one SA2 out of the training sample.
- Step 2: Estimate the model using the $(n-1)$ remaining SA2s.
- Step 3: Use the estimated coefficients to predict the left-out SA2 observation and calculate the prediction error.
- Step 4: Repeat steps 1-3 for all the remaining SA2 observations and take the average of the prediction errors.

The model validation for the leave-one-out technique showed a similar model performance for the detached dwelling model and a slightly worse model performance for attached dwellings.

The model performance for POPDAM is summarised in Table 5-1.

Table 5-1 Summary of POPDAM model performance (detached and attached dwellings)

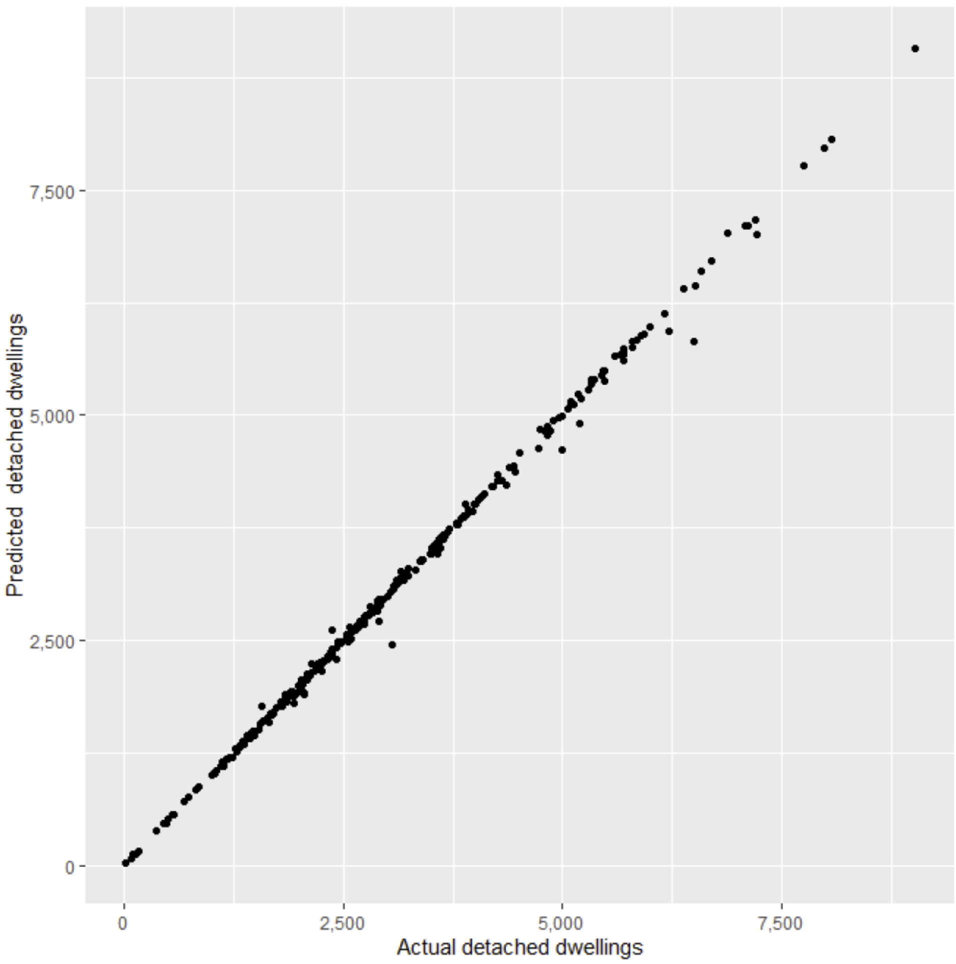
	Detached			Attached		
Error measure	**In Sample**	**Out of Sample**	**Leave-one-out**	**In Sample**	**Out of Sample**	**Leave-one-out**
Root Mean Square Error (RMSE)	48.7	72.8	49.4	66.3	107.1	99.1
Mean Absolute Deviation (MAD)	26.3	33.3	26.8	26.5	35.2	29.4

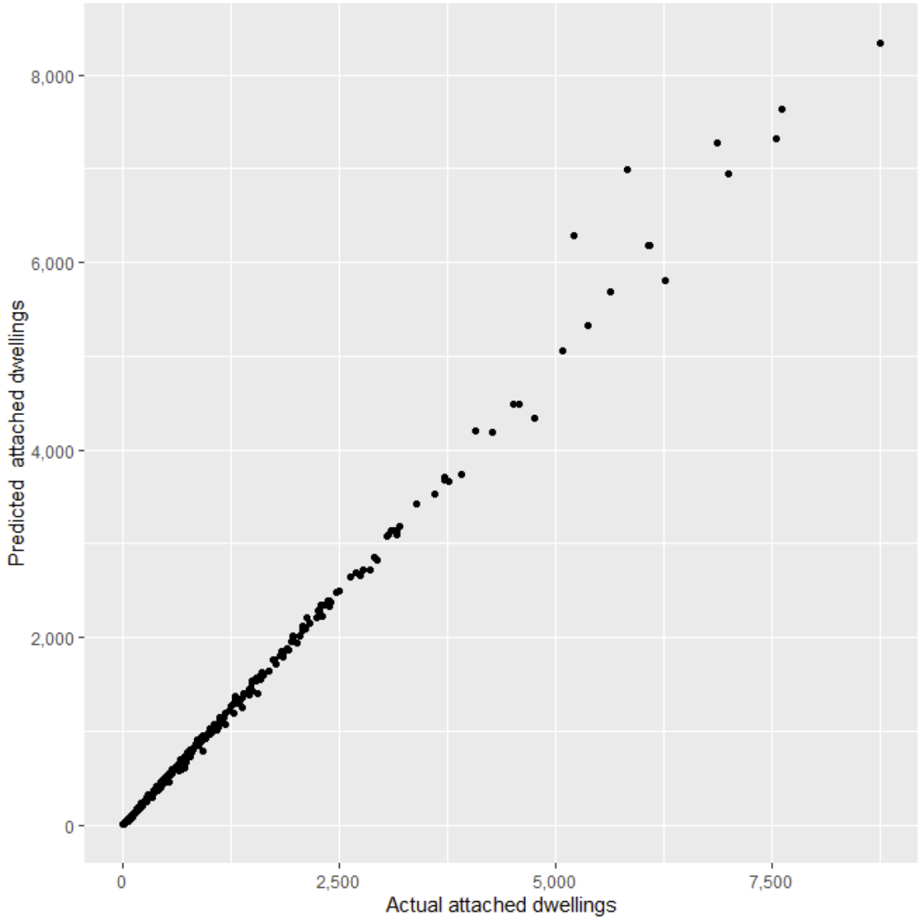
	Detached			Attached		
Ratio of RMSE to sample mean of dependent variable	0.017	0.024	0.017	0.055	0.089	0.082
Ratio of MAD to sample mean of dependent variable	0.009	0.011	0.009	0.022	0.029	0.024
N, sample size	3,378	327	3,378	3,174	323	3,174

Source: Pyrohova, et al (2025) Table B1

Additionally, the plots for out-of-sample model performance for the detached and attached dwelling projections by SA2 are presented in Figure 5-3 and the spatial distribution in Figure 5-4.

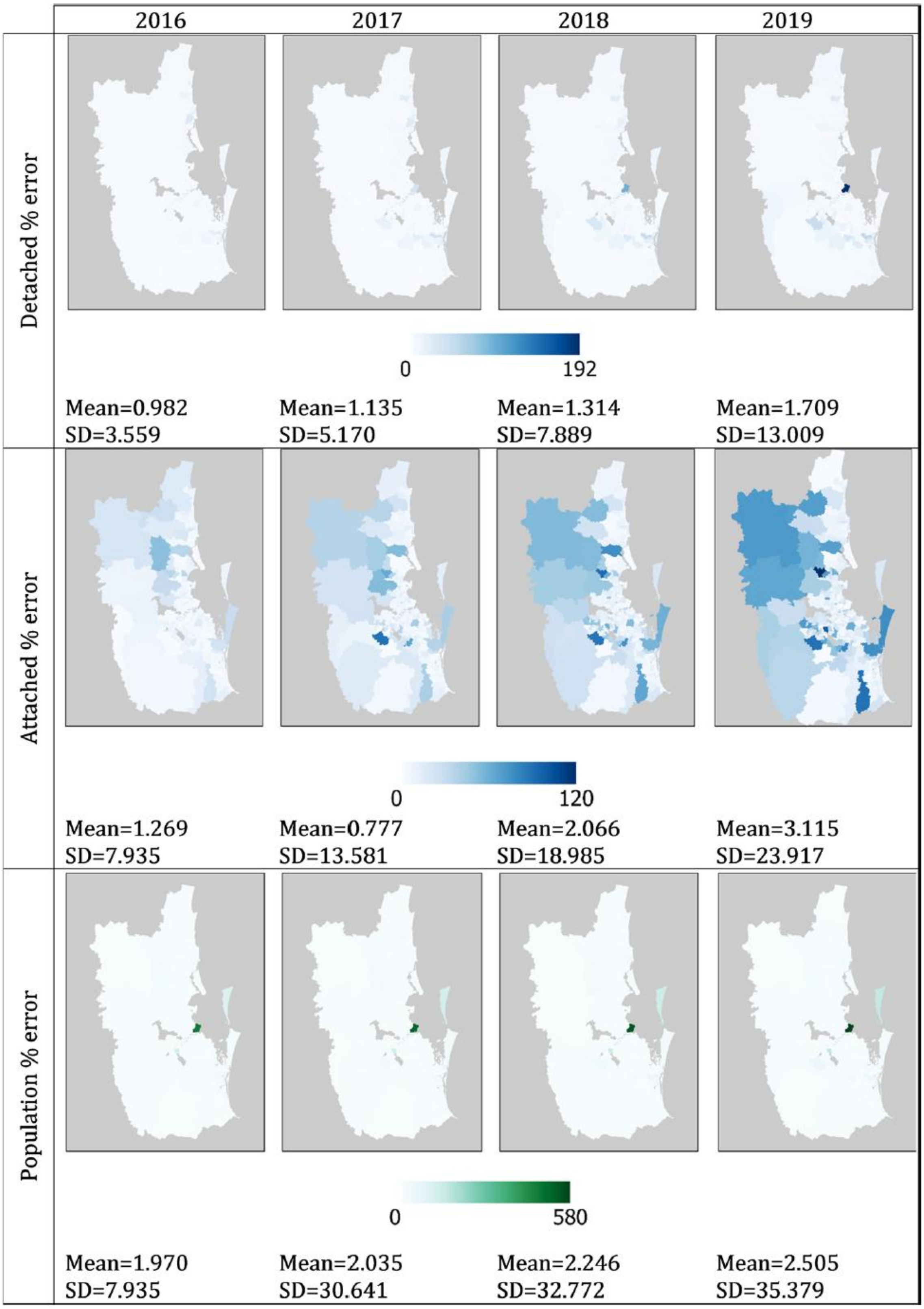
Figure 5-3 MULTI validation for detached and attached dwelling prediction, 2019





Source: University of Queensland (2022) Figure 2.2 and Figure 2.4

Figure 5-4 Spatial distribution of prediction errors in POPDAM model



Source: Pyrohova, et al (2025) Figure 4

5.1.5 Model should be dynamic

MULTI is a dynamic model which proceeds in single year time steps. The travel costs from SEQ Strategic Transport Model (SEQSTM) are typically updated in five-year time steps.

5.1.6 Model should represent economic relationships

MULTI has been developed to simulate the land use markets and their dynamic response to future changes in transport costs, infrastructure development and land use policies. This is achieved via the use of a simultaneous supply and demand equilibrium model to represent the housing market. Econometric techniques are applied to endogenously equilibrate the detached and attached housing market in each modelled year.

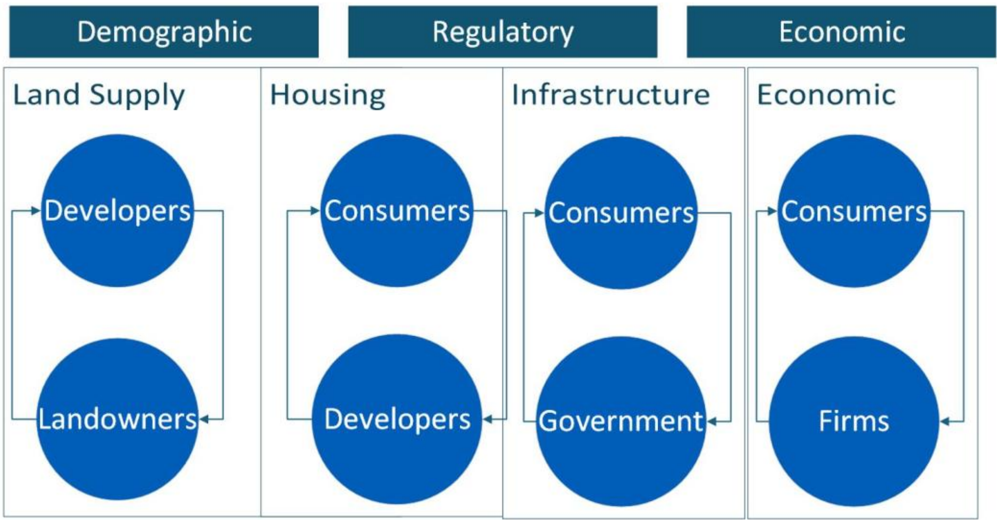
Furthermore, MULTI represents the economic relationships between developers and the land market. This is achieved using a financial feasibility modelling approach, which takes into consideration the economic and financial decisions of developers based on return on investment for each individual development site in order to maximise their utility. To achieve this MULTI includes a comprehensive framework to capture the development costs and revenues, from acquisition right through to market delivery.

MULTI includes an employment modelling framework linked into a dynamic modelling framework. The economic drivers of employment growth by industry in MULTI are represented through data sourced via an exogenous CGE modelling framework. This CGE modelling framework is used to represent the underlying demand for growth in employment by industry sector. The supply for employment by industry is then represented in the model via the use of gross floor area estimation and other activity types where applicable (such as construction and agriculture).

5.1.7 Model should represent demand appropriately

MULTI represents demand both through the underlying demand for dwellings, housing supply and employment by industry and occupation type. This is done through its connection with regional level economic and demographic models, which set the growth in demand for each projected year (as represented in Figure 5-5). The economic region of SEQ is treated as a “closed city”.

Figure 5-5 MULTI modelling ecosystem



Source: DTMR

Additionally, MULTI captures local demand for dwellings and non-residential development. This is achieved through capturing the local amenity factors driving demand. These factors can be broadly classified into the following groups:

- Natural features: ocean beach, coastline/rivers
- Land use composition: activity types in local neighbourhood such as retail, health, education, food, industrial etc.
- Service quality: such as school rankings
- Accessibility: employment, education, activity centres
- Socioeconomic characteristics
- Non-residential floorspace

5.1.8 Model should represent supply constraints appropriately

MULTI represents supply constraints in the following way:

- Ultimate capacity is represented for each individual parcel by dwelling and employment type. Parcel-level capacities are estimated and supplied by each local government authority in SEQ.
- A realistic take-up rate module represents ‘s-curves’, which effectively limits the maximum pace of development per SA2 and enforces a realistic progression of development, including a ramp-up stage, a peak production stage and a lower remaining capacity plateau when an SA2 is approaching ultimate capacity.
- Development feasibility is captured in MULTI to represent the interactions between developers and the land market (both in greenfield and consolidation areas). MULTI dynamically calculates the internal rate of return for each parcel in SEQ based on the site acquisition costs and the total development costs to develop the site to its ultimate capacity. MULTI assumes that buildings can only be knocked down and rebuilt once (at most) in the planning horizon, effectively dealing with ‘lock-in’ effects – when a new building is constructed, it is unlikely to be redeveloped until it is nearing the end of its economic life.
- MULTI captures other “supply unlocking” bulk infrastructure such as water, sewer and electricity to both represent the additional costs to developers in delivery of supply to market but to also provide realistic development sequencing and staging aligned with the current and future delivery of infrastructure.

5.1.9 Model should produce stable, repeatable outcomes

MULTI uses deterministic modules, which ensures the model outcomes are stable and repeatable when run with the same inputs.

MULTI includes a supply-demand equilibration as part of the dwelling allocation model which iterates to convergence in each annual time step. MULTI takes SA4 level employment from a regional CGE model as an exogenous input. MULTI uses the SEQSTM transport model, which includes its own specific convergence criteria parameters.

5.2 CityPlan for Suburban Rail Loop Business and Investment Case

The Suburban Rail Loop (SRL) is a joint urban renewal and rail investment project which connects Melbourne's radial rail lines in a middle suburban orbital railway. It encompasses both rail investment and changes to planning regulations in station precincts to enable integrated transport and land use outcomes. Refer to Figure 5-6 for the illustration of the project from SRLA (2021b).

The SRL 2021 Business and Investment Case (BIC) used the CityPlan LUTI model, a zone-based implementation of the UrbanSim model approach. It integrates with Victorian Integrated Transport Model (VITM).

CityPlan projected an increase in density in the middle suburban station precincts in the Program Case, and a reduction in outer suburban sprawl, particularly in Melbourne's south-eastern growth areas.

Figure 5-6 Map of the SRL network plan

Source: Figure from p. 11 of SRLA (2021b)

5.2.1 Model must be fit for purpose

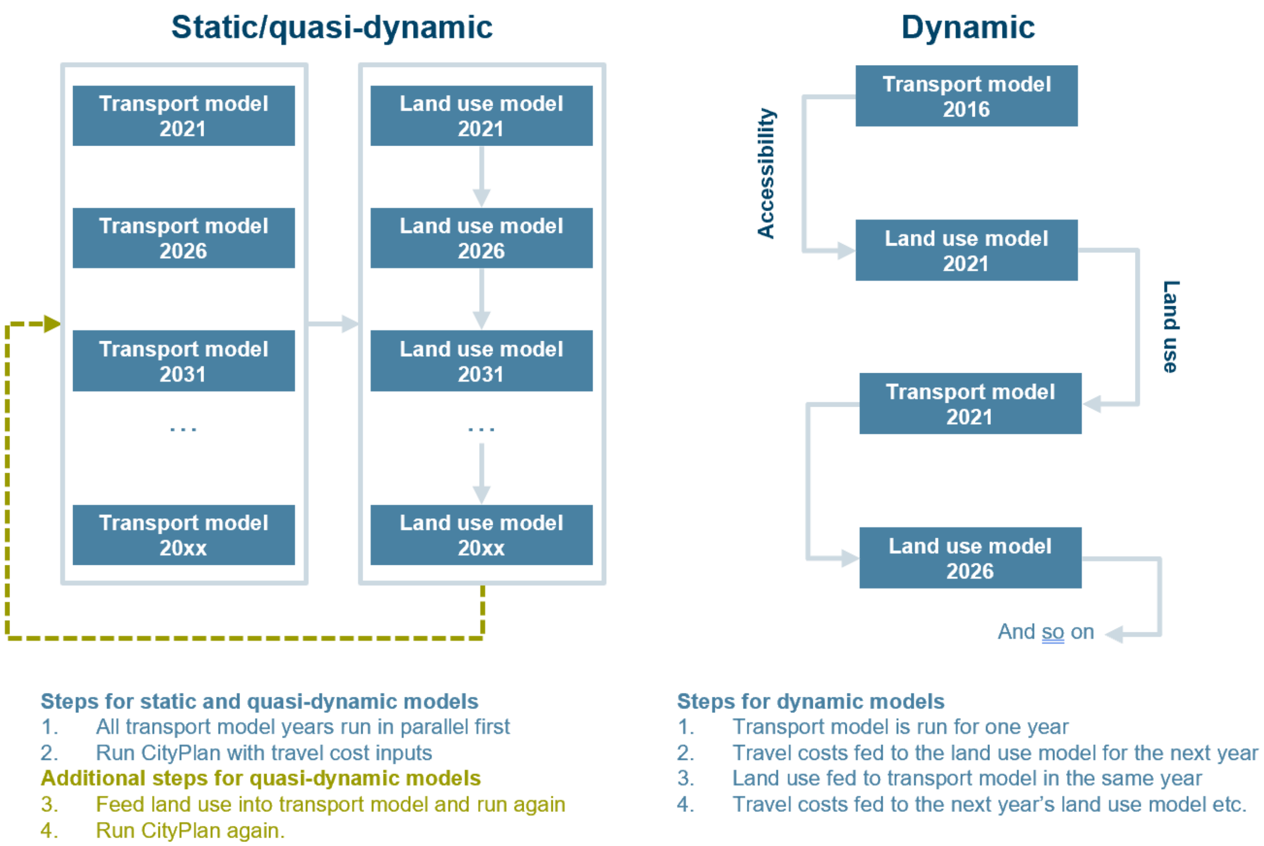
Model functionality: CityPlan has mechanisms to estimate land use impacts due to changes in accessibility from transport interventions, and changes to planning capacity and permissiveness. Accessibility is represented by cumulative opportunities accessibility measures relating primarily to commuting and business travel, where accessibility is impacted by both changes in travel costs and changes in land use resulting from interventions. Planning capacity and permissiveness are represented at a small area level by capacity and development rate assumptions which respectively dictate how much and how rapidly development can occur within the planning horizon. Capacity and development rates can also be impacted by changes in planning regulations resulting from interventions. The SRL Program included both transport (rail investment) and substantial land use (zoning and direct investment) interventions.

Run-time and performance: CityPlan takes about two hours to run 30 years in single year time steps, refer to Table 5-2 for the indicative time taken to run the CityPlan model by model type. CityPlan can be run on a standard laptop, but is usually run on computers suitable for the relevant transport model for reasons of practicality for iterating with the transport model. VITM can take two days to run. When CityPlan and VITM are run in dynamic mode, runtimes can be impractical. CityPlan can be run in static and quasi-dynamic modes, as shown in Figure 5-7, which allow for congestion and crowding feedback to occur at different levels of accuracy. These modes were used heavily in the early planning stages to make run times practical, and the dynamic mode was used for key runs, including those used in economic appraisal.

Table 5-2 Indicative time taken to run CityPlan model by model type

Mode of operation	Approximate run time	Notes
Static mode	~2 hours	Assuming Reference Case transport model runs are already available.
Quasi-dynamic mode	~52 hours (~2 days)	Two hours for CityPlan, 48 hours for VITM and another 2 hours for a second CityPlan run.
Dynamic mode	~146 hours (~6 days)	Assuming baseline year run (e.g. 2031) is already available and three forecast years are run (e.g. 2036, 2041 and 2051), 2 hours for CityPlan and three lots of 48 hours for VITM.

Figure 5-7 Static, quasi-dynamic, and dynamic modes of operation



Source: Author's analysis

Spatial resolution: CityPlan covers greater Melbourne plus major regional cities in Victoria, including Geelong, Ballarat and Bendigo. It uses roughly equal sizes zones of around 100 ha of which there are about 11,000 in the study area.

5.2.2 Model approach and assumptions must be transparent

SRL BIC includes a demand modelling appendix (*Appendix C1 – Demand Modelling Report*)[22], which describes the methodology in detail, including spatial plots and charts of the results and key drivers of outcomes. Economic appraisal outcomes are presented with land use changes in the economic appraisal appendix (*Appendix C2 – Economic Appraisal Report*)[23].

Victorian Government maintains thorough documentation in three volumes (model specification, model calibration, user guide)[24]. An independent external peer reviewer was appointed to review the model approach, assumptions and outputs.

[22] The SRL BIC Appendix C1 – Demand Modelling Report can be accessed via this link or go to Victoria's Big Build website.

[23] The SRL BIC Appendix C2 – Economic Appraisal Report can be accessed via this link or go to Victoria's Big Build website.

[24] CityPlan Model Specification (DTP 2024a), Model Calibration (DTP 2024b), and User Guide (DTP 2024c).

5.2.3 Model must represent accessibility

CityPlan uses location-based cumulative opportunities accessibility measures, with travel impedances represented by mode-choice logsum utilities. The accessibility measures influence unimproved land values and are used as part of location choice models by developers, households, and firms.

The key accessibility measures are Commuter to Jobs (C2J) and Business to Business (B2B). Each of these measures are cumulative opportunities that represent the ease and convenience of accessing employment from a given origin. Each measure contains a deterrence curve which represents how the willingness to access a destination declines as generalised travel cost increases. C2J uses a shallower deterrence curve than B2B, reflecting that people are generally willing to travel further when commuting from home to work than when undertaking business trips from their usual workplace. Both measures are multimodal (considering both car and public transport modes), but C2J uses a lower value of time than B2B. This effectively means that C2J puts more emphasis on slower travel modes (public transport) and B2B puts more emphasis on faster modes (car or taxi). Both measures also use a saturation function which reflects the diminishing returns of additional opportunities (i.e. the first 100,000 jobs is worth more than the second 100,000 jobs and so on). C2J and B2B is represented for each zone on a scale of 0 (no accessibility) to 1 (best).

CityPlan uses its own zone system called CityPlan Zones (CPZs) which has around 11,000 zones in the study area. Accessibility measures are represented at the VITM travel zone (TZN) level with around 3,000 zones across Victoria, then concorded to the CPZ zone system.

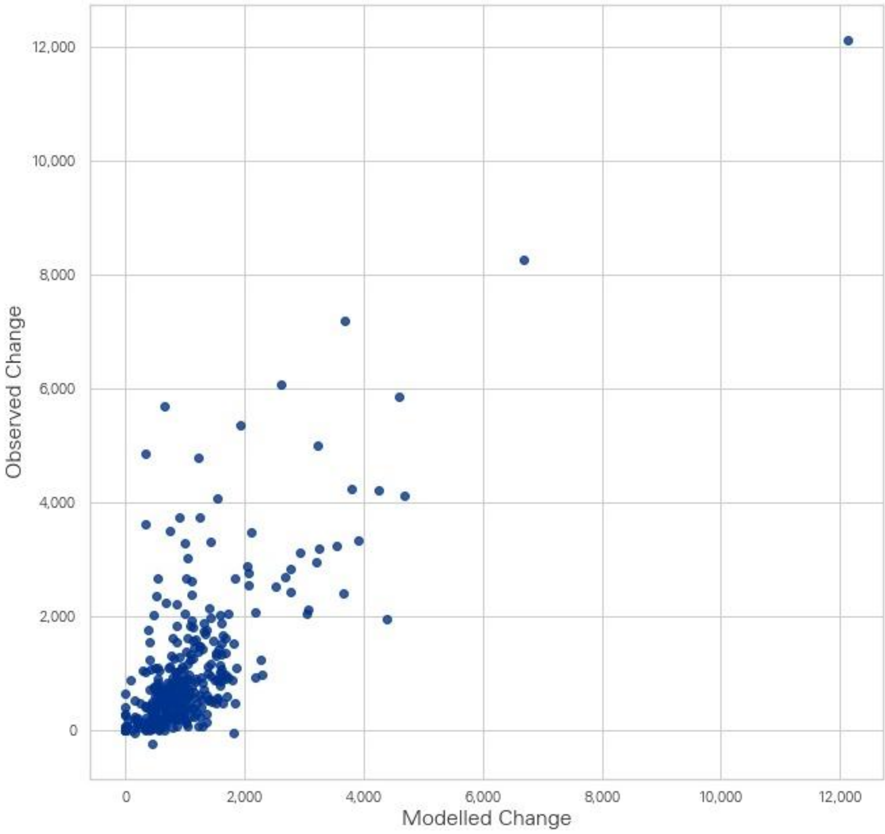
5.2.4 Model should be well calibrated

CityPlan uses a longitudinal (‘backcasting’) calibration approach where 2016 land use outcomes are predicted using 2006 as a baseline year and comparing modelled outcomes to actual outcomes from ABS Census. The calibration process included model estimation, model validation, and response testing, and was thoroughly documented and peer-reviewed by an independent external party.

The version of CityPlan that was used for the SRL BIC met or was within 1 precentage point of all three of its high priority validation criteria, and met two of its three medium priority validation criteria. It also performed well against a range of response tests.

Change in households between 2006 and 2016 at the SA2 level had a prediction accuracy of 75.0%, meeting the target of 70%. A scatter plot of the modelled versus observed change is shown in Figure 5-8.

Figure 5-8 Modelled vs observed change in households per SA2, 2006 - 2016



Source: Transport for Victoria (2020)

5.2.5 Model should be dynamic

CityPlan uses the UrbanSim framework which is dynamic and proceeds in one-year timesteps. CityPlan was run for the period from 2031[25] (five-years ahead of opening year) to 2056 for SRL, with transport model runs every five years from 2031 to 2056.

[25] Land use data up to 2031 was generated using the Victorian Government's Reference Case land use (known as Small Area Land Use Projections or SALUP).

5.2.6 Model should represent economic relationships

CityPlan represents unimproved land value (per m^2) as a function of accessibility in a hedonic regression equation. The hedonic regression is used to estimate the unimproved land value per square metre of a reference (typical) residential land parcel in a given CPZ. The explanatory variables include C2J accessibility, an amenity variable for access to coastline and a set of regional dummy variables intended to represent regional variations in amenity and other drivers of land value which are assumed to stay constant throughout the forecasting period. The hedonic regression explains more than 90% of the variation in unimproved land values per CPZ. The C2J coefficient implies that an increase in C2J accessibility of 0.01 (C2J is measured on a scale of 0 to 1) creates a 3.5% increase in unimproved land value. Most implementations of UrbanSim incorporate supply-demand equilibration, however, this functionality was not used in CityPlan modelling for SRL, which relied solely on the land value outputs from the hedonic regression.

Unimproved land value is used along with remaining land use capacity as a proxy for development feasibility. Unimproved land value is an input to a developer choice model based on random utility theory. Areas that have high unimproved land values and substantial remaining development capacity have high utilities and are most likely to be chosen for development. Areas that have low unimproved land values, low remaining capacity or both are unlikely to be developed.

In general, CityPlan represents economic relationships at a higher degree of abstraction than multi-level dynamic models (e.g. DELTA, TIGRIS-XL) and urban SCGE approaches.

5.2.7 Model should represent demand appropriately

CityPlan represents demand in the following way:

- Building types were represented by residential: high and low-density[26], and non-residential: office, retail, industrial, and other.
- Aggregate demand ('control totals') by year were input as endogenous external assumptions from Victorian Government modelling at a study-area level for households, population, and employment with further breakdowns for household types, ages and industries.
- A closed city approach was used, meaning aggregate demand at a study-area level was assumed to be the same between Base and Program Cases. Only the spatial distribution of growth varied between scenarios.
- Local demand was represented at a CityPlan zone (CPZ) level, around 11,000 in the study area and concorded to travel zones for input to VITM.
- Developer demand at the CPZ level was represented as described in Section 5.2.6.
- Local demand for households is represented using a random utility approach, with explanatory variables that relate to accessibility to jobs and education, local dwelling density, land prices (negative relationship to demand) and neighbourhood variables that reflect preferences for locating near to other households with similar demographic and socio-economic characteristics.
- Local demand for firms is represented using a random utility approach, with explanatory variables that relate to accessibility and density which vary by industry group. This reflects that firms seek agglomeration economies, preferring to cluster near other firms, with an emphasis for firms in the same industry.

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[26] A medium density category has been added to CityPlan, but this was subsequent to the SRL BIC.

5.2.8 Model should represent supply constraints appropriately

CityPlan is zone-based, meaning it represents regulatory and market constraints at the zone level per building type. Most UrbanSim implementations are parcel-based and represent planning constraints (e.g. density limits, setbacks, height limits) directly at a parcel level.

CityPlan represents 'ultimate capacity' per building type per zone for the whole study area and includes 'development rates', which represent the maximum pace of development per zone. This enforces a realistic 's-curve' progression of development, including a ramp-up stage, a peak production stage and a lower remaining capacity plateau when a zone is approaching ultimate capacity.

For the immediate station precincts, capacities per zone per building type were estimated using a parcel level model maintained by Victorian Government called the 'Population and Land Use Model' (PLUM) which explicitly considers the detailed planning regulations at a parcel level. The Program Case had more capacity than the Base Case around the station precincts due to upzoning which was part of the Program Case intervention.

5.2.9 Model should produce stable, repeatable outcomes

CityPlan uses a stochastic approach to simulating the random utility models, which include developer, household and firm location choices. This means the same model with the same inputs but a different random seed will produce slightly different results – sometimes referred to as model 'noise'. The CityPlan calibration process undertook rigorous testing of the impact of random seed, and concluded that the level of variation between scenarios was acceptably small for the purpose of estimating the land use impacts of SRL. More recent UrbanSim models use a differentiable, deterministic process which eliminates the issue of 'noise'.

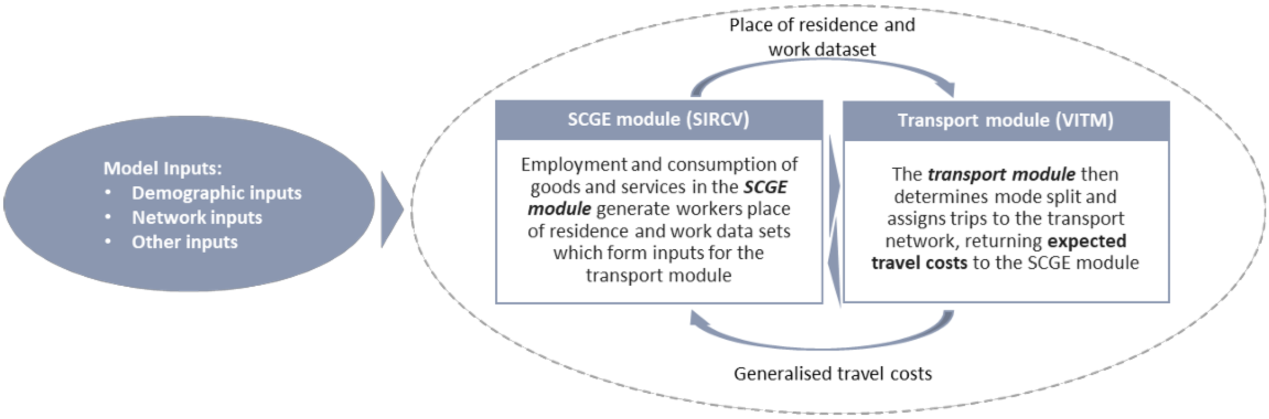
CityPlan uses a dynamic disequilibrium approach, which means there is no global equilibration process between the transport and land use model components. Most implementations of UrbanSim incorporate supply-demand equilibration within each model year, however, this functionality was not used in CityPlan modelling for SRL.

5.3 VLUTI for the Infrastructure Victoria 30 Year Strategy

Infrastructure Victoria's 30-year strategy (2021a) is a plan designed to address the state's infrastructure needs from 2021 to 2051. It involves integrating land use and infrastructure planning to guide urban development in optimal locations, ensuring timely provision of infrastructure.

The Infrastructure Victoria's 30-year strategy used the Spatial Interactions within and between Regions and Cities in Victoria (SIRCV) LUTI model; a Group 7 urban SCGE model. It integrates with VITM, referred to as Victorian Land Use and Transport Integration model (VLUTI) when combined with VITM. A model architecture diagram is shown in Figure 5-9.

Figure 5-9 VLUTI model components and integrated process

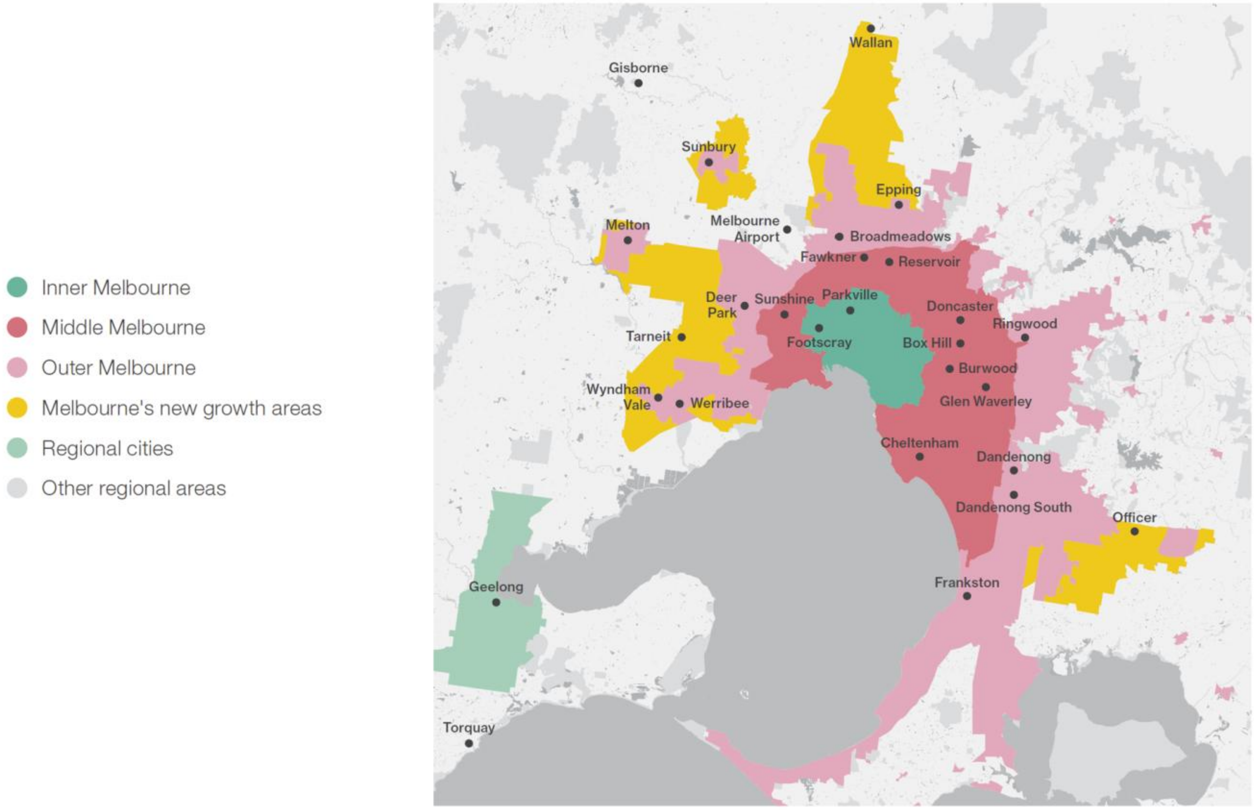


Source: Infrastructure Victoria 2021b

The model was used to test a range of programs as part of the 30-Year Strategy in 2021. Some example outcomes noted in the modelling report (ARUP 2021) include:

- Melbourne Metro 2 and the Direct Geelong Rail Line were estimated to attract substantial additional population to locate along the affected rail corridors.
- Road management systems project where operations across arterial roads within metropolitan Melbourne area were improved, was estimated to lead to decentralisation of population away from Inner Melbourne throughout the Middle, Outer and New growth area suburbs due to reduced road congestion and delays. Refer to Figure 5-10 for the illustration of the functional urban areas from Infrastructure Victoria (2021a).

Figure 5-10 Map of Melbourne’s functional urban areas



Source: Infrastructure Victoria (2021a) Figure 16

5.3.1 Model must be fit for purpose

Model functionality: SIRCV has mechanisms to estimate land use impacts due to changes in accessibility from transport interventions.

Run-time and performance: SIRCV is quick to run (15-60 mins). However, when run with VITM it can be slow as it needs to iterate six times within VITM for each model year. A simplified version of VITM (called rapid VITM) was used in the convergence loop with the full VITM run only once at the end to manage run-times.

Spatial resolution: The version of SIRCV used for the Infrastructure Victoria strategy (2021a) covers all of Victoria via 458 SA2s. SA2s are roughly suburb scale.

5.3.2 Model approach and assumptions must be transparent

The modelling report (ARUP 2021)[27] presents spatial plots of changes in population and employment between scenarios and, for many scenarios, also includes supporting plots demonstrating spatial changes in travel times which are key drivers of outcomes.

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[27] SIRCV modelling report from ARUP can be accessed via this link or go to Infrastructure Victoria’s website.

The SIRCV methodology was published in detail by Infrastructure Victoria (2021b)[28]. Urban SCGE modelling approaches are also well documented in peer reviewed academic literature (e.g. Ahlfeldt et al. 2015[29], Anas & Liu 2007[30])

5.3.3 Model must represent accessibility

SIRCV uses utility-based accessibility measures as part of a nested location choice model based on random utility theory where agents simultaneously choose occupation, place of work, and place of residence. Commuting and other travel costs (shopping, education etc.) are composite (combining car and public transport) and negatively impact utility.

SIRCV also uses a cumulative opportunities accessibility measure (effective density), which is assumed to positively impact firms' productivity in line with the theory of agglomeration economies.

5.3.4 Model should be well calibrated

Most SIRCV model parameters are derived from literature and are based mainly on studies of cities in North America or Europe. However, the parameter determining the response to commuting cost was estimated from Victorian data. These are referenced in Table 2-1 of Infrastructure Victoria's methodology paper (2021b).

A calibration process was undertaken for the baseline model year (2018). Such a calibration approach is standard in the literature (e.g. Ahlfeldt et al. 2015, Anas & Liu 2007).

Those calibrated parameters are then taken forward to forecast years, with amenity variables being adjusted for future years to enable the Base Case land use to approximate official Victorian Government forecasts.

5.3.5 Model should be dynamic

SIRCV is a long run comparative static SCGE model (a static equilibrium model). This means that all actors make all location choices in each modelled year. Lennox (2023) develops a dynamic urban SCGE approach (or DSM) and demonstrates it for a hypothetical rail project. However, this model has not been applied by any public agencies as yet.

5.3.6 Model should represent economic relationships

SIRCV is a Group 7 urban SCGE model which includes detailed representations of the urban economy in a general equilibrium framework. Wages clear labour markets, rents clear land markets, and product prices clear product markets. Demand for housing services must equal supply in each local market. This represents best practice in representing economic relationships in a LUTI modelling framework.

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[28] SIRCV methodology report from Infrastructure Victoria can be accessed via this link or go to Infrastructure Victoria's website.

[29] This peer reviewed urban SCGE modelling paper can be accessed via this link or go to academic publishing website for the Journal of the Econometric Society.

[30] This peer reviewed urban SCGE modelling paper can be accessed via this link or go to academic publishing website for the Journal of Regional Science.

5.3.7 Model should represent demand appropriately

SIRCV represents 458 economic zones in Victoria, using the ABS SA2 geographies (approximately suburb level spatial resolution). Total population and employment were held constant, meaning the model could only redistribute population and jobs within Victoria.

Households that contain workers choose their occupation, home location, work location and expenditure on good and services in a nested discrete choice model. For working households, utility depends on local residential amenity[31], wage rates and idiosyncratic preferences. Non-working households choose their home location and expenditure on good and services in a nested choice model. For non-working households, utility depends positively on residential amenity, their fixed transfer and capital income and idiosyncratic preferences. Firm locations result follow from worker location choices.

SIRCV does not explicitly represent buildings or floorspace, though the implications for built form could be inferred from households and firms' location decisions.

The SIRCV methodology paper (2021b) notes as a limitation that this approach does not account for the fact that buildings are often long lived and there are significant 'lock-in' effects with real estate development. This is partly mitigated by using a multi-decade time horizon for the forecast year (only 2036 and 2051 are modelled).

5.3.8 Model should represent supply constraints appropriately

SIRCV represents supply constraints only at a high degree of abstraction, using broad land categorisations (e.g. 'Permissive Residential and 'Restrictive Residential') with a mechanism to moderate growth in areas with more restrictive zoning.

Urban SCGE models in general represent supply constraints in less detail than UrbanSim (a Group 4 microsimulation dynamic model) and PECAS (a Group 5 Martin Centre model) which usually contain parcel-level representations of planning and market constraints.

5.3.9 Model should produce stable, repeatable outcomes

SIRCV and VITM are run iteratively until they reach equilibrium, indicating a stable combination of demographic distribution and network performance. The convergence is monitored by tracking changes in population distribution and accessibility to employment. If the changes fall below specific thresholds within three to six iterations, the model is considered converged. The model achieved convergence after four iterations but is set to run six iterations for consistency.

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[31] Residential amenity in SIRCV is a calibration parameter.

Appendix A Abbreviations

ABS	Australian Bureau of Statistics
ART3	Auckland Regional Transport Model
ASGS	Australian Statistical Geography Standard
ASP3	Aukland Strategic Planning Model
ATAP	Australian Transport Assessment and Planning
ATM2	Auckland Transport Model
B2B	Business to Business
BIC	Business and Investment Case
BLADE	Business Longitudinal Analysis Data Environment
C2J	Commuter to Jobs
CBA	Cost-benefit analysis
CBD	Central business district
CGE	Computable General Equilibrium
CLUE	Census of Land Use and Employment
CPZ	CityPlan zone
DaEDS	Dwelling and Employment Distribution System (WA)
DSDILGP	Department of State Development, Infrastructure, Local Government and Planning
DSM	Dynamic spatial model
DTMR	Department of Transport and main Roads (QLD)
DTP	Department of Transport and Planning (Victoria)
FAR	Floor area ratio
GCCSA	Greater Capital City Statistical Area
GUM	Generic Urban Model (UK)
HILDA	Household, Income and Labour Dynamics in Australia
HS2	High Speed Two
LUTI	Land Use Transport Interaction
MARS	Metropolitan Activity Relocation Simulator
MPO	Metropolitan Planning Organisation (North America)
MULTI	Model for Urban Land Use and Transport Interaction (QLD)
MUSSA	Modelo de Uso de Suelos de Santiago (or land use model of Santiago)
NSW	New South Wales
PLUM	Population and Land Use Model
POPDAM	Population and Dwelling Allocation Modelling
QLD	Queensland
RBA	Reserve Bank of Australia

SA2	Statistical Area Level 2
SA3	Statistical Area Level 3
SA4	Statistical Area Level 4
SALUP	Small Area Land Use Projections (Victoria)
SCGE	Spatial Computable General Equilibrium
SEIFA	Socio-Economic Indexes for Areas
SEQ	South-East Queensland
SEQSTM	South-East Queensland Strategic Transport Model
SIRCV	Spatial Interactions within and between Regions and Cities in Victoria
SRL	Suburban Rail Loop
SRLA	Suburban Rail Loop Authority
TZP	Travel Zone Projections (NSW)
UK	United Kingdom
US	United States
VIF	Victoria in Future
VITM	Victorian Integrated Transport Model
VLUTI	Victorian Land Use and Transport Integration
WA	Western Australia
WEB	Wider Economic Benefit

Appendix B Example calculation of trip-weighted average generalised minutes

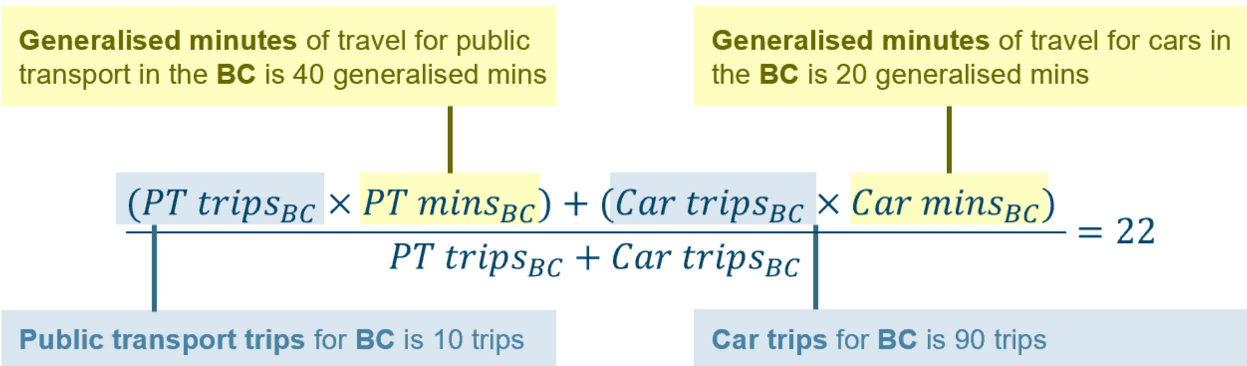
For a given origin-destination pair, consider an intervention that improves the public transport (PT) travel time in the Project Case (PC) compared to the Base Case (BC), while car travel time is unchanged between Base Case and Project Case. Faster PT travel time means some people will shift away from car travel and choose PT instead. The impacts of the intervention are presented in Table B- 1.

Table B- 1 Impacts of the intervention

	Generalised minutes		Trips	
Scenario	**Public transport**	**Car**	**Public transport**	**Car**
Base Case	40	20	10	90
Project Case	30	20	30	70

The trip-weighted average generalised minutes between Base Case and Project Case could be calculated using Method 1 (see Figure B- 1).

Figure B- 1 Method 1 to calculate trip-weighted average generalised minutes with variable (for Base Case)



Source: Author's analysis

Running the same calculation for the Project Case yields a result of 23 generalised minutes. This method gives a deterioration in average travel time to be under the Project Case despite the only difference between Base Case and Project Case being a PT improvement. If this measure is used in LUTI modelling it could erroneously cause the origin to appear less attractive in the Project Case than the Base Case for location choices.

To avoid this, the trip-weighted average time should be weighed by the sum (or average) of the Base Case and Project Case trips as shown in Method 2 (see Figure B- 2).

Figure B- 2 Method 2 to calculate trip-weighted average generalised minutes with summed weights (for Base Case)

Generalised minutes of travel for public transport in the **BC** is 40 generalised mins

Generalised minutes of travel for cars in the **BC** is 20 generalised mins

$$\frac{(PT\ trips_{BC+PC} \times PT\ mins_{BC}) + (Car\ trips_{BC+PC} \times Car\ mins_{BC})}{PT\ trips_{BC+PC} + Car\ trips_{BC+PC}} = 24$$

Total public transport trips between BC (10 trips) and PC (30 trips) is 40 trips

Total car trips between BC (90 trips) and PC (70 trips) is 160 trips

Source: Author's analysis

The above method yields a result of 22 generalised minutes for Project Case – an improvement in the Project Case relative to the Base Case. If this measure is used in LUTI modelling it would appropriately represent an improvement in the attractiveness of the origin in the Project Case relative to the Base Case for location choices.

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