



Model Calibration and Validation Report

Infrastructure Victoria
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1 Introduction

1.1 Background

Infrastructure Victoria released its 30-year infrastructure strategy in 2016. Among the top three recommendations in the strategy was the introduction of a comprehensive transport network pricing regime in a 10-15 year timeframe. As part of this recommendation, IV identified the need to undertake further research to identify the best ways to get the most efficient use out of the transport network. As part of Infrastructure Victoria's *Managing Transport Demand* research program, it sought to better understand travel patterns for Melbourne now and in the future.

1.2 Scope

Building on the research work completed to date, KPMG and Arup were engaged by IV to:

- developing an activity-based model that allows for the network wide travel patterns to be rigorously examined and effectively communicated;
- use the model to assess the social and distributional effects of different demand management interventions at the household and individual level;
- understand likely road travel behaviour and impacts on the transport network, including on transport network performance, transport accessibility, the environment and social equity; and
- analyse implications for IV's recommended transport investment program.

Short-listed demand management interventions will be taken forward by IV into the next stage of the research program for more detailed assessment.

1.3 Peer review

The Melbourne Activity-Based Model (MABM) calibration and validation as documented in this report has been independently reviewed by Meead Saberi of Monash University. The findings of the peer review have been incorporated into this report. The peer review findings and the associated responses are shown in Attachment E.

1.4 This report

This report forms a technical appendix, describing the approach to development of the MABM, the model's suitability and the approach adopted to validate and calibrate the model. Following this introductory section, the remainder of this Appendix is structured as follows:

- Section 2 sets out *the adopted modelling framework* including the rationale behind selecting an activity-based model, an overview of how activity-based models deviate from traditional four step transport models and the software platform selected.
- Section 3 discusses *the approach to model calibration and validation*. In particular, the key model components and validation criteria are highlighted.
- Section 4 lists *the data sources used* as model inputs and to calibrate and validate the activity-based model. This section also details any limitations associated with the data sources.
- Having described the modelling framework and the approach to model calibration and validation, Section 5 presents *the model validation results* and performance against the validation criteria, as well as a discussion on the model response to sensitivity and elasticity of demand on parameter tests.
- Section 6 provides the *approach to generating the demand and undertaking modelling runs for 2031*. The 2031 modelled results are compared against the 2015 benchmark run for validation to understand how the model behaves for a future forecast horizon (i.e. 2031 in this instance).
- Section 7 includes a discussion on the *application of the MABM*, including implications for transport network demand management policy analysis.

2 Modelling Approach

To analyse travel demand patterns for Melbourne now and in the future, and identify the potential impacts of various transport network demand management policy options, an activity-based model for the Greater Melbourne area has been developed.

The MABM uses the open source software platform and theoretical framework known as multi-agent transport simulation (MATSim). IV signed-off the model validation on 4 August 2017 and assessed the model as fit-for-purpose for transport network demand management policy assessment.

This section provides an overview of the general theory that underpins the MATSim framework, how it differs from traditional practices, and why this approach has been adopted for this study. It also explains how the model was developed within the selected software platform.

2.1 Theory

The MATSim framework uses an activity-based modelling approach. Activity-based models differ from traditional four step models in that they model the activities undertaken by individuals, and the travel required to move between these activities throughout the day.

There are some similarities between traditional four step 'trip-based' models, and activity-based models in that activities are generated, destinations identified, travel modes determined, and routes selected (Strategic Highway Research Program, Transportation Research Board, 2015). Four step models utilise aggregated data at the zonal level however, whereas activity-based models are disaggregated to an individual level using a tour based approach (refer to *Tour Based Modelling* below).

The key differences between activity-based models, and standard modelling practice are; the linkages between activities and travel, the allowance for variable departure time, and the incorporation of individual household and person-level attributes in utility functions (Strategic Highway Research Program, Transportation Research Board, 2015). Other key features of the MATSim framework is that it is agent-based and uses a co-evolutionary algorithm.

2.1.1 Activity Based Modelling

By modelling activities as well as travel, activity-based models allow for travel constraints to be linked with an individual's broader travel plans. While tours have been implemented within four step models, activity-based models offer a more natural framework as the concept of tours is an inevitable outcome when modelling activities.

The following example highlights the advantage that this approach has over traditional four step models. Consider the situation where there is some travel demand between an outer-suburb, a school, and commercial office. There is strong public transport connectivity between the school and the office, but not between the school and the residential suburb.

In a traditional four step model the travel associated with parents dropping their children to school on the way to work would be represented by home-to-education trips, and a separate independent 'non-home-based' trip to work. While the former would have a high car-driver percentage based on the trip-type, the latter would likely have a higher proportion of trips by

public transport. There is no connection between these two trips, merely an aggregated travel demand between zones.

An activity-based model overcomes this disconnection by modelling the two trips as part of a larger 'plan' undertaken by an individual. In using this approach, the mode choice for the journey from school to work recognises that the mode choice decision was already made in an earlier leg, and the parent would likely continue to use their car when driving to work.

This is highly relevant for transport network demand management or policy studies, as instances may need to be modelled in which a pricing scheme for example only applies to a single leg of a journey (e.g. a peak period charge that is accrued on the journey home, but not the journey to work). A traditional four step model would adjust travel behaviour for the work-to-home trips, including trip distribution and mode choice, independently of the travel behaviour for the home-to-work trips. An activity-based model however recognises that the two trips are linked, and any change in travel behaviour has flow on impacts on activities and travel across the entire day (Strategic Highway Research Program, Transportation Research Board, 2015, pp. 8-16).

In linking travel between activities as part of a plan, activity-based models enable individuals to adjust their plan based on travel constraints on individual legs of the journey. This could involve deferring an activity to account for expected congestion, or even dropping an activity with lower utility to ensure higher value activities are not delayed¹ (Strategic Highway Research Program, Transportation Research Board, 2015, pp. 8-16). This ties in with another aspect of activity-based models which is the incorporation of variable departure time.

2.1.2 Departure Time Choice

Standard modelling practice typically assumes a fixed departure time profile for each trip-type based upon household travel surveys. While this survey data similarly informs activity-based models, the linkage between travel and activities in the MATSim framework allows for greater flexibility in departure time. This is achieved through the scoring of alternative plans by individuals across an entire day.

In having the destination of one trip become the origin for the next trip, the geographic consistency of MATSim provides realistic bounds on 'where, how and when' individuals can travel. Opening and closing times at activities constrain when additional activities can be undertaken. Arriving early, or late at an activity brings additional disutility that weighs against the value of the activity. Within MATSim, each individual iteratively optimises their overall activity plan to maximise utility across the day (Horni, et al., 2016, pp. 24-29).

This is significant with respect to analysis of transport network demand management policy options. Initiatives such as peak period charging are intended to encourage shifts in travel behaviour, including adjusting departure times to an earlier or later period. MATSim allow individuals to adjust their activity and travel plan to respond to a scenario that implements such a road user charge. In modelling individuals, MATSim also enables different income levels (as a proxy for valuation of travel time savings) to be accounted for when testing the impact of pricing schemes for example.

2.1.3 Individual Attributes

Traditional four step models assume that each travel zone is economically homogenous, with trip generation a function of metropolitan-wide factors for population, employment, or car ownership. Similarly mode choice and route assignment are purely a function of the transport network, and general population wide calibration parameters. The traditional four step modelling approach does not recognise differences in travel behaviour stemming from socio-economic constraints, and

¹ Please note the current version of the MABM does not allow for adding or dropping of activities to plans.

consequently limits the ability to assess the equity impacts of transport network demand management policies including pricing schemes for instance (Strategic Highway Research Program, Transportation Research Board, 2015, pp. 8-16).

MATSim overcomes this limitation by modelling individuals, each with unique household or person-level attributes. In this sense, MATSim is an agent-based model. By incorporating individual attributes in this manner, variables such as household income can be used when scoring alternative activity and travel plans. Consequently MATSim can be used to explore how travel benefits or costs associated with a specific initiative impact on different segments of the population, and can be used to support equity analyses (Strategic Highway Research Program, Transportation Research Board, 2015, p. 7).

This is the primary reason why MATSim has been selected to help IV assess the impacts of various into transport network demand management schemes.

2.1.4 Co-evolutionary algorithm

The MATSim framework uses a co-evolutionary algorithm for each individual agent to maximise their scores (i.e. utility) while competing with each other for time and space on the transport network to execute their daily plans. Agents randomly mutate their plans, with the best performing plans more likely to be retained, and the worst performing plans discarded. In the MABM, the following mutations are allowed:

- Departure time change
- Subtour mode choice
- Routing
- Park and ride behaviour (for workers only)

A small percentage of agents in each iteration attempt a random mutation of their plan. The majority of agents in a given iteration select from an existing plan and execute it.

This approach allows the agents to 'learn' as the simulation progresses. This learning occurs within the constraints of the simulation configuration. These constraints include windows for activity start and end times and desired activity durations. The last 20% of iterations disable plan mutations ('innovation') to allow the network to achieve equilibrium. The MABM uses 500 iterations (400 with innovation and 100 without).

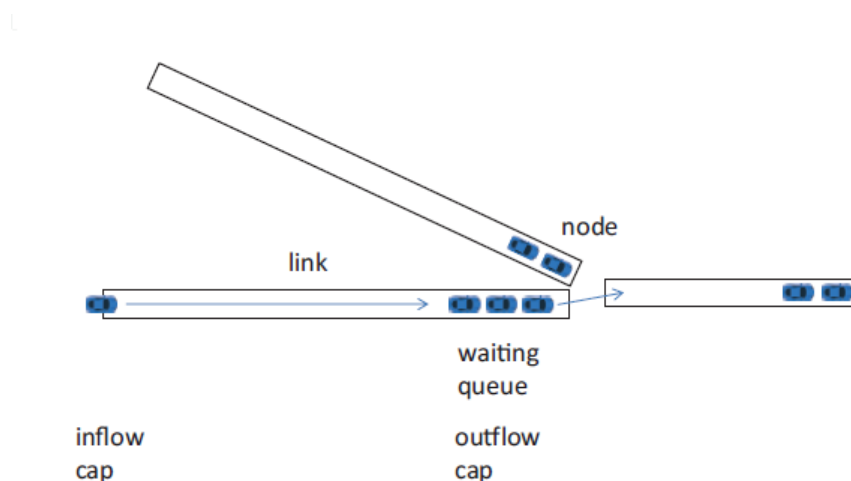
2.1.5 Queue simulation

Most four step models use a static assignment process where all the demand is distributed from origins to destinations along routes over a given time period. The MATSim framework uses a dynamic assignment process where individual agents travel from origins to destinations.

MATSim also uses queue dispersion as the main method of modelling congestion, which is more sophisticated than volume delay functions used in most four step models. The assignment methodology is similar to a mesoscopic model. The traffic flow model uses storage capacity and flow capacity and a 'waiting queue approach'. Under the waiting queue approach, cars are added to the end of waiting queues as they enter the road network. Cars wait in the queue until the travel time under free flow has passed and the car is at the head of the queue, and the next link is available to enter (Horni, et al., 2016, p. 6). While static assignment assumes each vehicle is at every location along a route at the same time, dynamic assignment simulates the entire trip from beginning to end. This provides an advantage for modelling time of day pricing schemes over four step models.

A diagrammatic representation of the queue simulation dynamics are shown in Figure 1.

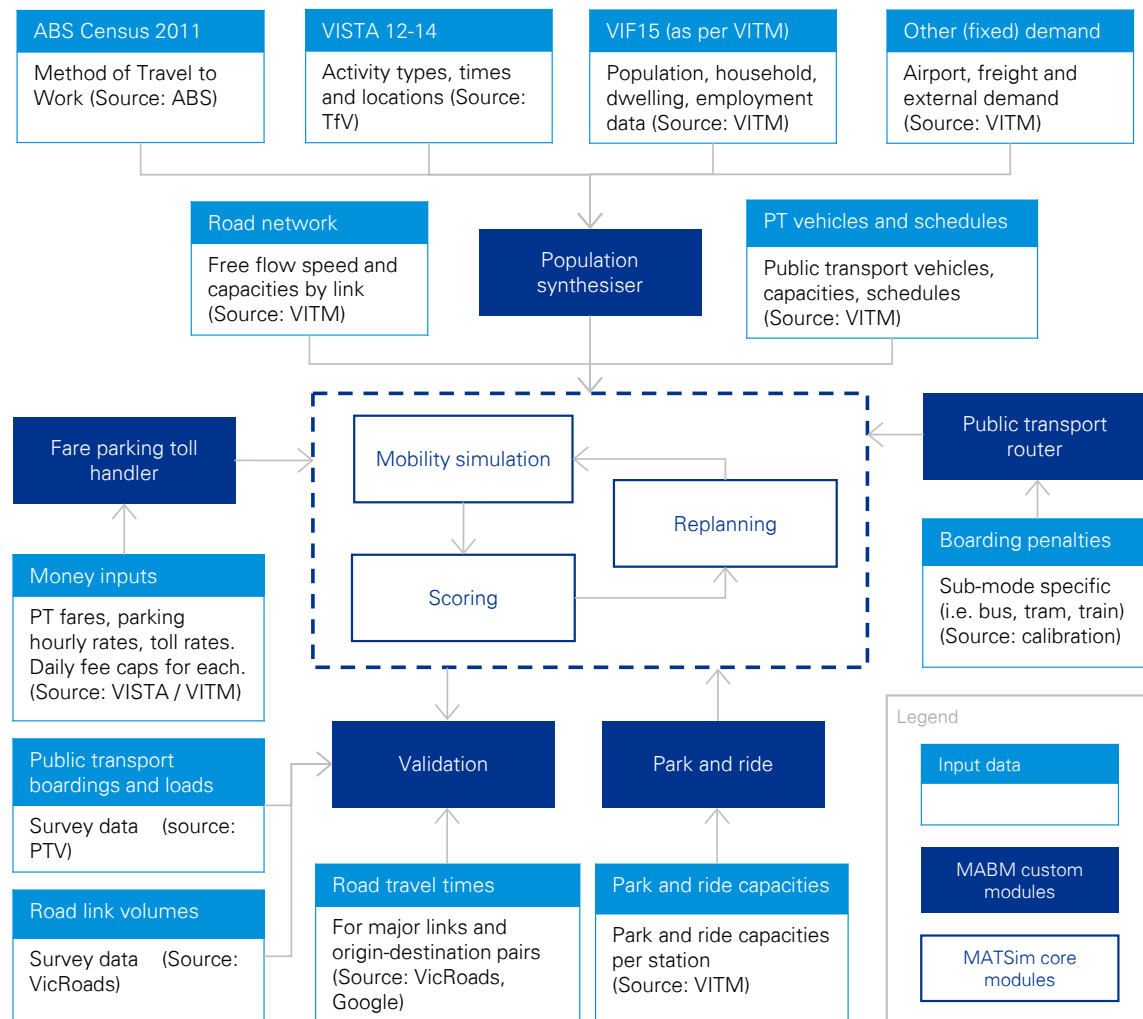
Figure 1: Diagram of the queue simulation dynamics



Source: (Horni, et al., 2016, p. 6)

2.2 Model structure

The full model structure used for the MABM is shown in Figure 2 overleaf. MATSim is the software platform used for the MABM and is discussed further in Section 2.3. The approach to calibration of the modules is discussed in Section 3.1, and the data sources used are outlined in Section 4 of this report.

Figure 2: Model structure of the Melbourne Activity Based Model

2.3 Software

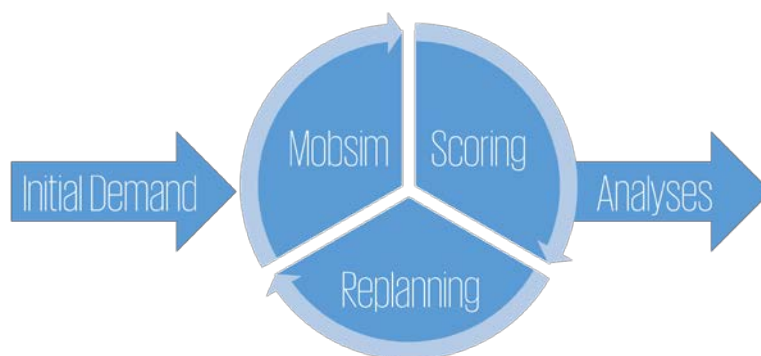
MATSim is the software platform selected for the MABM. MATSim is an activity-based, multi-agent simulation framework that is designed for large scale scenarios (Horni, et al., 2016, pp. 4-6). MATSim was developed incrementally as the combination of several parallel research streams, commencing in the early 1990's. These research streams included microscopic modelling of traffic, computational physics, behavioural modelling of demand, and complex adaptive systems (Nagel & Axhausen, 2016, pp. 307-314).

MATSim incorporates best practice activity based modelling theory and techniques. One notable difference between MATSim and some other activity based modelling tools is that MATSim does not support adding or dropping of activities. MATSim is also agent-based and uses a co-evolutionary algorithm. These aspects of MATSim make it a best practice tool for strategic transport modelling.

MATSim models individuals, who are referred to as 'agents'. Each individual repeatedly optimises its schedule of activities across a day, competing for space on the transport network with other individuals. This approach enables MATSim to account for an array of travel decisions such as time choice, mode choice, destination choice and route choice (Horni, et al., 2016, pp. 4-6).

MATSim uses an iterative process shown in Figure 3.

Figure 3: MATSim cycle



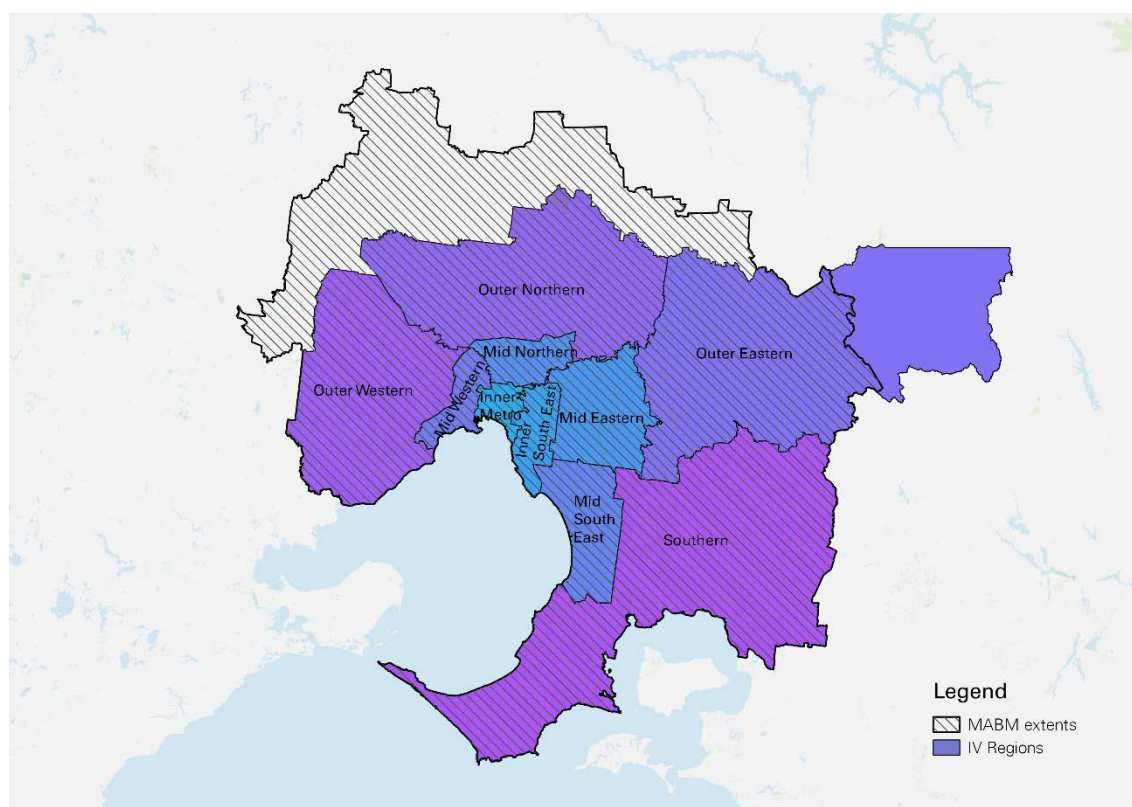
Initial demand is provided as an input into the MATSim model, based upon the population characteristics of the study area. Daily activity chains are developed from empirical data, with each activity chain having a corresponding score representing the value of the plan to an individual.

Each individual selects a plan for the day based upon an initial score, and once the plan has been implemented on the loaded network using *mobsim*, the score is then recalculated (Horni, et al., 2016, pp. 4-6). This revised score allows individuals to optimise their plan. Each iteration, a proportion of individuals (typically ten percent) are selected to modify their plan during the *replanning* stage (Horni, et al., 2016, pp. 4-6). This optimisation includes adjustments to departure time, activity duration, destination, mode, and route. This iterative cycle continues until the average score across the population stabilises (Horni, et al., 2016, pp. 4-6). The comprehensive modelling framework used for this analysis, including details of inputs, is provided in Section 2.2.

2.4 Geography

The geographic coverage of the MABM includes Greater Melbourne and is illustrated in Figure 4. Using the sub-regional boundaries as provided in the *Plan Melbourne* as a starting point, Greater Melbourne was sub-divided into ten sub-regions for reporting purposes. The sub-regions have been defined in this way to help address project objectives. Indicators are able to be generated using the MABM at these sub-regional levels. All network wide results presented in this report refer to the MABM coverage. All results broken down by sub-region refer to the coverage of the sub-regions (therefore omitting some trips and activities from the MABM coverage).

Figure 4: Regions of metropolitan Melbourne



3 Modelling Calibration and Validation Approach

This report section details the approach adopted for calibrating and validating the MABM. The method of calibration is outlined, including the approach for generating a population synthesis, activity-based pattern generation, as well as coefficients for utility of time and cost. The approach to validating the model, including the specific validation criteria adopted is also explained.

The methodology used to estimate initial calibration parameters for MABM is detailed in Attachment A and a summary of the calibration and validation model runs undertaken for this project is shown in Attachment B.

3.1 Calibration

3.1.1 Approach

In the MATSim framework, agents with demographic characteristics and their initial plans need to be generated as an input into the model. In addition, parameters used in the scoring function need to be estimated. This is achieved using the following components of the calibration process:

- *Population synthesis*: Development of a list of individuals to match population projections and current demographics for each region.
- *Activity-based pattern generation*: Assigning activity (and travel) plans to individuals based upon reported travel behaviour.
- *Scoring function parameters*: Derivation of coefficients of travel utility to reflect broader travel behaviour, including income dependent cost sensitivity, across the Greater Melbourne area.

3.1.2 Key Model Components

3.1.2.1 Population Synthesis

The population of Greater Melbourne is reflected in the MABM as a list of individuals, each with unique demographic identifiers. These individuals need to be created proportionally to match broader demographic trends, and household totals for each region (Muller, 2012, pp. 1-14).

This synthetic population is developed using a combination of aggregated population and household Census data for each region, projected population for a reference year, and method of travel to work data.

The population synthesis process requires one main input; a 'control total' for each Victorian Integrated Transport Model (VITM) travel zone (approximately 3,500 zones). The control total is a dataset that includes the number of individuals of each key demographic (i.e. age, and employment status) within each VITM zone. The control total acts as a constraint to ensure that the final population is representative of the study area. By definition, the age profile and

residential geographic distribution of the synthetic population at the travel zone level matches the 2015 reference year from the 2016 version of *Victoria in Future (VIF)* estimates.

Method of Travel to Work data was attained from the 2011 Census at an aggregate level, and population and household control totals from the VIF estimates. These data sources are discussed in greater detail in Section 4 of this report.

An 'inflation factor' was calculated for each VITM zone to scale up the Census data (2011) to the modelling reference year (2015). This inflation factor was calculated as the ratio of the number of households projected for the reference year, with the number of households recorded in the Census. For SA2s with zero population in 2011, the MTWP proportions of a neighbouring SA2 were applied to the VIF2015 forecast to estimate the 2015 mode split. It is this final scaled dataset that is termed the 'control total'.

Age and income profiles of the synthetic population relative to the ABS 2016 Census are shown in Attachment D.

3.1.2.2 Activity-Based Pattern Generation

Once a virtual population was created for use in MATSim, each individual 'agent' was assigned an activity plan that represents their movement and activity across a single day. These activity plans were developed using a combination of the 2011 census results for journey to work data, and the *2012-14 Victorian Integrated Survey of Travel and Activity (VISTA)* as a source of realistic travel and activity plans.

Activity-based pattern generation was undertaken in two stages, with the first assigning an activity plan to workers. The location of work was sourced from Method of Travel to Work Profile (MTWP) from the 2011 Census which effectively forms a wide-scale reported origin-destination matrix. Corresponding method of travel to work profile data was used to assign a mode of travel to each worker. Nine combinations of mode choice were used to build home to work trips, with this data needing to be scaled up by 5.95% to account for non-responses in the census, as well as the responses which corresponded with more complex mode chains which were omitted.

As noted in Section 3.1.2.1 this journey to work data, and corresponding method of travel to work was scaled up to match the control total for the population using VIF projections for each respective modelling reference year.

To assign a whole of day activity plan to each worker, VISTA records were used to determine additional trips, trip lengths, and timings. Each weekday trip recorded across approximately 23,000 individuals who participated in VISTA formed a database of potential activity patterns. Individuals in the model were matched with an activity plan from VISTA using a 'demographic signature'.

The demographic signature is created using the individual attributes associated with the individual including age (for non-workers), household location at an SA4 level, and employment status. SA4 is selected to provide a large enough bank of persons to ensure heterogeneity of activity patterns and timing within small areas. This is critical to avoiding high concentrations of activities which can lead to gridlock when traffic is assigned. Person weights from the VISTA sample are also applied to account for known sample biases. Despite this, demographic characteristics in the MABM are subject to error arising from unknown VISTA sample bias, and the aggregation of characteristics used in the demographic signature.

The trip purpose reported within VISTA was used to allocate each activity a trip type within MABM. The trip types considered are:

- Home;
- Work;
- Business;
- Education (primary / secondary);

- Education (tertiary);
- Education (drop-off / pick-up); and
- Other.

To allocate an activity plan to an individual, the VISTA records that matched the demographic signature, and whose home location was within the same SA4 as that of the individual were identified. One of these activity plans was randomly selected, and assigned to the individual. This activity plan provided only the trip types, timing, trip lengths, and individual income level. Activity locations from the VISTA records were not adopted.

The method of assigning activity locations was dependent on the activity type itself. For education trips, the location for primary and secondary education trips were 'snapped' to the school that was nearest to the trip distance reported in VISTA. The location of tertiary education trips were determined based on total enrolments at each university, and trip distance reported in VISTA.

Other activity types were randomly assigned to a viable location based upon the trip length reported in VISTA. To ensure that the final location presented a realistic travel option, the probability of that trip type occurring in that location (at an SA2 level) was determined from the collective VISTA records. Where the probability of this activity occurring in the specific location was negligible, a new location was determined based upon the trip length reported within the VISTA record. This process was undertaken iteratively to ensure that the activity patterns generated are reasonable.

Activity pattern frequencies of the synthetic population relative to the full VISTA 12-14 sample are shown in Attachment D.

3.1.2.3 Scoring Function Parameters

Competing travel plans within MATSim are compared using a scoring mechanism that balances the positive utility associated with undertaking activities, with the dis-utility associated with travel. These scoring functions are pre-established within the MATSim software, however the coefficients for the parameters have been modified to reflect travel behaviour that is representative of Greater Melbourne.

Calibration of these scoring coefficients was achieved using a process of multinomial logistic regression for existing travel data for Melbourne. Through this process, utility functions for travel by alternative modes were derived which were adapted for use in the MABM. The utility equations selected were a function of travel time, travel cost and income to correspond with the parameters in the MATSim scoring functions. These calibration parameters are therefore specific to Melbourne. More detail about how the parameters were derived can be found in Attachment A.

The data used in the regression analysis was sourced from the latest VISTA. Records from the journey to work leg were used to identify mode choice, start and end times and destinations, as well as relevant household income information. This trip data was supplemented with travel time information for each alternative mode sourced from HERE Maps.

The cost coefficient from the results of the regression analysis was adopted as the value for the marginal utility of money (β_m), representing the sensitivity of individuals within the model to changes in price (Nagel, et al., 2016, pp. 23-34). As household income per person was included as a parameter in the regression analysis, the effective value of β_m in the MABM varies depending on an individual's income.

This allows individuals to respond to price signals such as fares and tolls according to their income, and consequently their willingness to pay. An activity-based model such as the MABM is uniquely suited to incorporating income dependent travel behaviour at an individual level.

The calibration parameters adopted in MATSim for the MABM are presented in Table 1.

Table 1: Calibration parameter values

Parameter	Calibration Value
β_m	28.30 utils / \$
β_{dur}	2.14 utils / h
$\beta_{tt,car}$	0 utils / h
$\beta_{tt,PT}$	-0.98 utils / h
$\beta_{tt,walk}$	-2.43 utils / h
$\beta_{tt,cycle}$	-6.64 utils / h
$\beta_{late,ar}$	-6.42 utils / h
$\gamma_{d,car}$	17.6 c / km

The following should be noted in relation to the calibration parameters:

- β_m is to be divided by the individual daily household income per person with an income floor of \$65 / day.
- β_{dur} was selected as the pre-factor of car travel time from the regression analysis, with the parameter sign changed to a positive value.
- $\beta_{tt,car}$ was set to zero, recognising that travelling by car will be implicitly punished by the opportunity cost of time. The marginal utility of travelling for other modes were similarly offset relative to the value for travel by car.
- $\beta_{tt,PT}$, $\beta_{tt,walk}$ and $\beta_{tt,cycle}$ parameters were derived from the regression analysis.
- $\beta_{late,ar}$ was set at a scale of three times the marginal utility of activity (β_{dur}) as per MATSim's default value.
- The monetary distance rate for travel by car ($\gamma_{d,car}$) was estimated to be 17.6c/km from the fuel price estimated using the Australian Transport Assessment and Planning (ATAP) guidelines (ATAP, 2017).

3.2 Validation

3.2.1 Approach

Activity-based models are a relatively recent development in Australia. As such, standard guidance on calibration and validation criteria such as those provided in ATAP is limited. To date, KPMG and Arup are not aware of any standard activity-based model development guidelines published by a transportation agency in Australia. As part of this study, validation criteria specific to the MABM needed to be devised.

As discussed in Section 2.1, activity-based models share a number of similarities with traditional four step models. However, activity-based models substantially diverge in their approach to determining when and where a trip will occur. Rather than directly modelling trips between discrete activities, the movement of individuals throughout the day is explicitly modelled, with

trips on the transport network resulting from an individual's need to travel between consecutive activities. Due to this difference, typical trip generation and distribution criteria used to validate the demand side of a four step model are not directly applicable. Rather, criteria specific to activity-based models that are able to cover activity generation and scheduling are required.

The network assignment aspects of an activity-based model also differ from the approach typically used in a traditional four step model. Rather than a 'macroscopic' analytical assignment calculation covering an averaged fixed period, MABM employs a traffic simulation model which is continuous over the entire modelled day. As such, while the output results from a MABM assignment will be in familiar units of measurement, validation of the results needs to consider:

- The selection of measurement periods; and
- Traffic in a simulation model does not propagate through the network instantaneously, allowing the timing of peak periods to vary across the network.

Based on our review of published literature covering activity-based model validation in practice (Roorda, 2008) (Drchal, 2015), the validation of activity generation should cover the following:

- *Temporal properties:* Start times and durations;
- *Spatial properties:* Where activities occur in space; and
- *Structural properties:* Activity frequency and arrangement of consecutive activity types.

Table 2 provides a comparison of how each of these activity properties relates between activity-based models and four step models.

Table 2: Activity property relationship to model components

Activity property	Activity-based model component	Four step model equivalent
Temporal	Activity scheduling	None
Spatial	Activity location choice	Trip distribution
Structural	Activity frequency / chaining	Trip generation

The criteria devised for validation of activity generation within MABM covers each of the three described activity properties, drawing on VISTA household survey data and Census data. Validation criteria covering trip assignment aspects of the model largely draws from criteria applied to the Victorian state government's strategic transport model, the Victorian Integrated Transport Model (VITM), a traditional four step strategic transport model. These are adjusted as required to reflect the differences in modelling approach and the specific requirements of this study.

3.2.2 Validation criteria

Desired validation criteria were developed to:

- Be consistent with validation frameworks implemented for major policies or projects such as the Melbourne Metro project;
- Recognise that some aspects are critical in developing a model that is fit-for-purpose and tailored to meet the requirements of the analysis and agreed scope of works; and
- Be suitable for assessing the impact of potential transport network demand management including network pricing options, while other components are of lower importance.

For each validation criteria, performance of the MABM is rated according to the ranking and expected performance range shown in Table 3.

Table 3: Rating of model performance against validation measures

Rank	Expected Performance Range	Validation measures
Very important	1-2	Travel demand on toll roads Trip generation Mode share by region
Medium importance	2-3	Road screenline volumes Train loads at CBD cordon Train boardings
Low importance	3-4	Bus and tram boardings

The desired criteria adopted for validation of all components of the MABM is detailed in Table 4.

Table 4: Criteria adopted

Level	Desired criteria
1	At least good quality data and base year validation meet desired criteria for 80% of elements
2	At least good quality data and base year validation meet desired criteria for 60% of elements
3	At least good quality data and base year validation within range for majority of the highest priority items
4	Complies with most global validation criteria and uses at least representative data
5	Model has not been validated against global criteria

The validation steps for all components in the MABM are detailed in Table 5.

Table 5: MABM validation steps and elements

Element	Segmentation	Ranking	Desired Criteria	Comparing to
Activity generation and distribution				
Number of persons and households	By Local Government Area (LGA)	Very important	± 5%	VIF 2015
Total modelled trips	By activity type By region	Very important	± 20% on at least 60% of elements to demonstrate that the model replicates household survey data; report on comparison with survey data and VITM	VISTA household survey data VITM
Activity start time distribution	By activity type By region	Very important	Demonstrate that the model replicates household survey data via visual comparison ²	VISTA household survey data
Activity duration distribution	By activity type By region	Very important	Demonstrate that the model replicates household survey data via visual comparison ²	VISTA household survey data
Activity frequency	By activity type By region	Very important	± 20% on at least 60% of elements to demonstrate that the model replicates household survey data and Census data	VISTA household survey data, ABS Census data
Travel distance to activity location	By region	Very important	Demonstrate that the model replicates household survey data; report on comparison with survey data ²	VISTA household survey data
Overall travel demand patterns	LGA to LGA matrix CBD	Very important	± 20% on at least 60% of elements to demonstrate that the model replicates travel demand patterns; report on comparison with VITM	VITM

² These are required validation steps, but not a key consideration in deciding whether the model is well validated and calibrated.

Element	Segmentation	Ranking	Desired Criteria	Comparing to
Multiple Modes				
Mode share	By region	Very important	± 10%	VISTA household survey data, ABS journey to work data (work activities only)
Highway				
Screenline volumes by time of day	By direction By region	Medium importance	Percent difference for all screenlines within the bounds of the VicRoads target curve as defined by VicRoads ($\%Diff \pm 50 \times V - 0.3953$), comparing 2 hour, one-way volumes ³	Synthetic 2015 traffic volume data set
Toll road volumes by time of day	By direction	Very important	50% of cases with a GEH statistic <5 and 80% of cases with a GEH statistic <10. The GEH statistic compares surveyed and modelled volumes and is based on VicRoads guidelines ³	Toll road traffic volumes
Motorway corridor travel time	On key routes	Medium importance	Modelled time within 95% confidence limit of the mean surveyed time >85% of routes in line with VicRoads guidelines ³	HereMaps dataset
Private vehicle occupancy	By region	Relevant	Comparison spatially and by trip purpose; vehicle occupancy to be between 1.0 and 1.8.	VISTA household survey data

³ VicRoads, Transport Modelling Guidelines (Volume 2: Strategic Modelling, 26 April 2012)



Public Transport

Daily train boardings	Overall MABM region	Medium importance	± 20%	PTV survey data
Peak period train loads at CBD cordon	By group	Medium importance	± 20%	PTV survey data VITM comparison
Daily tram boardings	Overall MABM region	Low importance	± 20%	PTV survey data
Daily bus boardings	Overall MABM region	Low importance	± 20%	PTV survey data

4 Data sources

This section lists the data sources that were used as primary inputs in developing the MABM. Associated data limitations are also noted where relevant.

4.1 Model Inputs

The MABM was developed using many of the same inputs as the Victorian Government's Strategic Transport Model, Victorian Integrated Transport Model (VITM). The purpose of this was to maintain compatibility with the VITM as well as leveraging the significant amount of investment that has gone into the development of VITM. Further detail on the network conversion process is outlined in Attachment C.

4.1.1 Road network

The VITM base transport networks for 2015 and 2031 are derived from the Department of Economic Development Jobs, Transport and Resources Reference Case. The VITM networks were converted from the .NET format associated with Cube Voyager (the software platform used for VITM) to a more universal XML format, enabling use as an input to MATSim.

4.1.2 Public transport capacities and schedules

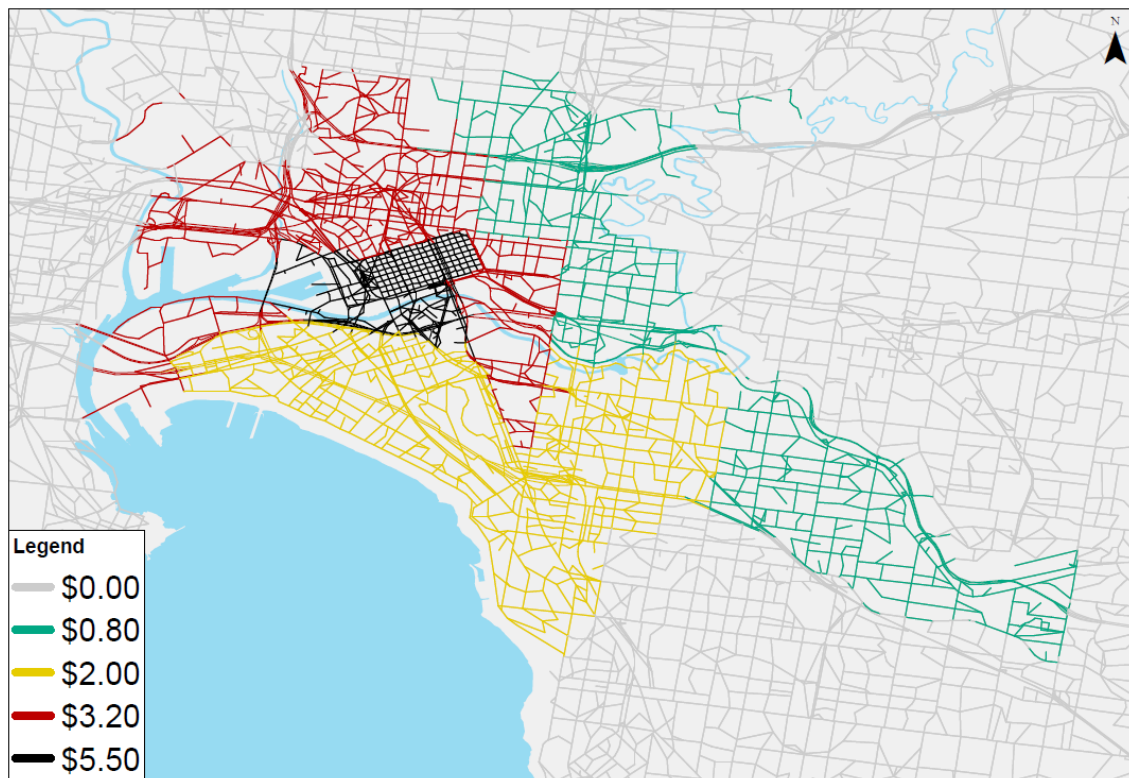
Public transport services implemented in MATSim reflect the public transport line files that are coded into the VITM base model scenarios for 2015 and 2031 (as per the Reference Case). Train, tram and bus vehicle capacities are also derived from the VITM base model.

4.1.3 Parking

Hourly parking rates are adopted based on information from the City of Melbourne websites as of May 2017⁴. Four levels of hourly parking rates are adopted as shown in Figure 5. A global parking cap of \$22 per day is applied. This corresponds to approximately four times the maximum hourly rate and is slightly higher than most early bird rates.

⁴ <http://www.melbourne.vic.gov.au/parking-and-transport/parking/Pages/parking-faqs.aspx>

Figure 5: Hourly parking rates



4.1.4 Fares

Consistent with transport economic theory and the approach adopted for VITM, a reduction factor of 0.63 was applied to full public transport fares. This reduction factor is designed to account for the perceived cost of public transport use after accounting for different ticket types (e.g. monthly, annual passes) and reduced fares (e.g. concession). The reduction factor of 0.63 was adopted from the 2011 Melbourne Integrated Transport Model (MITM) validation report (AECOM & SKM, 2011)⁵.

The reduction factor is applied to a full fare of \$4.10 as of May 2017 which equates to a perceived fare of \$2.58 in MABM. The daily fare cap is set at twice the single trip fare at \$5.17.

4.1.5 Tolls

Toll prices are set per gantry according to the 'Toll Calculator' websites for CityLink⁶ and EastLink⁷ as of May 2017. A toll cap of \$7.52 per trip was applied to approximate the toll caps specified on those websites.

⁵ See Appendix F, page F-4. A fare of \$2.34 was used compared to a full fare of \$3.70 (2009 dollars).

⁶ <https://www.citylink.com.au/using-citylink/toll-calculator>

⁷ <https://www.eastlink.com.au/toll-calculator>

4.2 Calibration Data Sources

4.2.1 Population Synthesis

The data sources detailed below were used to inform the development of a population for use in MABM.

Victoria in Future Projections

The latest Victoria in Future population projections were utilised to enable scaling of the Census data to the 2015 base year (Department of Environment, Land, Water and Planning, 2016). Household and population totals for each SA1 were used as inputs to this process.

Victoria in Future is the official state government projection of population and households (Department of Environment, Land, Water and Planning, 2016). For small areas below the size of local government boundaries, it covers the period from 2011 to 2031 (Department of Environment, Land, Water and Planning, 2016).

4.2.2 Activity-Based Pattern Generation

To inform the development of an activity plan for the population within MABM, the data sources detailed below were utilised.

Victorian Integrated Survey of Travel and Activity (VISTA)

Revealed preference survey data from the 2012-14 household travel survey were used to develop trip patterns for individuals (Department of Economic Development, Jobs, Transport and Resources, 2017).

The VISTA is an ongoing survey of household travel activity that is conducted across the Greater Melbourne area. Households are randomly selected to complete a travel diary to create a comprehensive travel plan of all activities conducted on a specified day (Department of Economic Development, Jobs, Transport and Resources, 2017). A database of potential activity patterns for individuals was formed using the approximately 23,000 individuals who participated in VISTA. This data was used to ensure that the activities and travel undertaken by individuals within the model are realistic, and are representative of travel behaviour of specific demographics.

2011 Census – Method of Travel to Work Profile

As part of the 2011 Census, information on the method for travel to work on the day of the Census was recorded (ABS, 2017). This data was used to calibrate the activity patterns used within the MABM. The number of workers, corresponding places of work, and initial mode choice for the MABM were adopted from the journey to work Census data (2011).

4.2.3 Calibration of Scoring Functions

The scoring functions within the MABM software are used to rank competing activity and travel plans. The software's default values were modified to represent travel behaviour across Greater Melbourne using a process of multinomial logistic regression. Data to inform the regression was sourced from the VISTA.

Victorian Integrated Survey of Travel and Activity (VISTA)

Revealed preference data tables for person and household travel information from 2012-14 were used to collect the following information for the journey to work leg of home-work-home trips:

- Household income;

- Household size;
- Mode taken for journey to work (car, PT, walk or cycle only);
- Home location (SA1);
- Work location (SA1); and
- Departure time and day.

While sourced from the same dataset as used to create the potential travel plans, this VISTA data was limited to journey to work trips only. This means that non-work trips use the same scoring parameters as work trips. This is a function of the MATSim framework. Work trips were chosen to calibrate the scoring function parameters as these trips are considered most critical to achieving a high quality validation during peak travel periods.

HERE Maps

To supplement the VISTA data, the HERE Maps API was used to estimate expected travel distance and travel times by mode for each of the VISTA records outlined above. Centroids for SA1 boundaries were adopted as origin and destination locations to enable the VISTA trips to be mapped. Departure time and day was specified to match the time recorded for the corresponding trip in VISTA.

As route choices and hence toll charges could not be determined from this process, routing for trips by car was directed to avoid tolled routes where possible. This was done to ensure that the travel utility was not artificially reduced by omitting road pricing components while including reduced travel time from the faster tolled routes.

4.3 Validation Data Sources

Table 6 presents the data sources that have been used to validate the network assignment components of the MABM. These data sources correspond with and build upon that used by the VITM.

Table 6: Data sources used in validation process

Data source	Description	Limitations
Toll road traffic volumes*	EastLink and CityLink volume data in hourly intervals as provided by VicRoads.	- The available data sets are not comprehensive. The month of June is missing from the EastLink data set, and CityLink data is only available for Q4, 2014 and Q1, 2016. While this data does not align with the MABM modelled year, it is the best available at this time. - Data is not classified into light and heavy vehicles.
Travel speed data (HERE Maps)*	Travel speed information derived from GPS measurements. Data is broken down on a link-by-link basis according to the HERE GIS road network database. Individual link speed information is averaged into 1 hour periods.	- Sample size may be limited on low volume roads. - The sample of vehicles supplying travel speed information to HERE may be biased relative to the overall Melbourne vehicle fleet.
Public transport survey data (PTV)	Data describing activity on the public transport network, including: - Entries/boardings by station/stop across train, tram and bus modes derived from 2015 myki validation data. - Train loading information derived from physical surveys at key stations undertaken in May 2015.	- The accuracy of boarding data will be impacted by fare evasion. This is somewhat mitigated by correction factors applied based on physical surveys. - Correct route allocation of myki validation data on trams and buses requires manual driver input, creating a potential source of error. - Train loading information is derived from a limited number of surveys which do not capture seasonal variation.
Synthetic 2015 traffic volume data (VicRoads) ⁸	Traffic volume data derived from the 2011 VicRoads RSMS programme, scaled to assume estimated 2015 volumes based on observed traffic growth. Data provides hourly traffic volumes at a large number of key locations across the metropolitan road network.	- Applying broad growth factors will not fully capture the impact of localised environment changes, such as nearby road alterations or substantial developments. - Possible longer term temporal trends such as changes in peak starting times may not be reflected in the data.

*Please note this data is subject to confidentiality undertakings, and cannot be reported in detail in this report.

4.4 Limitations

This section outlines the key limitations associated with the data used to develop the Melbourne Activity-Based Model (MABM).

Victorian Integrated Survey of Travel and Activity (VISTA)

VISTA records were utilised in developing activity and travel plans for individuals within MABM. Although approximately 23,000 records were used in this process, these records were then filtered by a 'demographic signature' that included attributes of age, employment status and household location. This process ensured that the activity plans that were adopted aligned with the specific agent's individual attributes. It also reduced the number of VISTA records that could be drawn from in selecting an activity plan for some individuals. The relatively small sample size and unknown non-response bias of VISTA is a notable limitation of the MABM.

To address this limitation, an iterative process of calibration and validation was undertaken during the model development process to ensure that model wide travel metrics closely matched observed travel behaviour.

Victoria in Future Projections

Future year projections are used for modelling of 2015 and 2031. These projections are based on observed data from the 2011 Census. As with any future year projections, there is a degree of uncertainty associated with the VIF household and population projections. This is particularly the case for the 2031 scenario which is the furthest projection year. This uncertainty, and associated modelling error increases the more refined the study area is. Metropolitan wide aggregated projections for instance have a higher likelihood than the projections for individual VITM zones that are used as the control total for population synthesis.

2011 Census Data

The clearest limitation of the Census data that has been used in model development is the time that has passed since the data was recorded. The extent to which the data reflects current demographics across Greater Melbourne is uncertain. As discussed in Section 4.2 the Census data is used as a control total to establish the proportion of population by age, and employment status at a VITM zone level. These proportions are scaled up from 2011 to the modelling reference year by using the Victoria in Future projections.

Using 2011 Census data for the control total has the effect of locking the demographic profile at each area to what it was at the Census. In addition, any error or bias inherent in the Census data would also be inherited by the MABM.

Validation data

The limitations associated with the validation data noted in Table 6 may impact on the way in which "observed" data represents reality and so may contribute to overall model uncertainty.

⁸ Synthetic 2015 dataset derived from 2011 VicRoads RSMS Metropolitan Screenline Project data and VicRoads Homogeneous Traffic Volume Network, available at <https://www.data.vic.gov.au/data/dataset/homogeneous-traffic-volume-network>

5 Validation Performance

This section reports on the validation performance of the MABM 2015 final baseline validation run, Run 162.

For the purpose of reporting various periods of the day have been defined, consistent with periods defined for the VITM model. These are:

- AM peak (AM) – 7:00 – 9:00;
- Interpeak (IP) – 9:00 – 15:00;
- PM peak (PM) 15:00 – 18:00; and
- Off Peak (OP) 18:00 – 7:00.

In some cases the volumes reported represent an average hourly volume for the respective time periods; 24 hour results are also reported where relevant.

5.1 Model Convergence

MABM does not use a fixed criteria to determine when model convergence has been reached and if further iterations should be stopped. Rather, the model is run for a fixed number of iterations. Post run completion, convergence of MABM is evaluated based on two measures:

- Change in average agent activity plan scores; and
- Change in highway link volumes.

Model equilibrium in MATSIM is achieved through the use of a co-evolutionary algorithm, where optimisation is performed in terms of agent plan scoring (Horni, et al., 2016, p. 7).

A standard MABM run is completed over two distinct stages: (1) initial iterations where plan innovation is enabled, allowing agents to generate and follow new activity plans and (2) final iterations where plan innovation is prevented and agents must choose from an existing stored plan.

During iterations where innovation is enabled, at the replanning step, each agent either selects an activity plan from an existing previously executed plan or generates a new plan incorporating alternative route choice, mode choice or activity departure times, based on information from the previous mobility simulation.

When selecting between existing activity plans, choice is performed by a multinomial logit model, under which plans with higher expected scores are more likely to be selected. When a new plan is generated instead of selecting from an existing, if an agents total number of stored plans exceeds the allowable maximum (configured to 5 plans), the lowest scoring plan is discarded.

The approach of preferring selection of higher scoring plans and discarding poor performing plans will push agent behaviour across the simulated day towards user equilibrium. As this equilibrium is reached, agents will be unable to further improve their plans and the average score of all executed plans will stabilise between iterations. As such, the relative change in

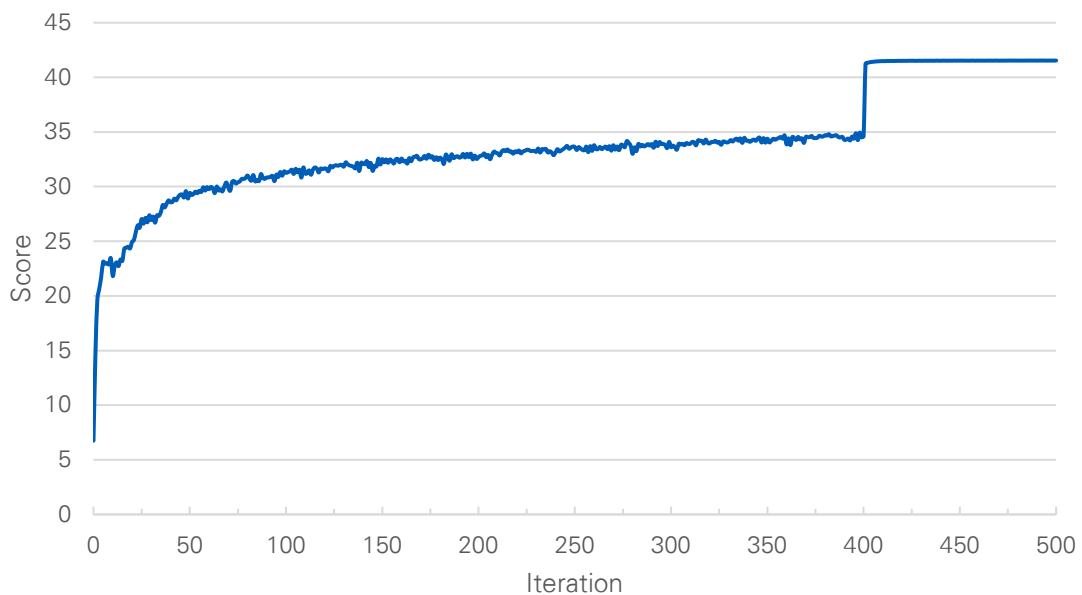
average executed plan score is an effective measure of MABM convergence, considering agent whole of day activities and travel.

Although highway travel forms a component of agent activity plan scoring, highway link flow equilibria is not explicitly considered when measuring convergence by plan scores. Given the intended application of MABM will include evaluation of road based schemes, a check of convergence based on the more traditional approach based on relative change in link flow has been included to provide an additional measure of model convergence.

5.1.1 Convergence results

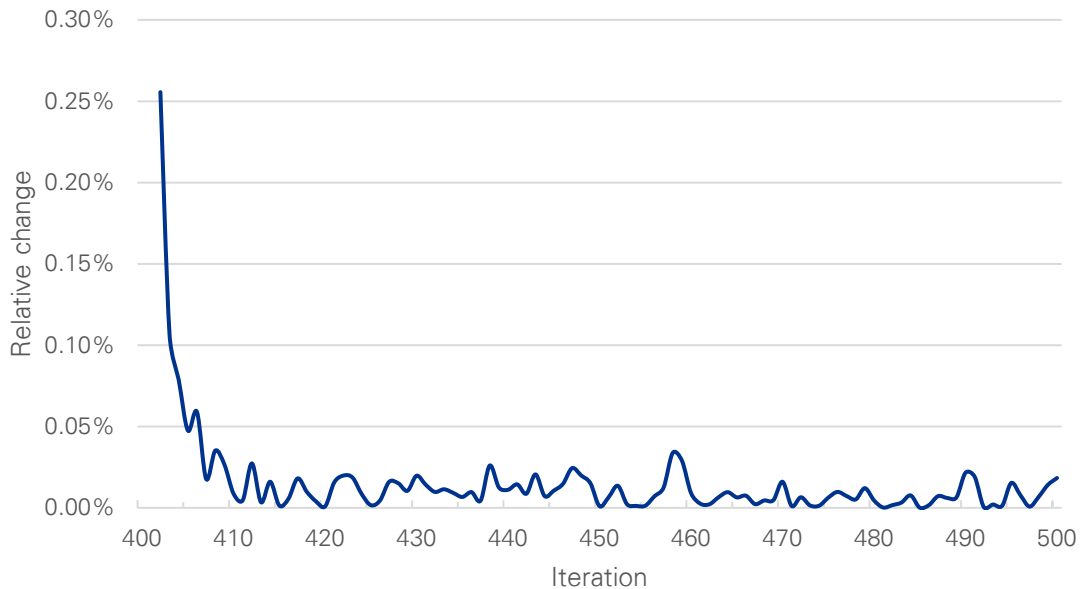
The progression of average agent plan scores across model iterations is shown in Figure 6. The plot shows a scoring progression typical of MATSim models, with the average score quickly increasing in early iterations as the co-evolutionary algorithm allows agents to 'learn' what works best for them. Prior to iteration 400, average executed scores are dampened as agents deliberately choose suboptimal plans in order to test out alternative options. This process is known in MATSim as 'innovation', and allows agents to explore their potential options. At iteration 400, agents are forced to stop iterating (innovation is switched off). At this point the agents are considered to have already found the best performing plans, with no additional learning required. The last 100 iterations then allows the network to reach equilibrium. The step change evident in the plot is a result of this – agents stop generating novel (and often suboptimal) plans and start choosing from among the best possible plans.

Figure 6: Average agent executed plan scores, iteration 0 to 500



The relative change in average plan score over the last 100 model iterations is shown in Figure 7. This shows the model quickly stabilises once plan innovation is disabled, with change in average score effectively tending to zero. Based on this, it is considered that the model has converged to a sufficiently stable result.

Figure 7: Relative change in average agent plan scores, iteration 402 to 500

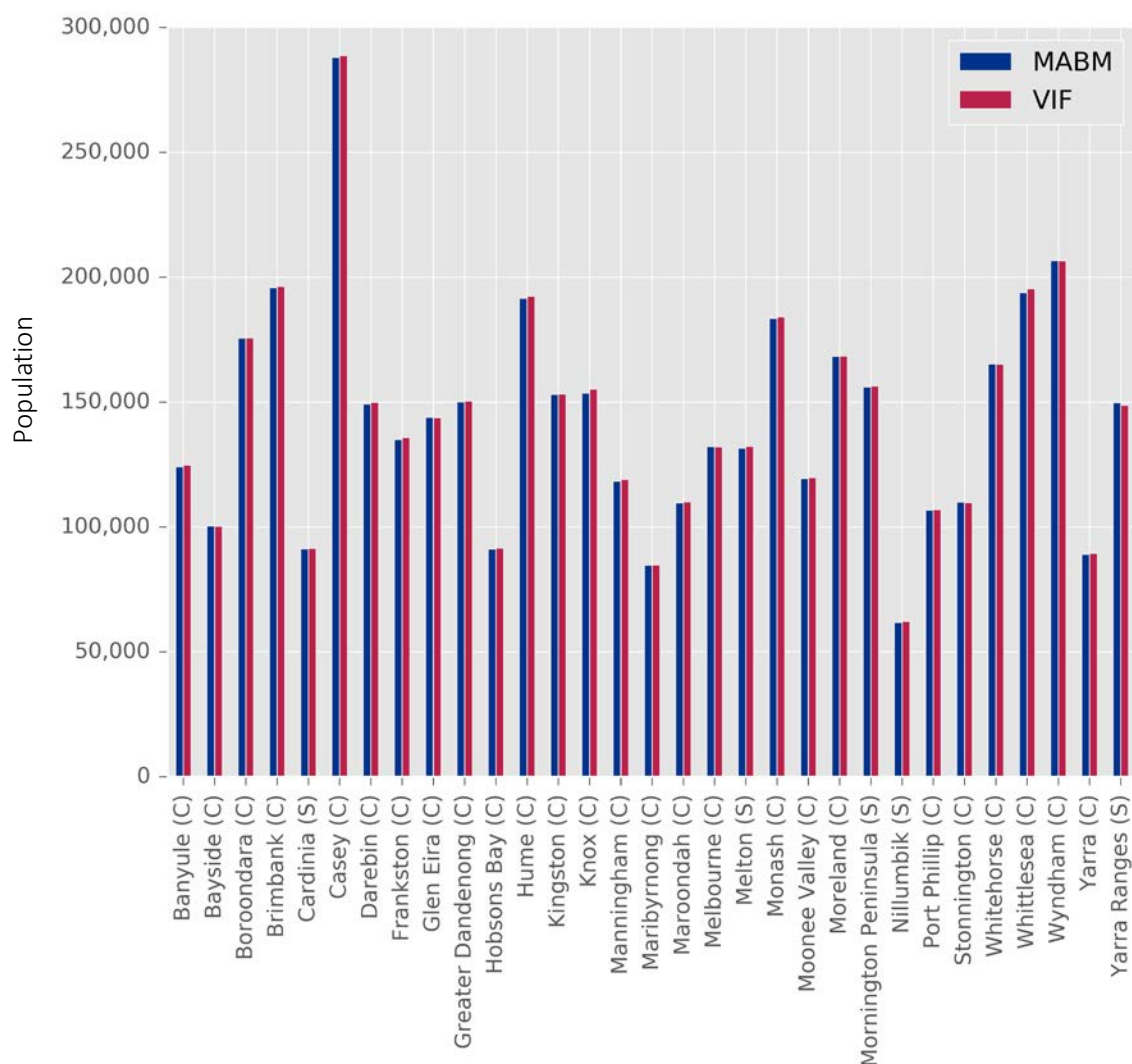


5.2 Activity Generation and Distribution

5.2.1 Modelled persons by Local Government Area

The MABM generates agents and distributes them spatially based on the VIF population figures. The desired criterion is for population to be within $\pm 5\%$ of the VIF values when compared by LGA. Figure 8 shows the synthetic population generated in MABM against the VIF control total for each LGA. The modelled population counts for all LGAs are within 1% of the target population.

Figure 8: Population (2015) by LGA



5.2.2 Total modelled trips

The number of trips generated by the model was compared to VISTA, both by activity type and by region. The desired criterion is for the modelled trips to be within $\pm 20\%$ of the weighted VISTA trips.

As seen in Table 7, for all activity types, the number of trips generated in MABM is within 20% of the VISTA target.

Table 7: Modelled trips by activity type

Activity type	MABM trips	VISTA trips*	% Difference
Home	4,953,992	4,921,396	1%
Work	1,869,032	1,624,487	15%
Business	380,940	387,589	-1%
School	586,680	554,838	6%
University/TAFE	105,672	94,477	11%
School pickup/ drop-off	668,452	587,257	13%
Other	4,001,536	4,377,791	-9%

* Note VISTA trips are weighted to represent the entire population. For more information please refer to the VISTA documentation

For each of the 10 regions, the number of trips generated in MABM is within 20% of the VISTA target, as listed in Table 8.

Table 8: Modelled trips by region (origin)

Region	MABM trips	VISTA trips	% Difference
Outer Eastern	453,432	416,530	9%
Inner Metro	1,535,508	1,827,729	-16%
Inner South East	1,533,240	1,631,200	-6%
Mid Eastern	2,122,652	2,105,856	1%
Mid Northern	1,075,292	1,083,549	-1%
Mid South East	1,340,628	1,215,853	10%
Mid Western	746,488	849,320	-12%
Outer Northern	1,160,284	979,022	19%
Southern	1,362,276	1,342,275	1%
Outer Western	1,205,956	1,093,819	10%

5.2.3 Activity start times

Activity timings in MABM are generated based on daily activity plans from VISTA. The distribution of activity timing in MABM is compared against VISTA for key activities in Figure 9 to Figure 12. MABM emulates the distribution of activity start times in VISTA well for most activity types. The most notable difference between MABM and observed is the discrepancy between observed and actual work starting times in Figure 9. This should have the effect of bringing the morning peak earlier than observed data. This is discussed further in Section 7.1.

Figure 9: Activity start time – Work

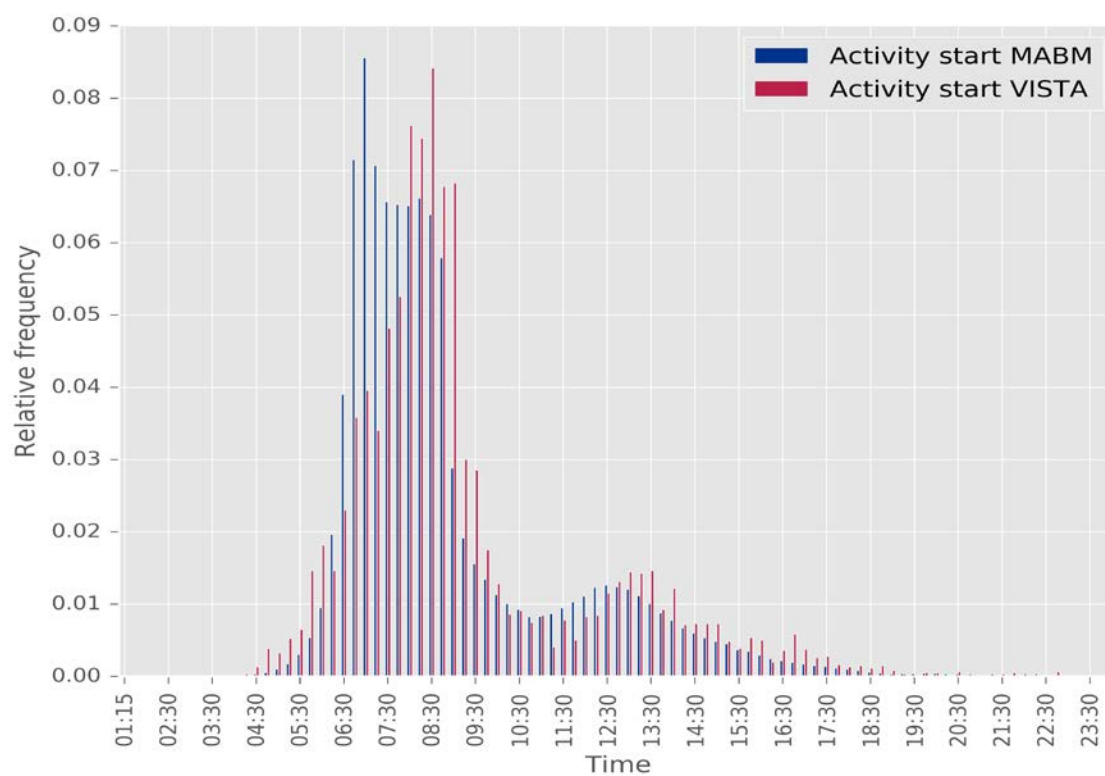


Figure 10: Activity start time – School

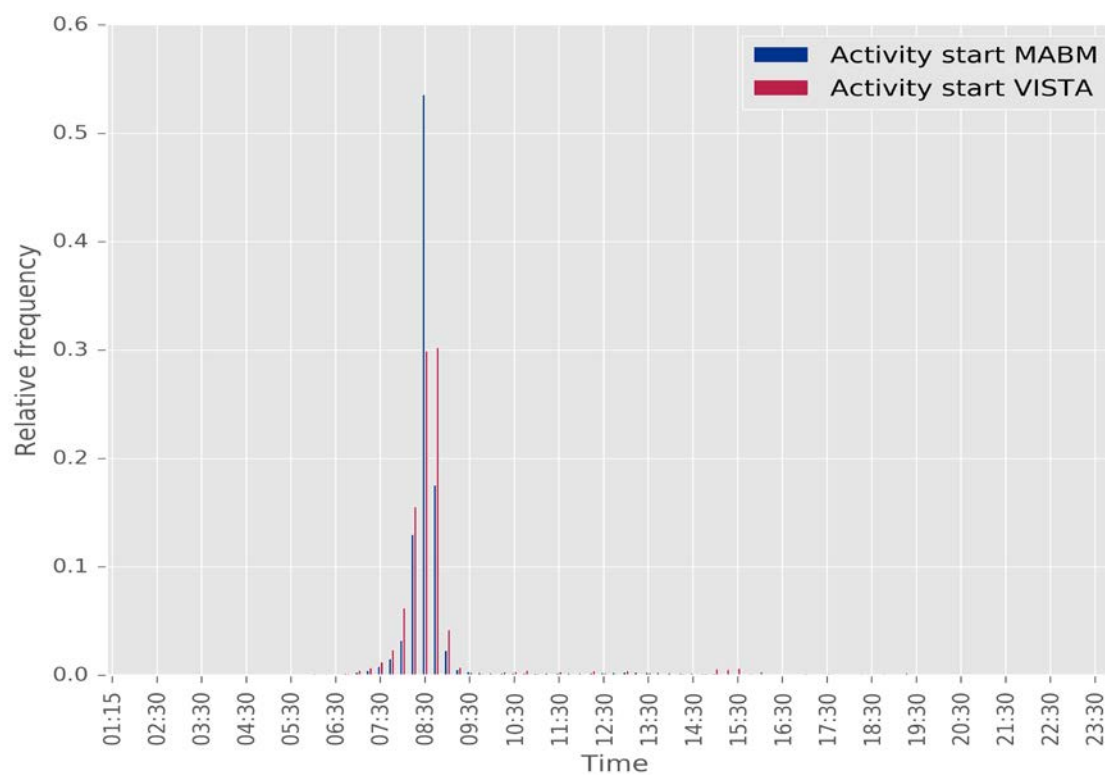


Figure 11: Activity start time – Business

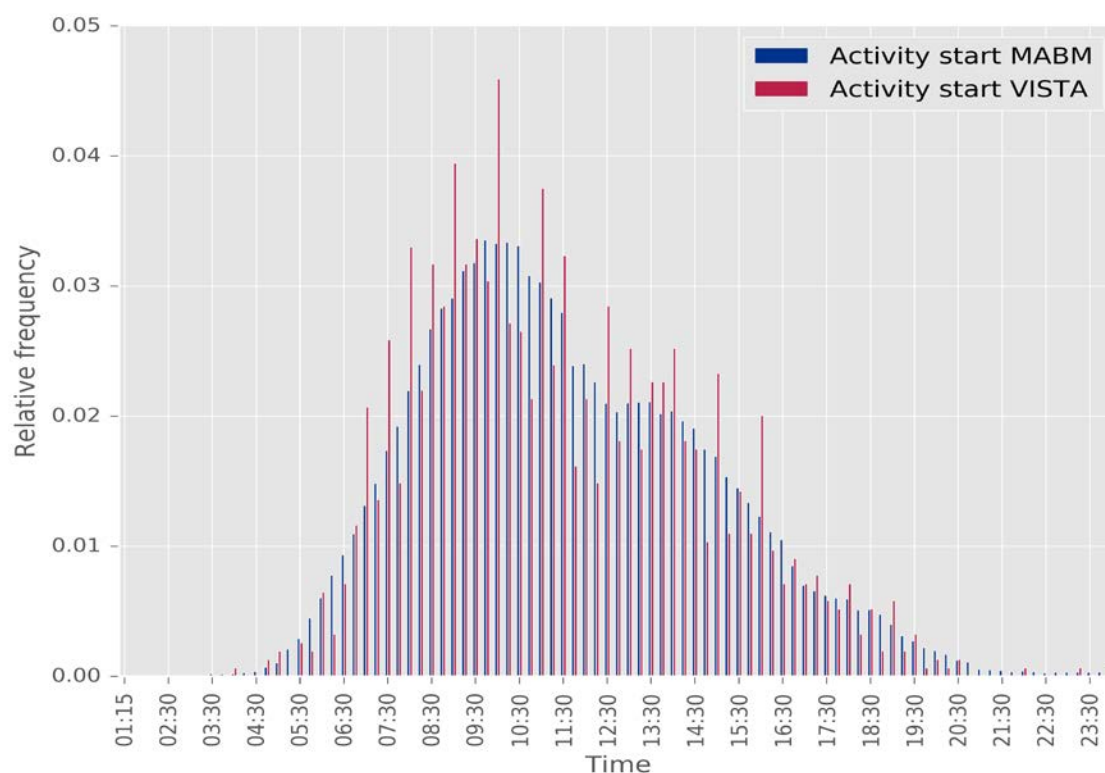
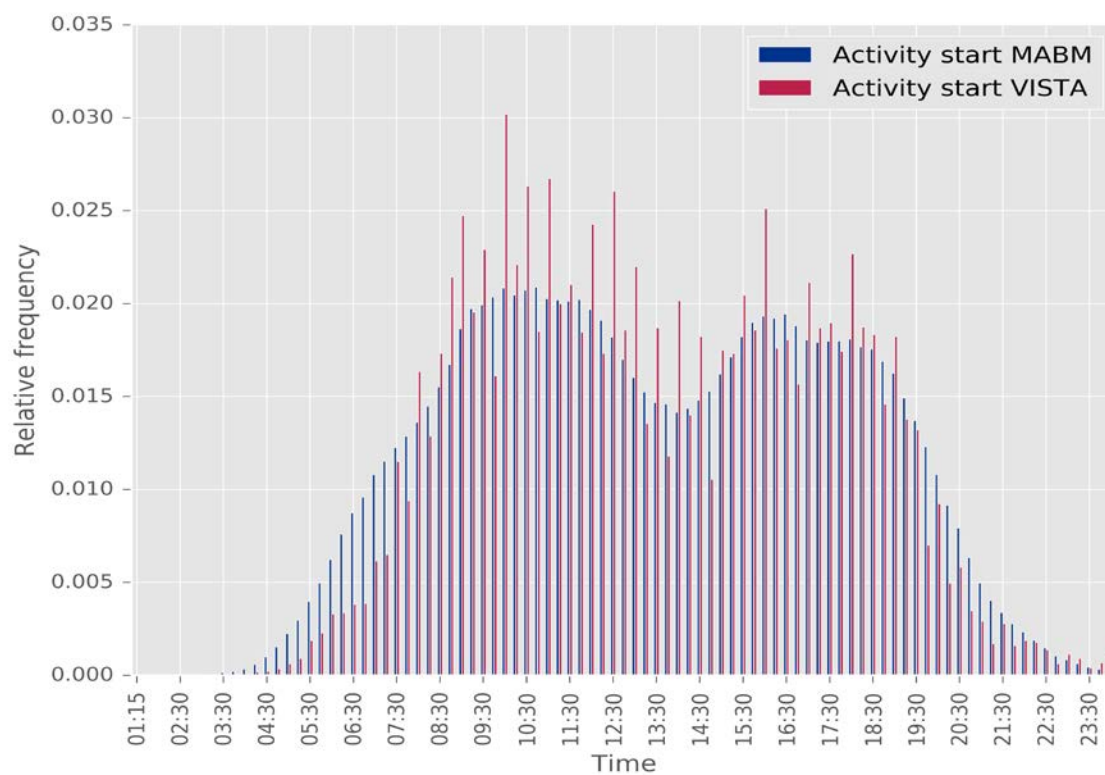


Figure 12: Activity start time – Other activities (shopping, leisure, social)



5.2.4 Activity durations

Activity durations in MABM are generated based on daily activity plans from VISTA. The distribution of activity durations in MABM is compared against VISTA for key activities in Figure 13 to Figure 16. The MABM closely approximates the distribution of activity duration for key activity types. The most notable difference between MABM and observed is the discrepancy between observed and actual work durations in Figure 13. This is discussed further in Section 7.1.

Figure 13: Activity duration – Work

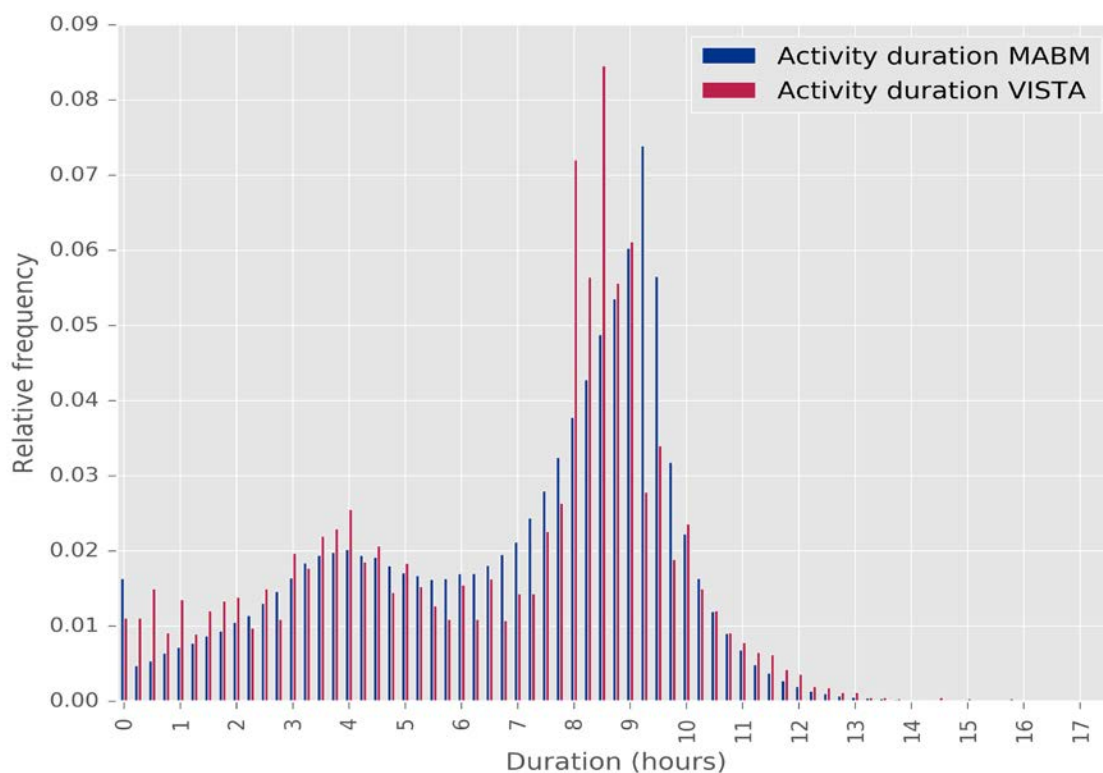


Figure 14: Activity duration – School

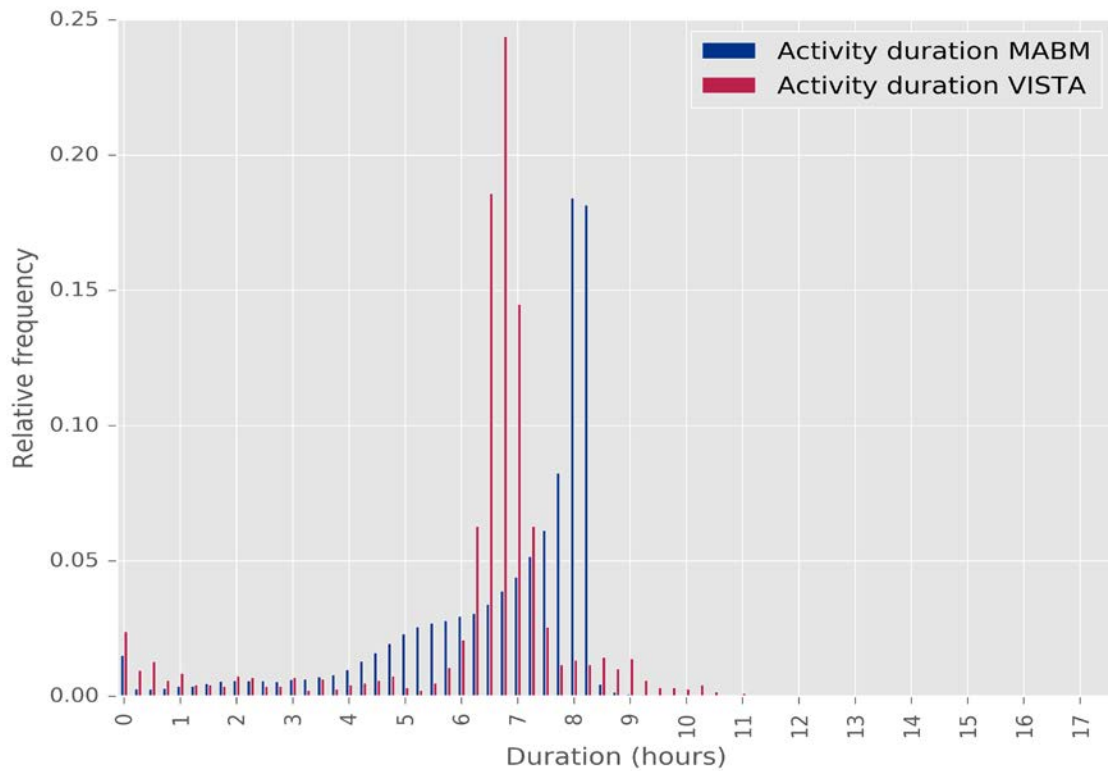


Figure 15: Activity duration – Business

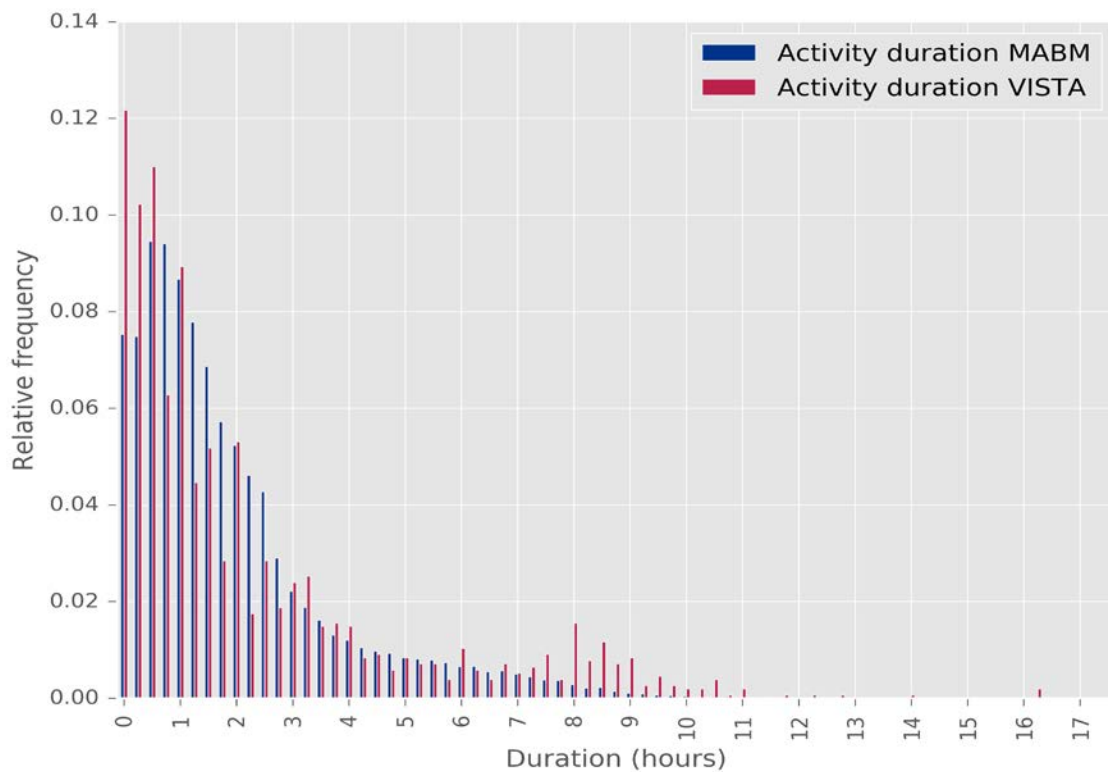
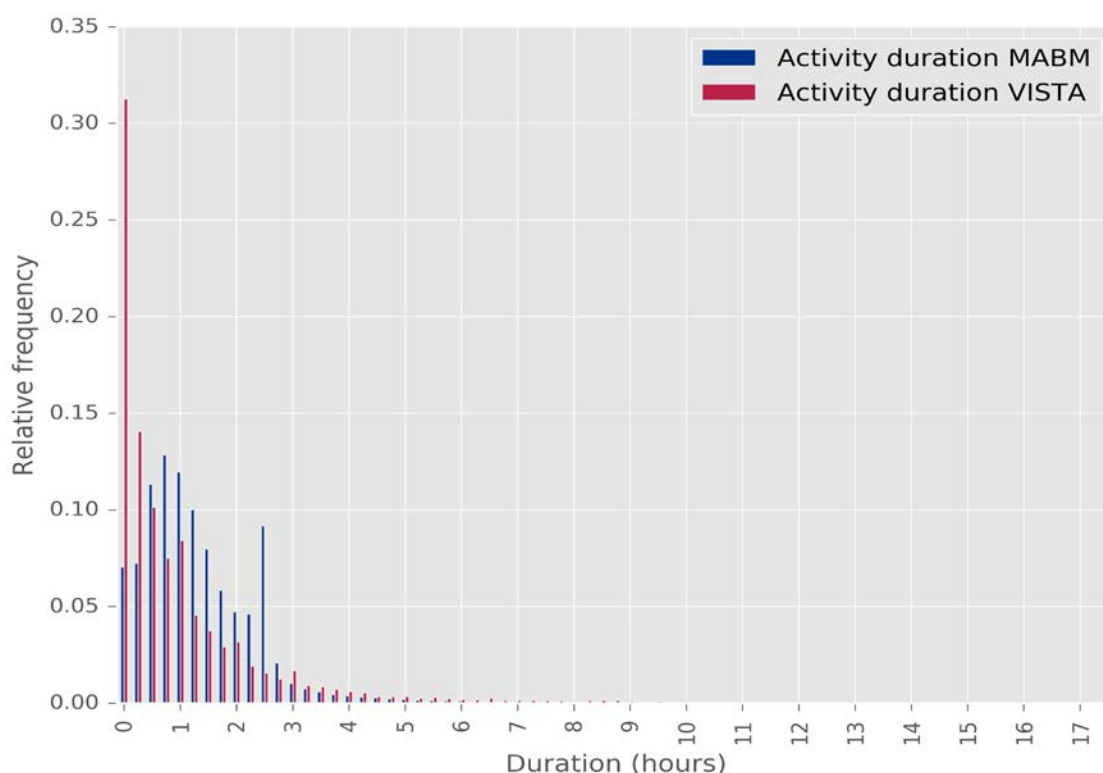


Figure 16: Activity duration – Other activities (shopping, leisure, social)

5.2.5 Activity frequency

Activity frequency is the average number of occurrences of an activity per person for a typical weekday. The frequency of activities in MABM is generated based on daily activity plans from VISTA.

The desired criteria for activity frequency is for the modelled occurrences per person of each activity to be within 20% of the VISTA value. The distribution of activity frequency in MABM is compared against VISTA for key activities in Table 9. The number of occurrences per person is within the target 20% for all activity types.

Table 9: Activity occurrences per person for a typical weekday

Activity type	MABM	VISTA	% Difference
Work	0.39	0.39	2%
Business*	0.08	0.09	-8%
School	0.13	0.16	-19%
University/TAFE	0.02	0.02	-8%
School pickup/ drop-off	0.14	0.16	-11%
Other	0.86	0.97	-11%

* *business activities are any work-related activity that does not occur at a person's own work place.*

5.2.6 Travel distance to activity location

Travel distance between most activities in MABM are assigned to agents based on survey responses from VISTA. Each trip in VISTA has a corresponding travel distance, which is used in MABM to assign locations to all activities with the exception of Home and Work. Trips between home and work are based on Census data, which is a more accurate accounting of commuting patterns between different areas.

The distribution of activity frequency in MABM is compared against VISTA for key activity pairs in Figure 17 to Figure 21. There is no specific numerical target for travel distance; however the plots of the distance distributions demonstrate that MABM closely emulates the VISTA and Census survey data.

Figure 17: Distance distribution – All activity types

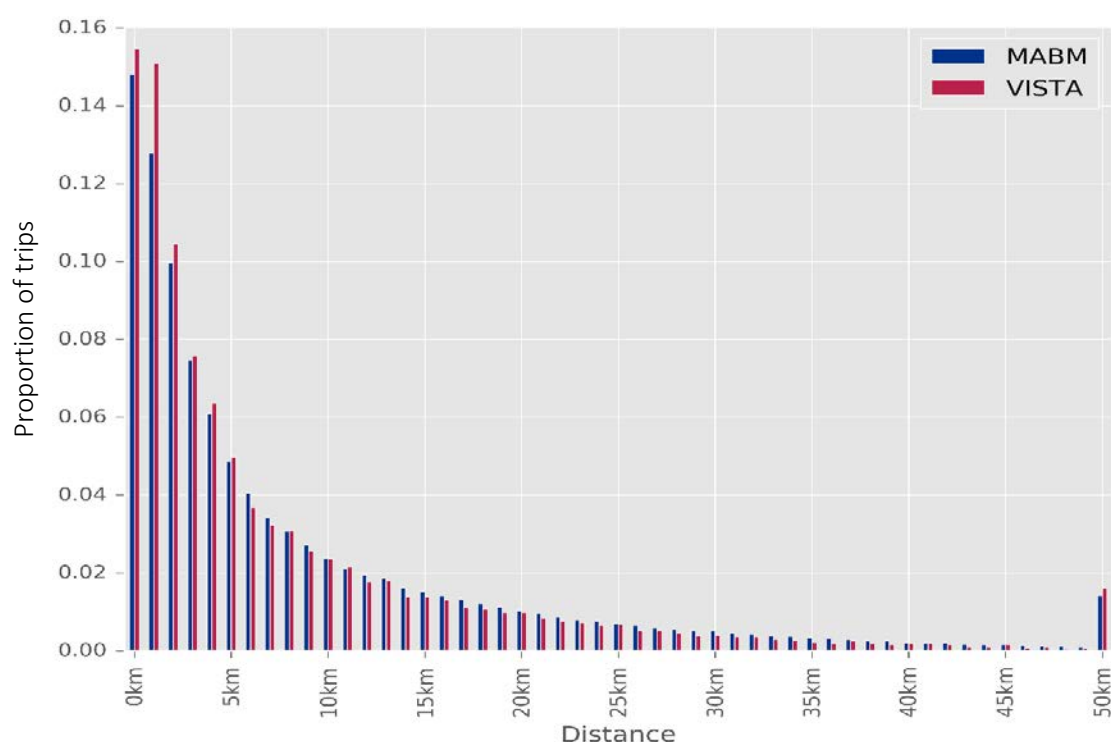


Figure 18: Distance distribution – Home to Work

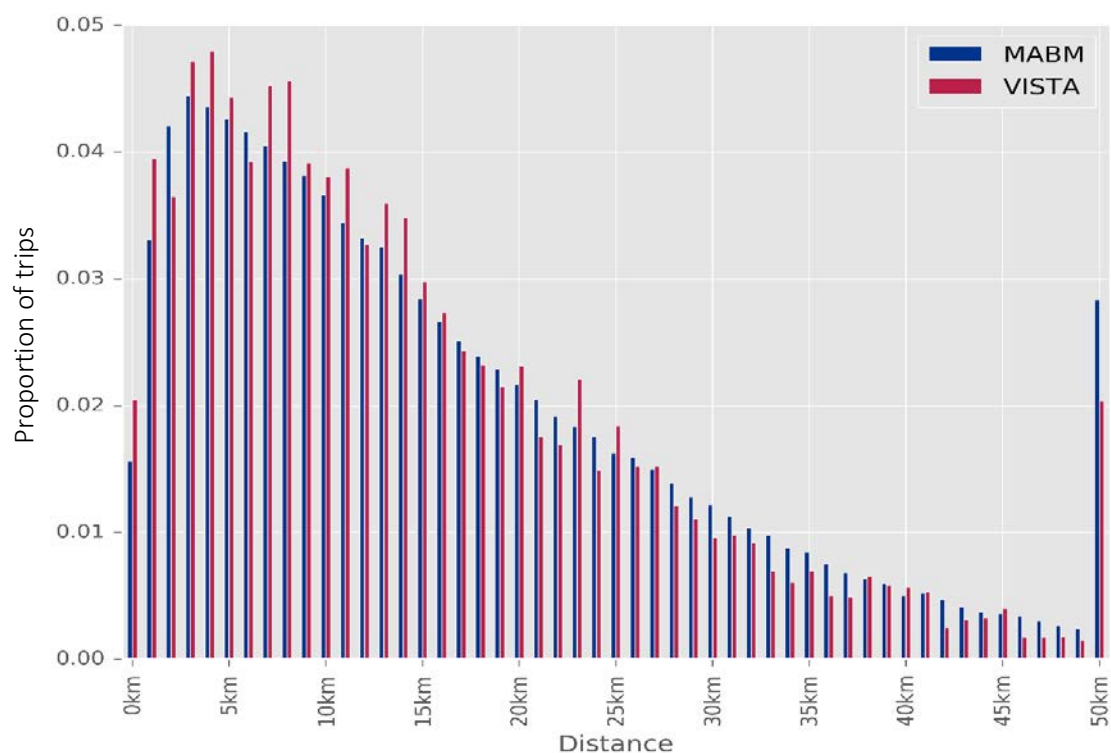


Figure 19: Distance distribution – Home to Other (shopping, leisure, social)

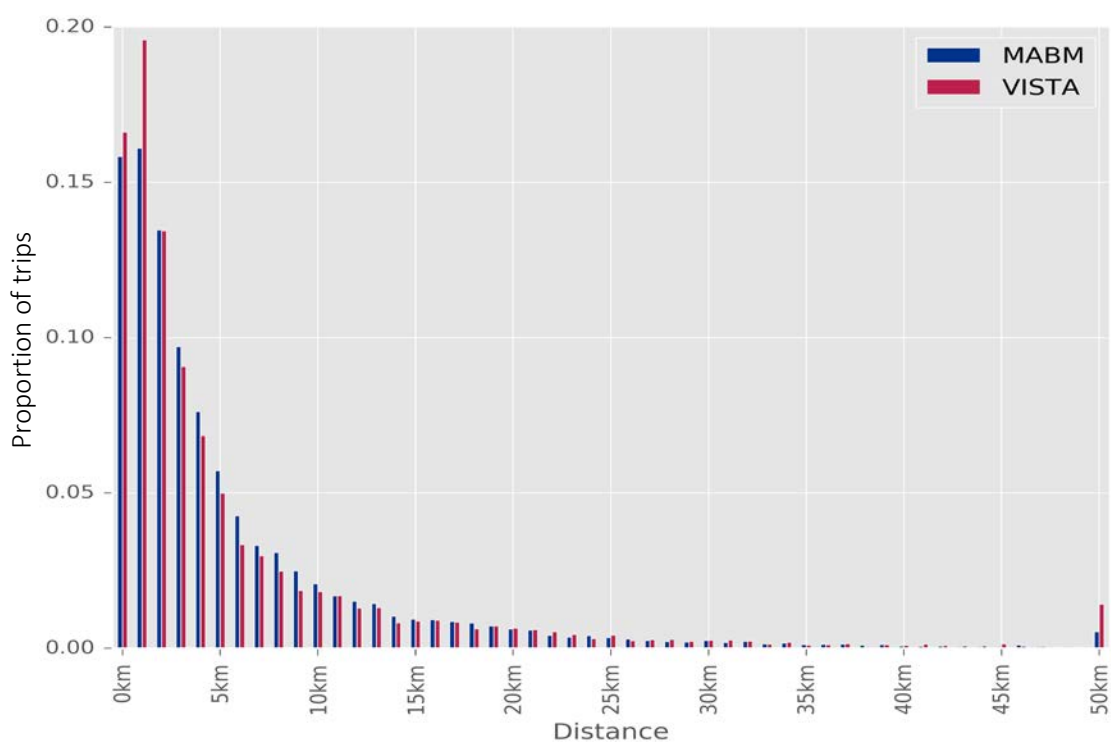


Figure 20: Distance distribution – Home to School

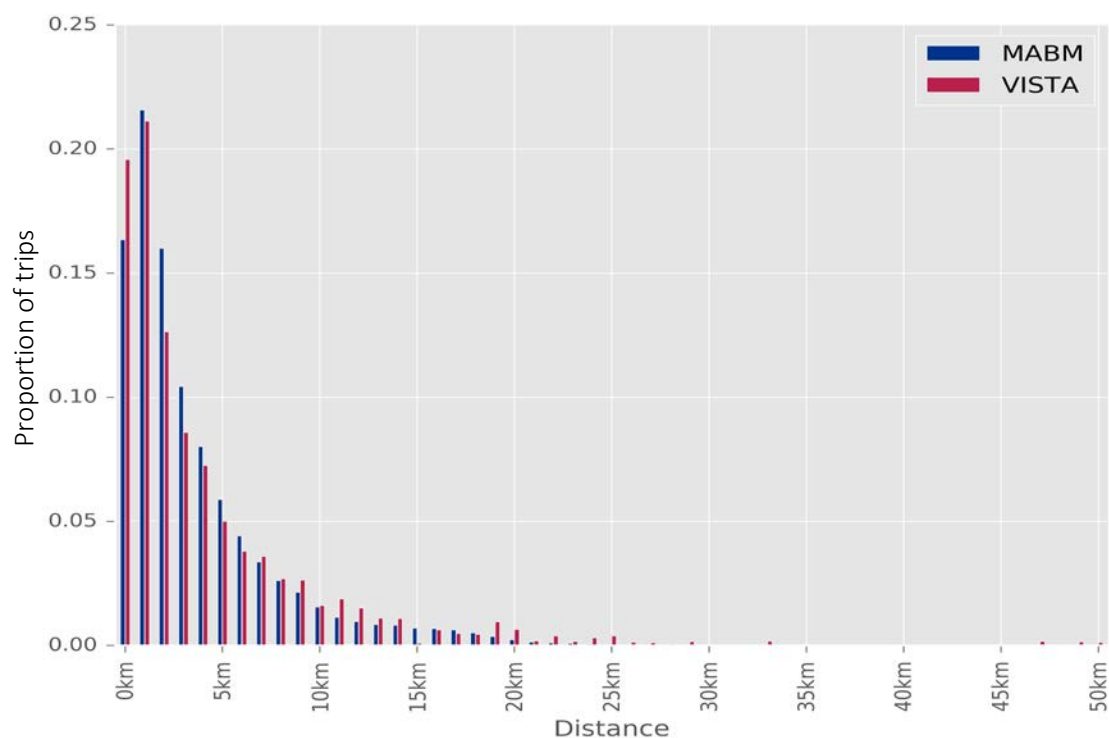
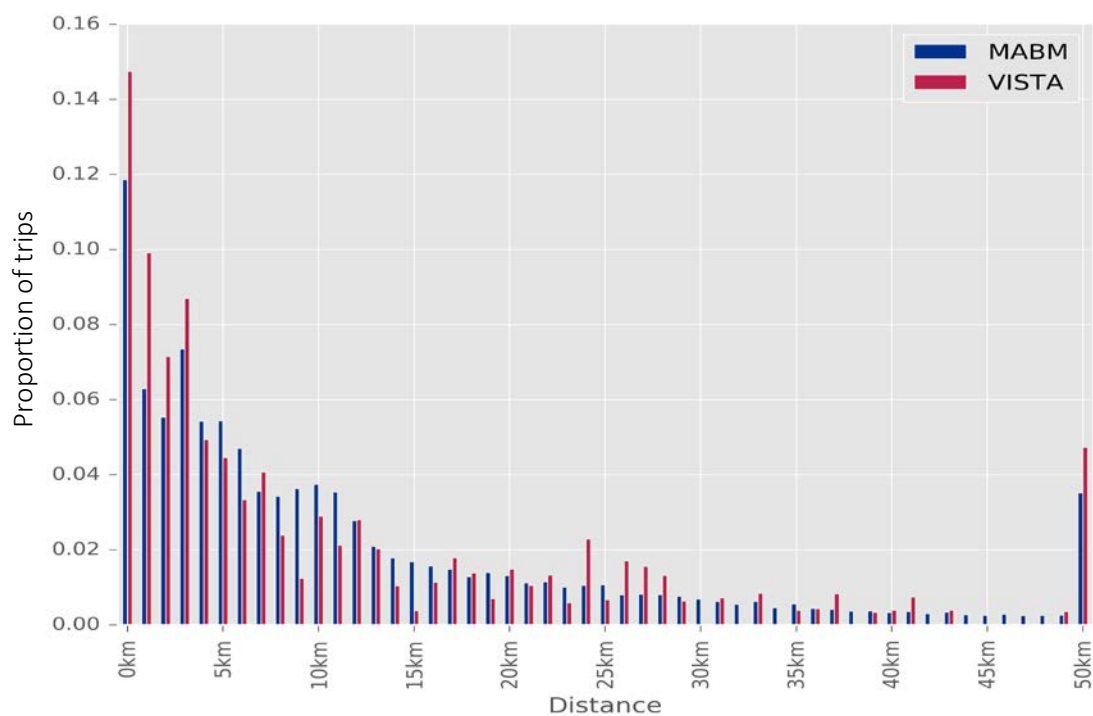


Figure 21: Distance distribution – Work to Business



5.2.7 Overall travel demand patterns

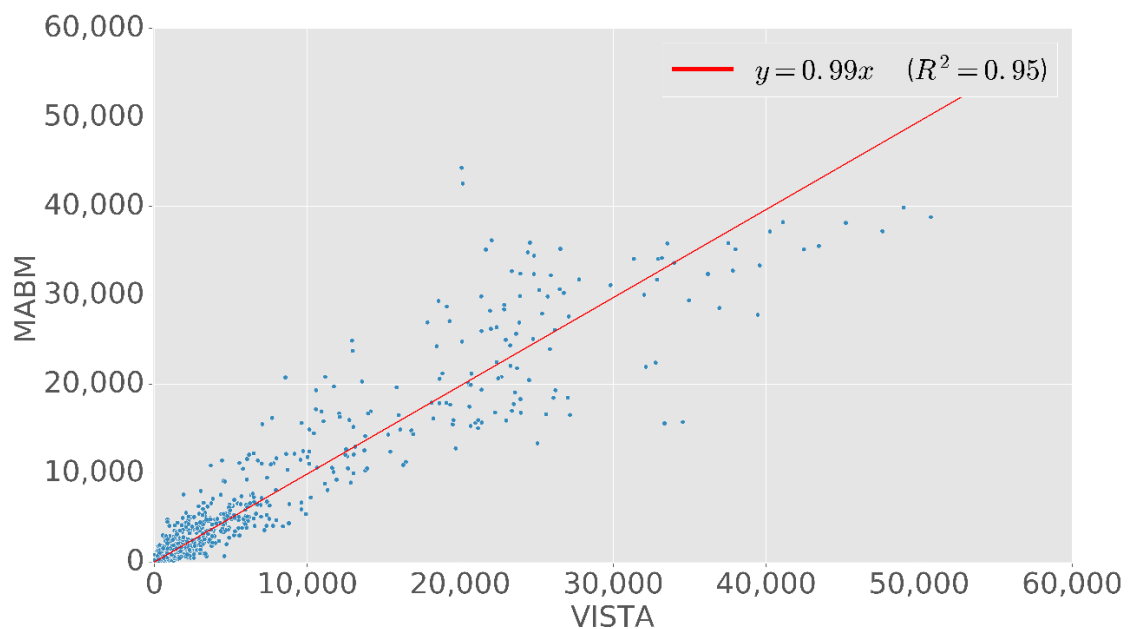
Travel demand is assessed by comparing the travel demand for LGA origin-destination (OD) pairs against the weighted VISTA survey. The target is for 60% of OD pairs to be within 20% of

the VISTA values. The margin of error for individual origin-destination pairs in VISTA is high due to its small sample size. For this reason, LGA pairs with fewer than 1,000 trips in VISTA were excluded from the comparison.

For OD pairs with greater than 1,000 weighted trips in VISTA, 32% were modelled within the target range of 20% in MABM. The MABM modelled values are plotted against the weighted VISTA values in Figure 22. Although MABM does not achieve the desired criteria of 60% of OD pairs, the scatter plot demonstrates close linear correlation between MABM and VISTA (R^2 of 0.95). The linear regression coefficient of 0.99 suggests that there is no systematic bias in travel demand patterns by OD pair.

It should be noted that the sample size of VISTA for trips at an origin-destination pair level by LGA are often very small. This means the level of uncertainty for each pair is high. This is considered the principle cause of the MABM not achieving the desired criteria. Nonetheless, given the high correlation coefficient and regression coefficient close to 1.0, the MABM is considered to produce a good representation of observed data.

Figure 22: Travel demand for LGA origin-destination pairs



Travel demand patterns for LGAs that contain National Employment and Innovation Clusters (NEIC) are presented in Figure 23-Figure 29 below. For each selected LGA, the travel demand from each origin LGA is compared to the weighted VISTA sample.

Figure 23: Travel demand to Melbourne (C) by LGA

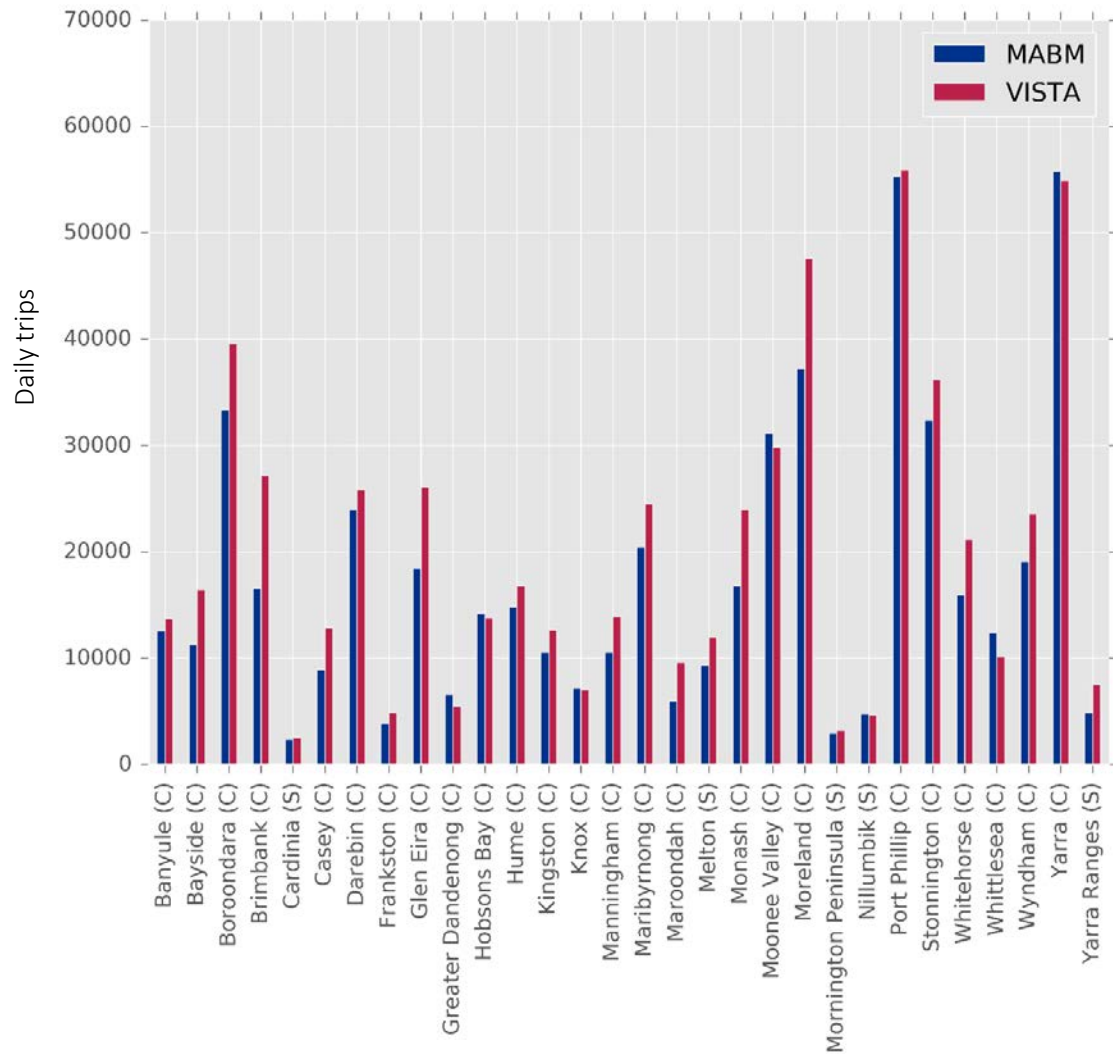


Figure 24: Travel demand to Monash (C) by LGA

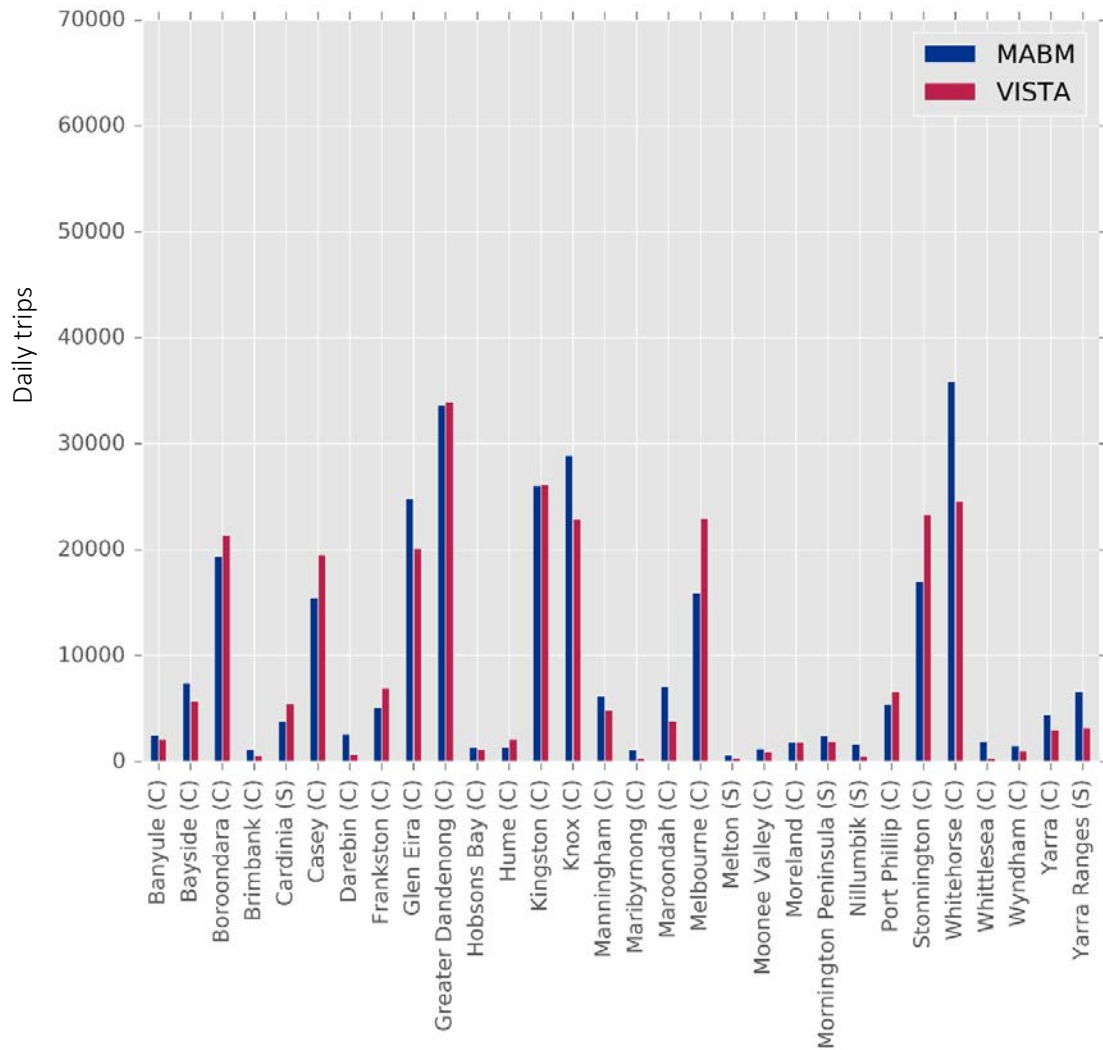


Figure 25: Travel demand to Port Phillip (C) by LGA

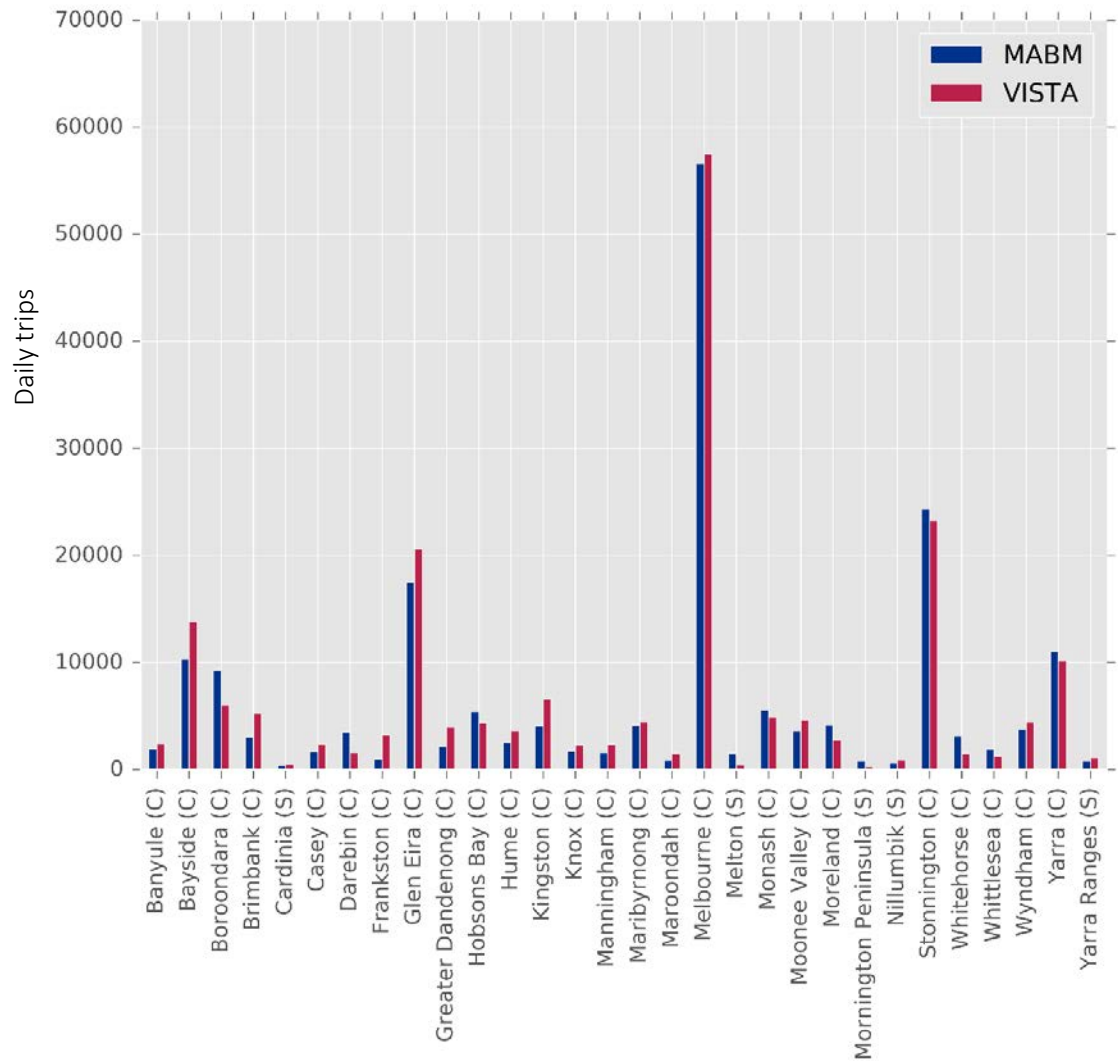


Figure 26: Travel demand to Greater Dandenong (C) by LGA

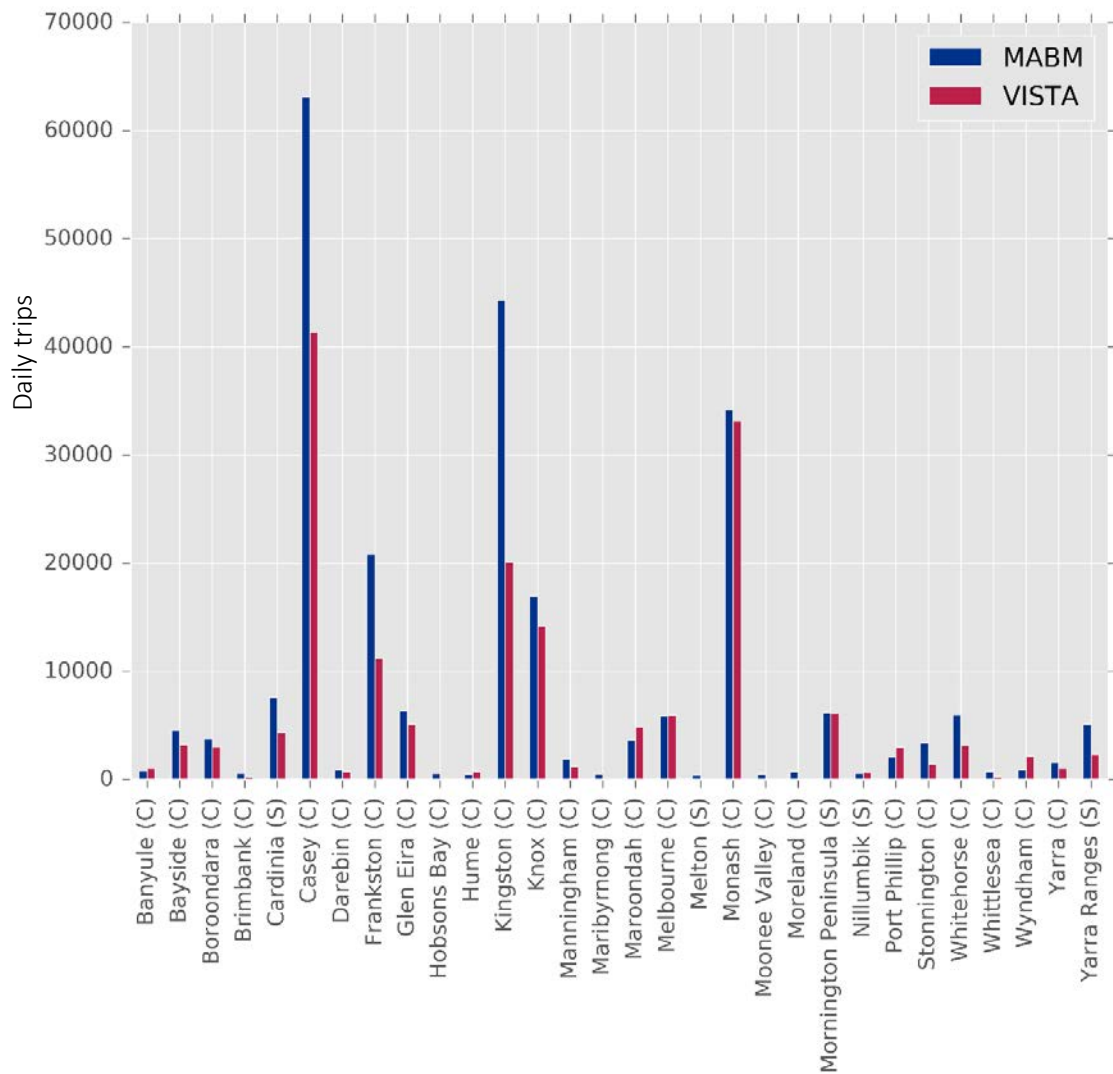


Figure 27: Travel demand to Darebin (C) by LGA

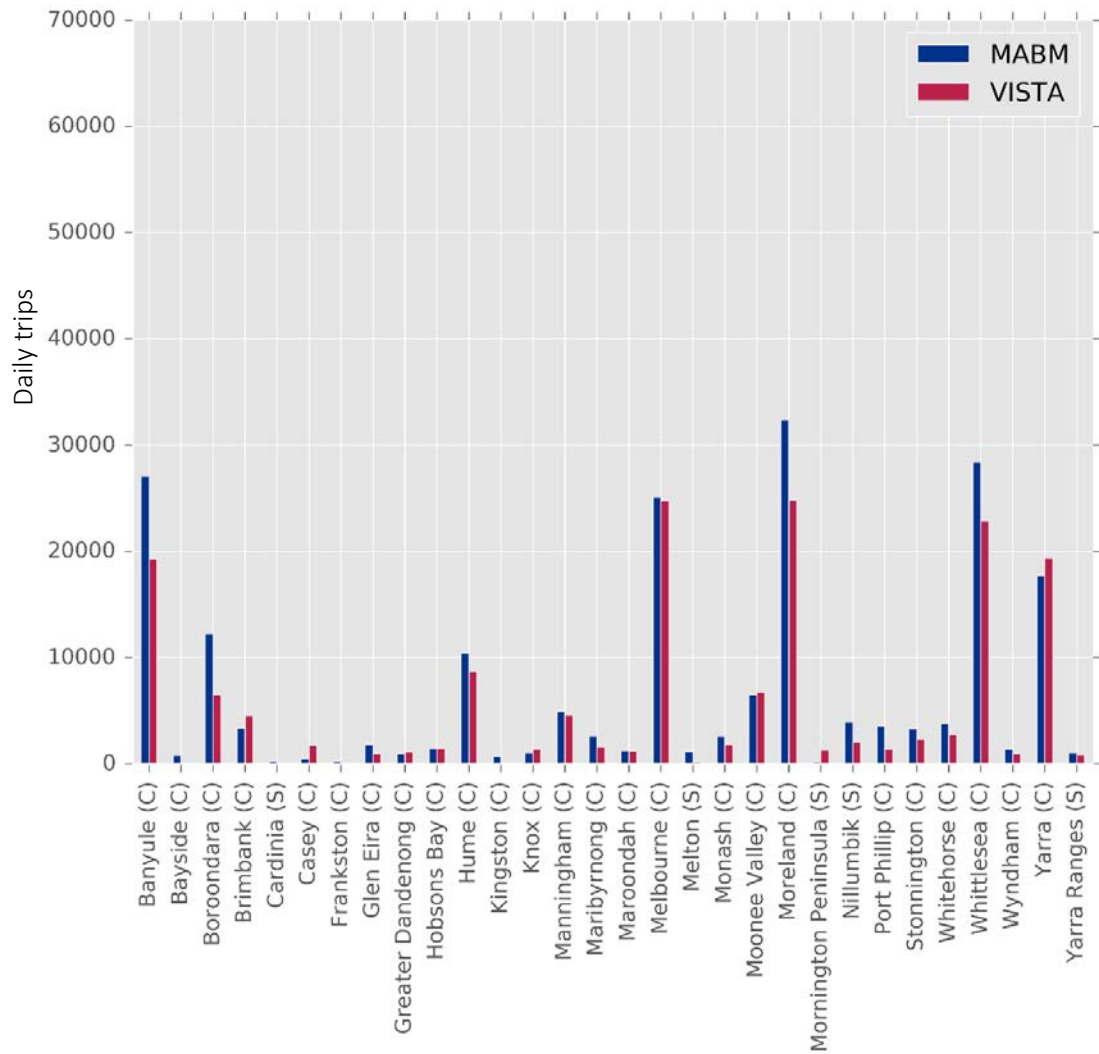


Figure 28: Travel demand to Brimbank (C) by LGA

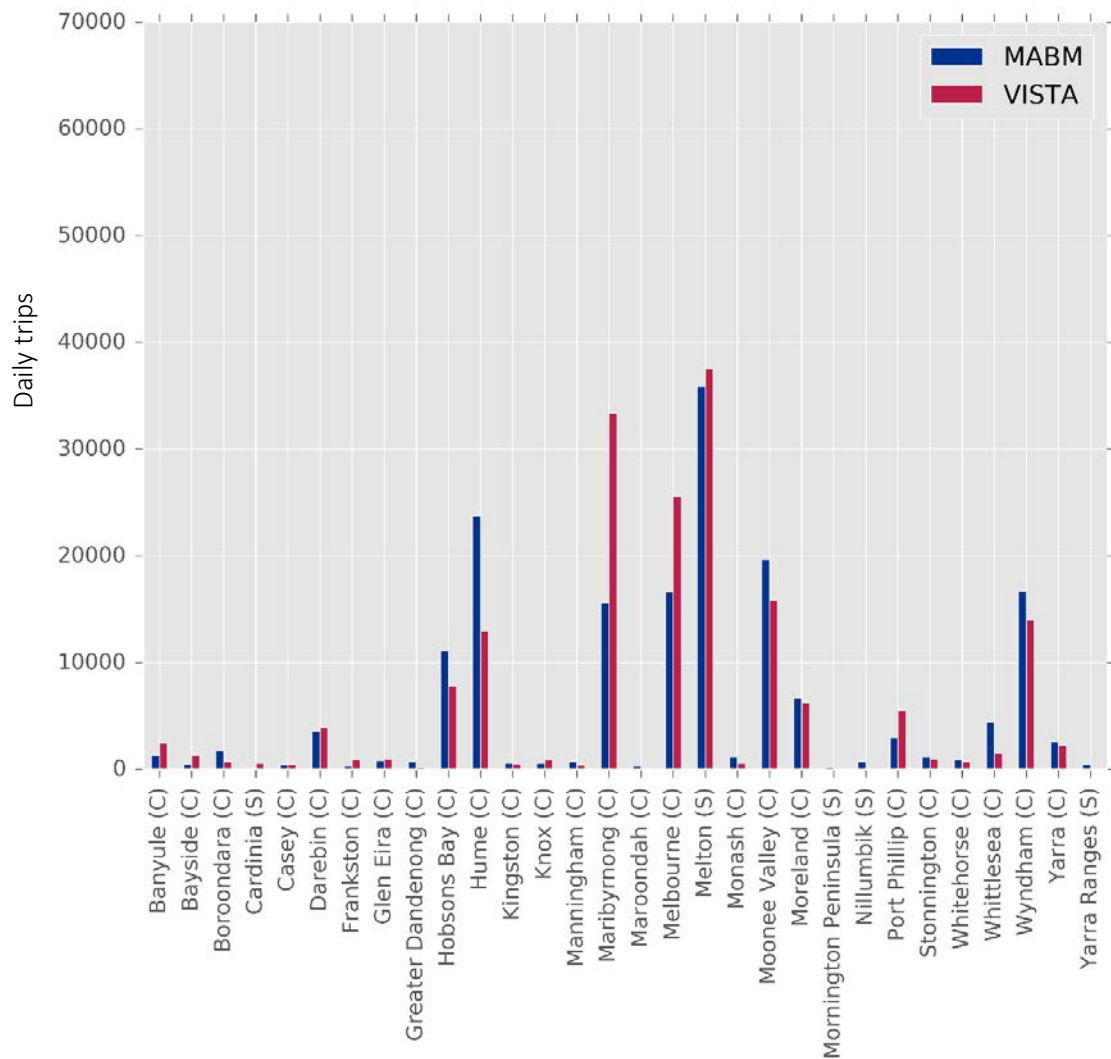
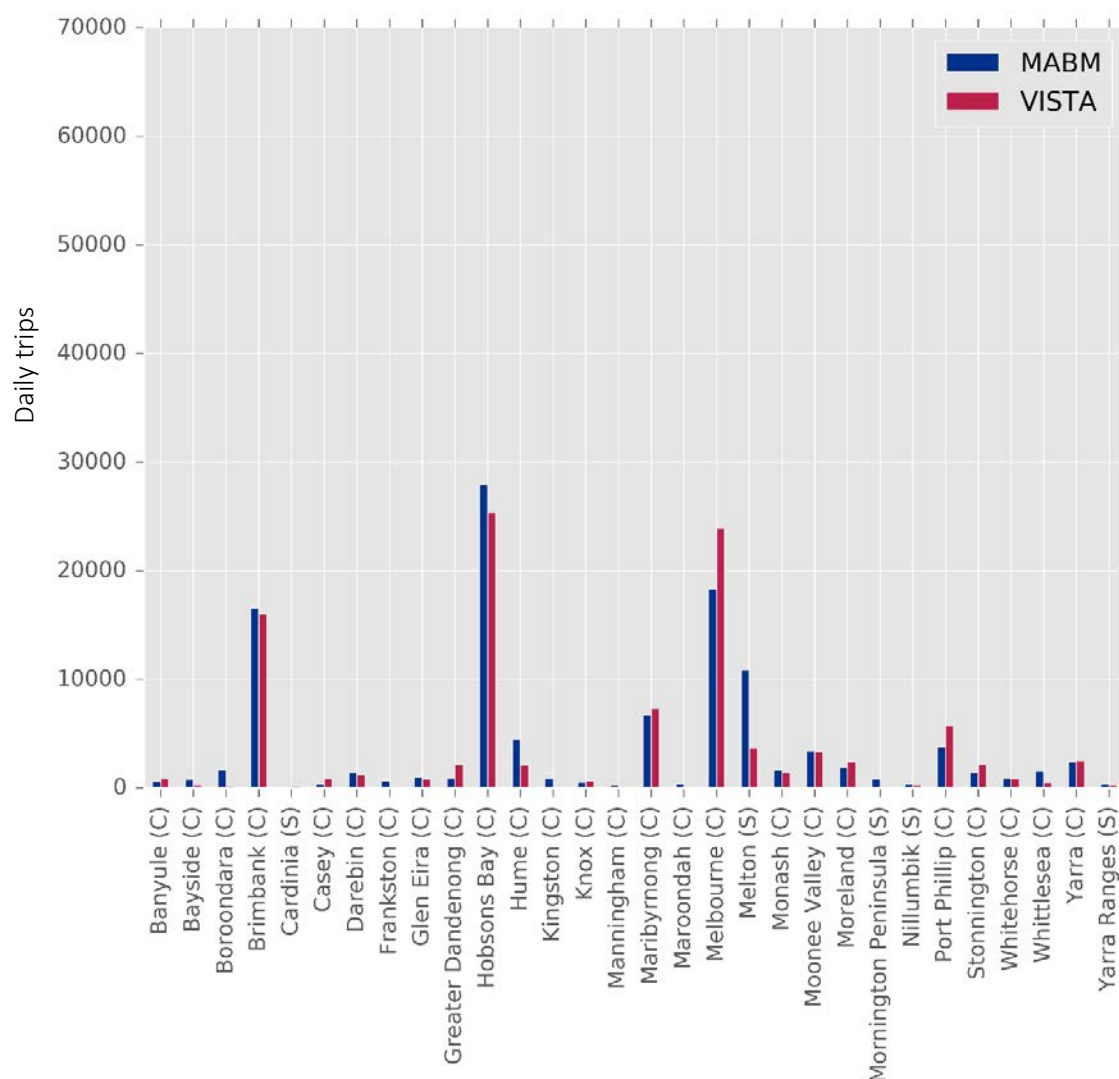


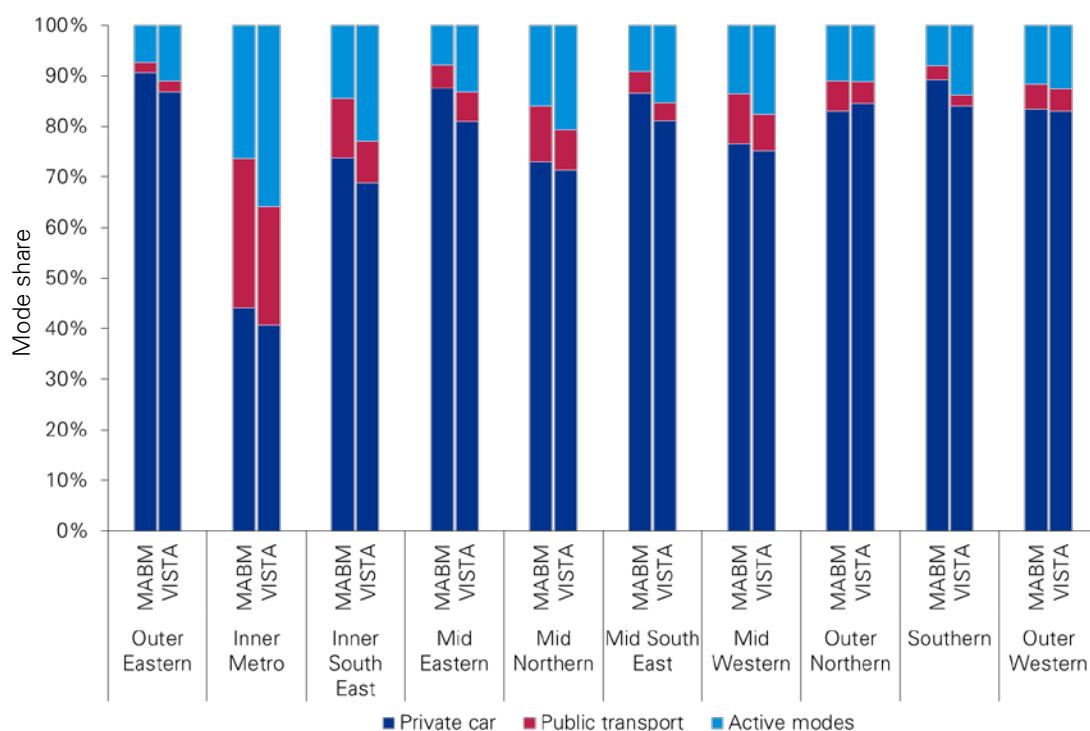
Figure 29: Travel demand to Wyndham (C) by LGA



5.3 Mode share

In the MABM, individuals are able to choose from multiple modes for each leg of their journey and are able to switch mode to maximise their utility. The final mode share is a result of individuals interacting with the network over many iterations of the model, eventually reaching an equilibrium. The model was calibrated based on mode share data from VISTA and the Census.

For the purpose of validation, mode share is compared by region against the VISTA survey data. Figure 30 shows a comparison of final network mode share for each region against VISTA. In most cases, MABM closely approximates the VISTA mode share but tends to underestimate active modes.

Figure 30: Mode share – all trip purposes by origin

The desired criterion is for the modelled mode share to be within 10% of the VISTA value.

Table 10 shows that the percentage difference between MABM and VISTA is within the target criteria for all regions.

Table 10: Car mode share (driver and passenger) in MABM and VISTA

Region	MABM trips	VISTA trips	% Difference
Outer Eastern	90%	85%	5%
Inner Metro	44%	40%	9%
Inner South East	73%	68%	7%
Mid Eastern	87%	80%	8%
Mid Northern	72%	71%	2%
Mid South East	86%	80%	7%
Mid Western	76%	74%	2%
Outer Northern	82%	83%	-1%
Southern	88%	83%	6%
Outer Western	83%	82%	1%

Figure 31 shows the mode share by destination for work trips. The MABM slightly overestimates mode shares for work trips on public transport relative to Census data. This limitation is discussed further in Section 7.1.

Figure 31: Work mode share by destination, MABM vs Census

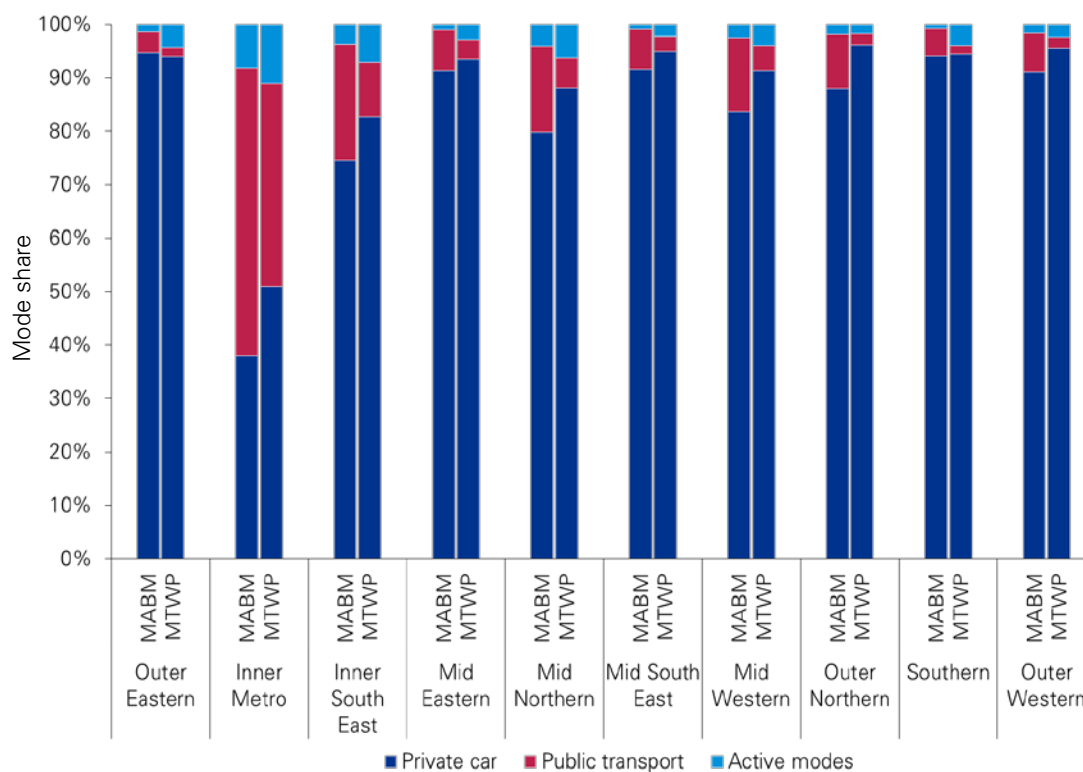


Table 11 shows car mode share for work trips by destination. As demonstrated in Figure 31 above, MABM underestimates car mode share for these trips. However, all regions are within the validation criteria of plus or minus 10 percent except for the Inner Metro region.

For the Inner Metro region, car mode share for all trips by destination is 44% in the MABM compared to 40% in VISTA, a result that does meet the 10% criteria. This suggests that the underestimation of car mode share by car trips is compensated for by an overestimation of car trips to Inner Melbourne for other (non-work) purposes. For this reason, it is not considered that the MABM underestimates inner city congestion in an overall sense. However this limitation should be considered for interpreting the split between workers and non-workers accessing the inner city by car.

Table 11: Car mode share for work trips by destination, MABM vs VISTA

Region	MABM trips	VISTA trips	% Difference
Outer Eastern	95%	94%	1%
Inner Metro	38%	51%	-26%
Inner South East	74%	82%	-10%
Mid Eastern	91%	93%	-2%
Mid Northern	80%	88%	-9%
Mid South East	91%	95%	-3%
Mid Western	84%	91%	-8%
Outer Northern	88%	96%	-8%
Southern	94%	94%	0%
Outer Western	91%	95%	-4%

5.4 Highway

5.4.1 Screenline volumes

Highway volume validation has been primarily carried out against 2015 synthetic traffic volume data sourced from VicRoads⁹. Figure 32 illustrates the location and extent of all validation

⁹ Derived from 2011 VicRoads RSMS Metropolitan Screenline Project data and VicRoads Homogenous Traffic Volume Network available at <https://www.data.vic.gov.au/data/dataset/homogeneous-traffic-volume-network>

screenlines. These screenlines are the standard set of screenlines used for reporting VITM performance.

The desired criterion is defined as the per cent difference between modelled and observed screenline volume within the bounds of a target curve specified by VicRoads Strategic Transport Modelling Guidelines (refer to Table 5, pg. 16).

The percentage of screenlines meeting the desired validation criterion across AM, IP, PM and OP periods is detailed in Table 12. Model performance is best during the AM period, with approximately half of modelled screenline volumes meeting the target criteria and declining to 27% by the OP period.

Figure 32: Screenline locations



Table 12: Modelled screenline volumes meeting VicRoads target curve

Period	Direction	% Screenlines meeting criteria
AM	Inbound	41%
	Outbound	55%
IP	Inbound	32%
	Outbound	36%
PM	Inbound	36%
	Outbound	32%
OP	Inbound	27%
	Outbound	27%

Screenline results for the critical travel directions are shown overleaf graphically, along with the percentage difference to observed screenline volumes.

When considering the screenline locations that have not met the validation criteria explicitly, the majority of these locations fall within 10-20% of the observed volumes, as depicted in Figure 33 and Figure 34. This is especially the case in the PM peak, outbound direction, where most screenlines either meet the criteria or have volumes within 10% of observed screenline volumes. This indicates that across the entire metropolitan region, the model is consistently predicting sensible highway volumes.

Figure 33: Screenline validation results for AM peak, inbound

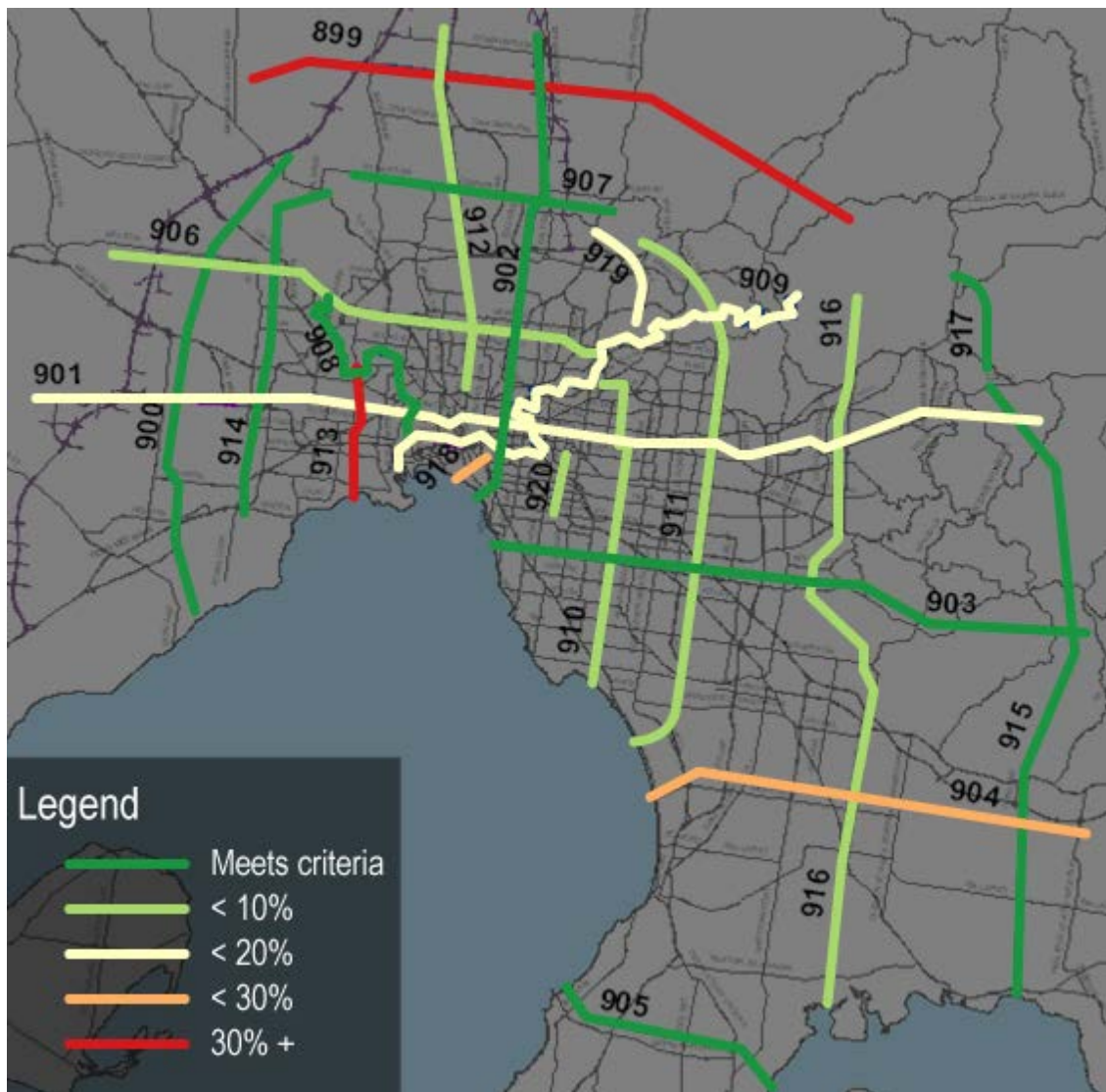
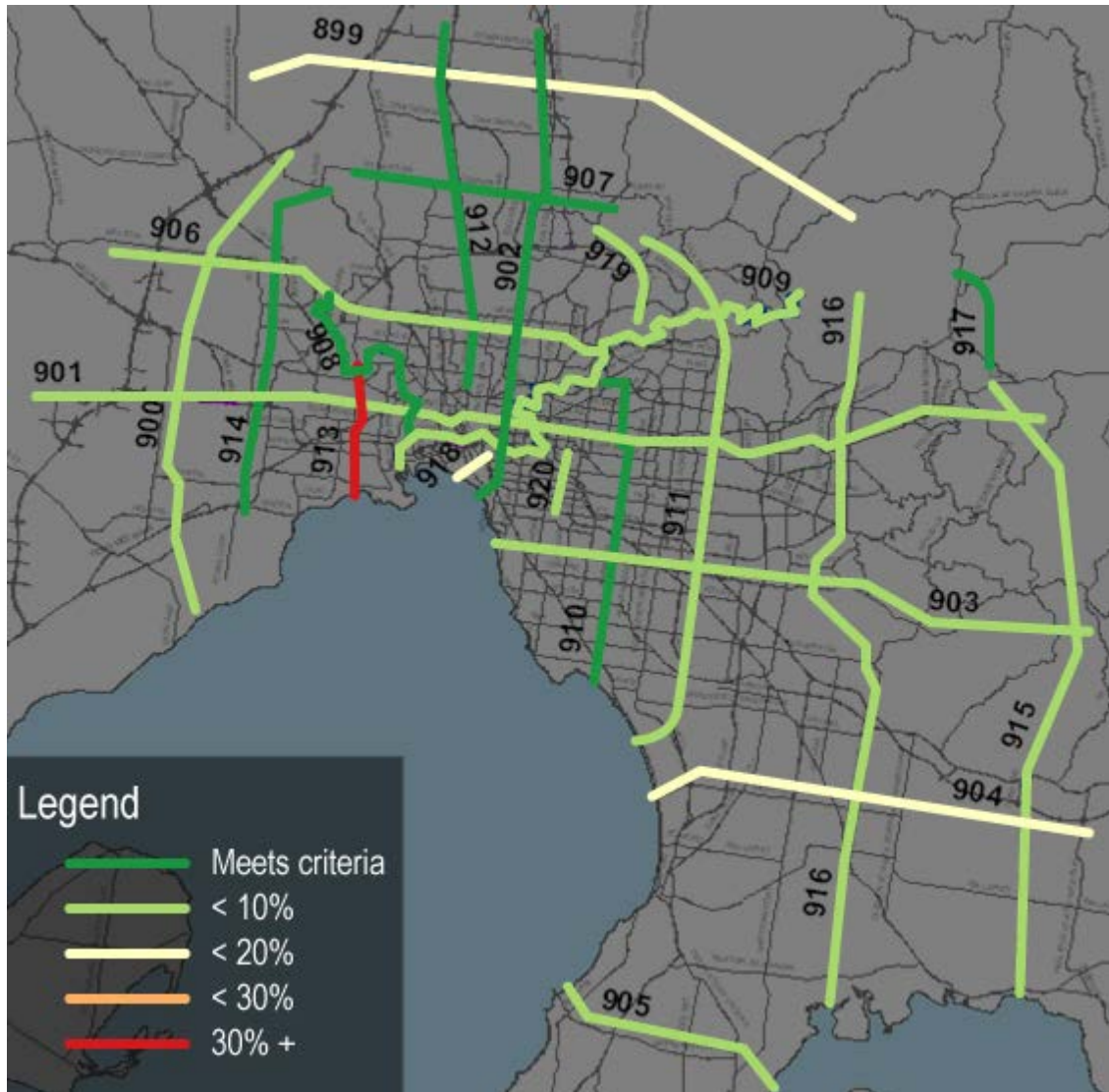


Figure 34: Screenline validation results for PM peak, outbound



A key benefit of the MABM's 24 hour continuous simulation is the ability to replicate the profile of traffic volumes across the whole day. Examples of these traffic profiles by time of day are illustrated in Figure 35 to Figure 40, showing 24 hour modelled and observed screenline volumes crossing the three highest volume screenlines (901, 902 and 908). These figures show good correlation of the observed and modelled volumes, including patterns related to peak build up and decline prior to and after the AM and PM peaks. These observations provide additional support that MABM is providing acceptable performance against screenline volumes.

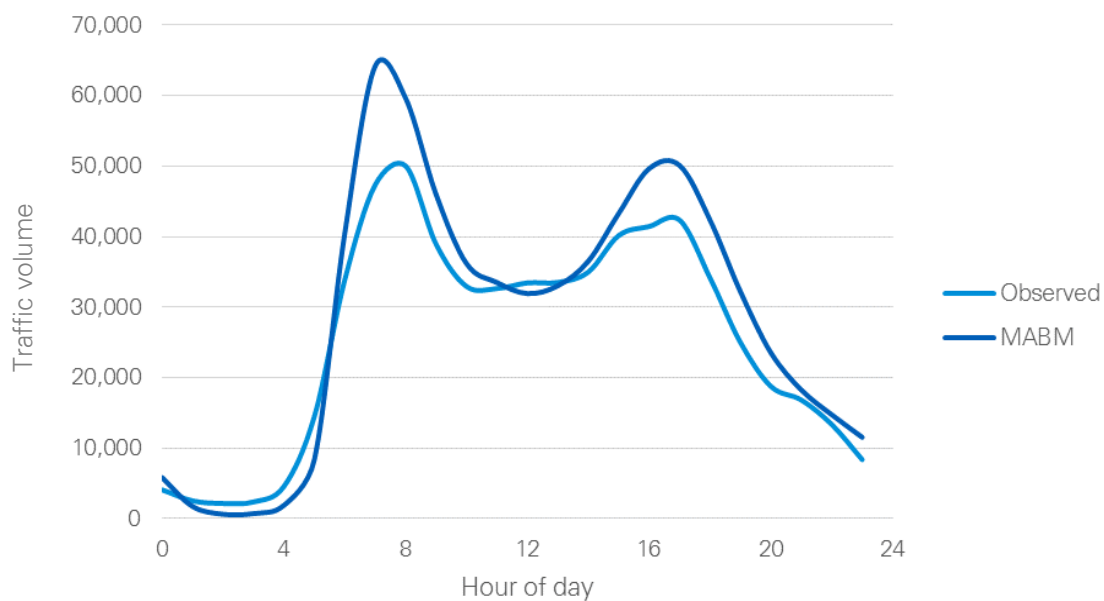
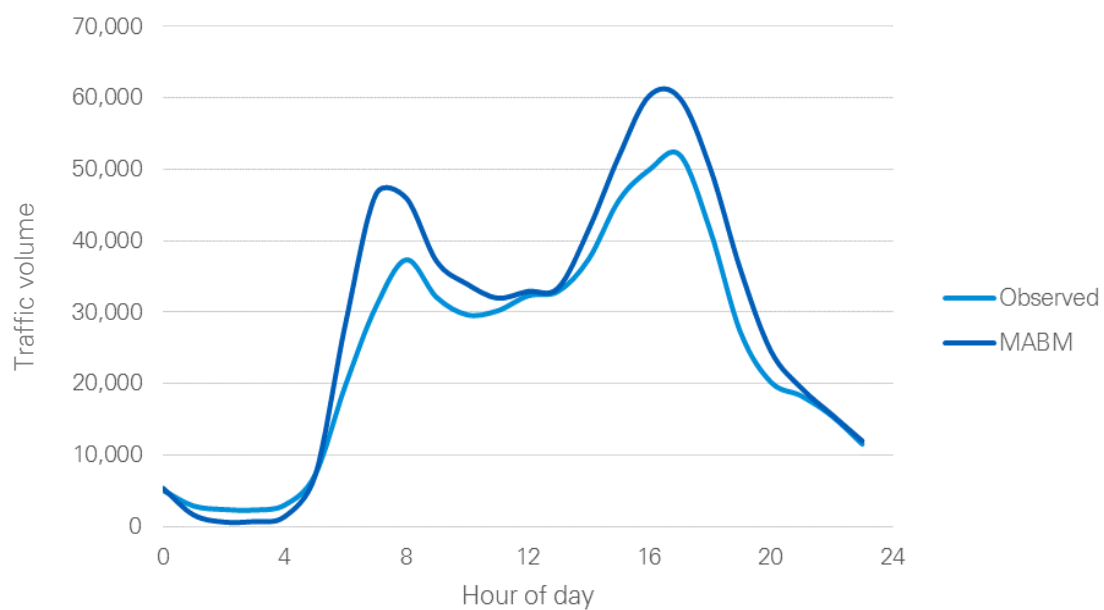
Figure 35: Screenline 901, inbound, number of vehicles by time of day**Figure 36: Screenline 901, outbound, number of vehicles by time of day**

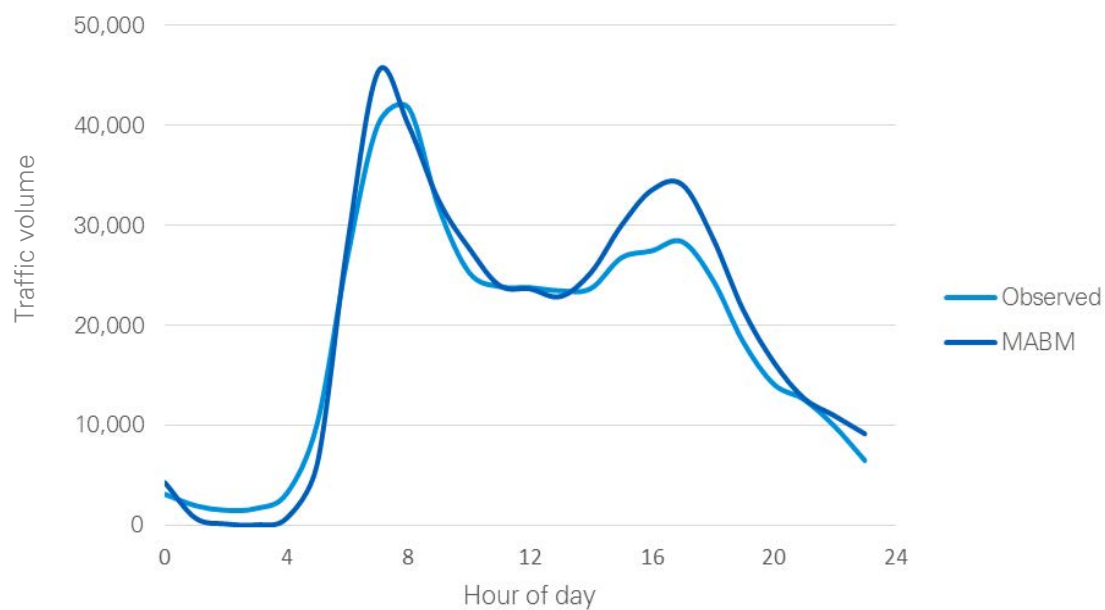
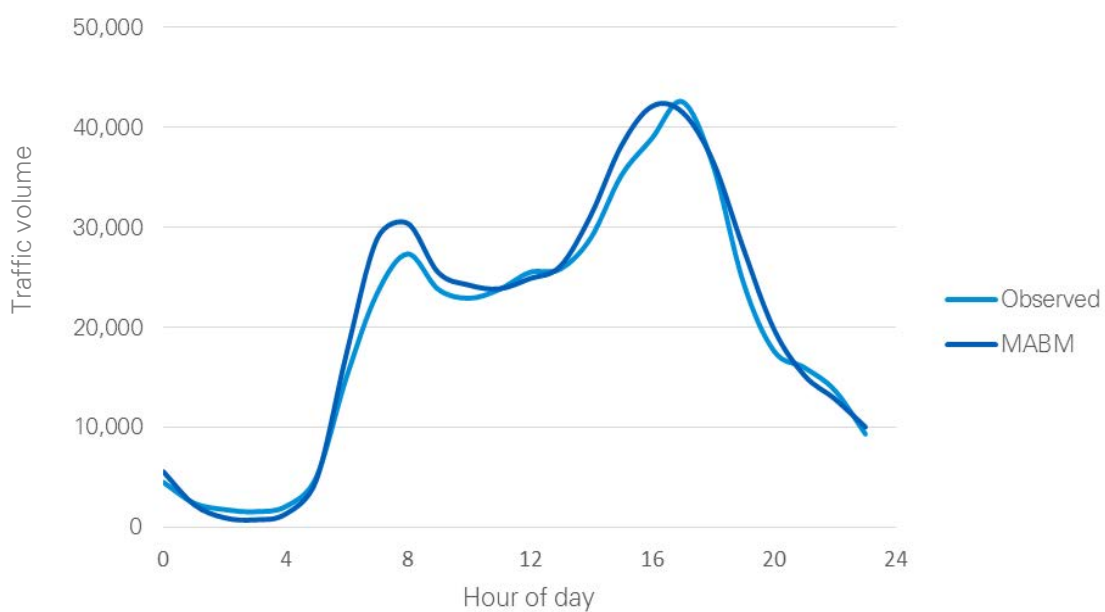
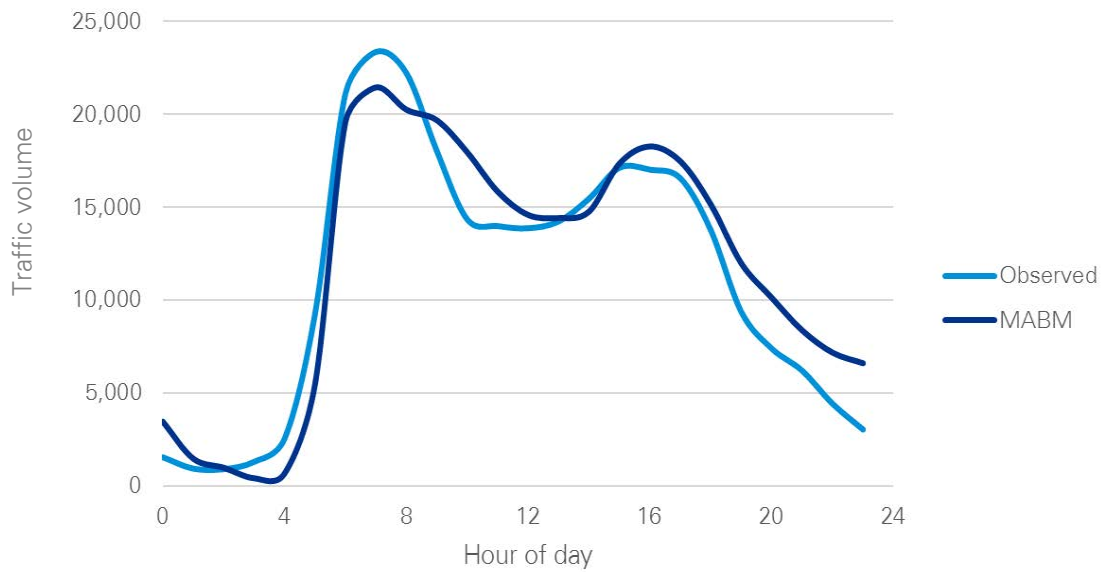
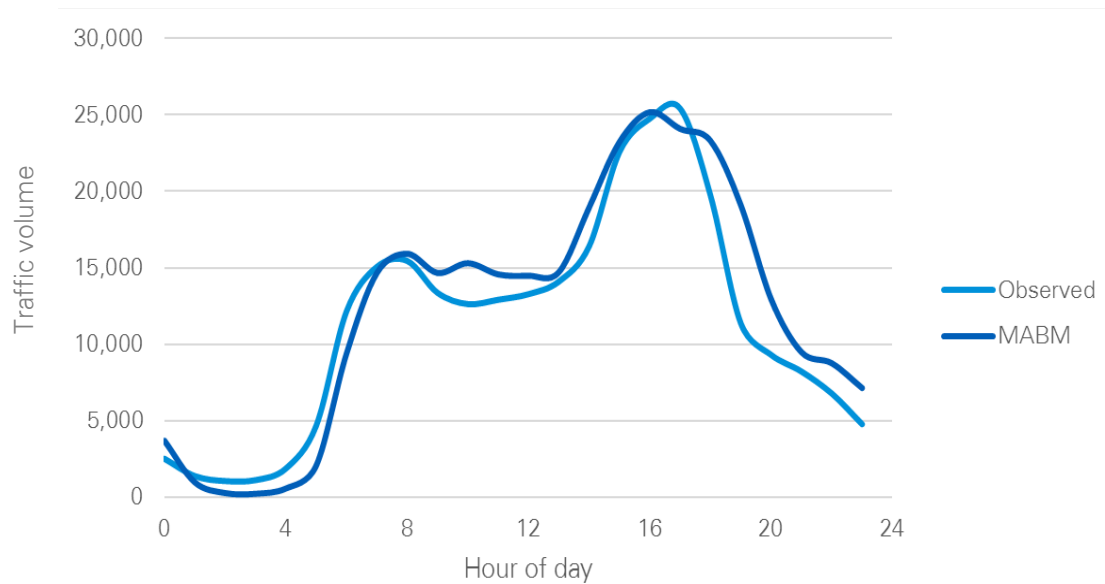
Figure 37: Screenline 902, inbound, number of vehicles by time of day**Figure 38: Screenline 902, outbound, number of vehicles by time of day**

Figure 39: Screenline 908, inbound, number of vehicles by time of day**Figure 40: Screenline 908, outbound, number of vehicles by time of day**

5.4.2 Toll roads

Modelled toll road volumes by time of day were compared against CityLink and EastLink toll road volumes provided by VicRoads. Toll road volume validation at selected key locations, measured by the GEH statistic (desired criterion is 50% of cases < GEH 5, 80% < GEH 10) and is summarised in Table 13. Note that the volumes calculated for the GEH statistics are the average hourly volumes of each respective period. The validation of toll road volumes in MABM is considered to be reasonably good. While not strictly meeting the desired criteria the results are reasonably close, with 33% of measured locations within GEH 5 and 50%-75% within GEH 10. Given the known difficulty in accurately replicating toll road patronage in a large scale strategic model, this is considered an acceptable result.

Table 13: Modelled toll road volume GEH statistic

Location	Direction	AM	PM
EastLink between Maroondah Highway and Canterbury Road	Inbound	6	1
	Outbound	3	11
EastLink between Monash Freeway and Princes Highway	Inbound	15	2
	Outbound	11	6
EastLink between Thompson Road and Frankston freeway	Inbound	13	8
	Outbound	1	10
CityLink - Albion Street	Inbound	17	7
	Outbound	16	10
CityLink - Bolte Bridge	Inbound	5	1
	Outbound	16	16
CityLink - Yarra Boulevard	Inbound	8	5
	Inbound	5	6
GEH <5		33%	33%
GEH <10		50%	75%

Time of day profiles for selected toll road count stations were also assessed. Similar to screenline profiles, the analysis demonstrated that MABM closely replicated the actual travel patterns by time of day. These are profiled in Figure 41 to Figure 48. Note that the count locations are de-identified due to the confidentiality provisions under which the data was

obtained from VicRoads. The locations are presented in descending order of typical weekday daily traffic volume.

Figure 41: Toll road count location A, direction 1

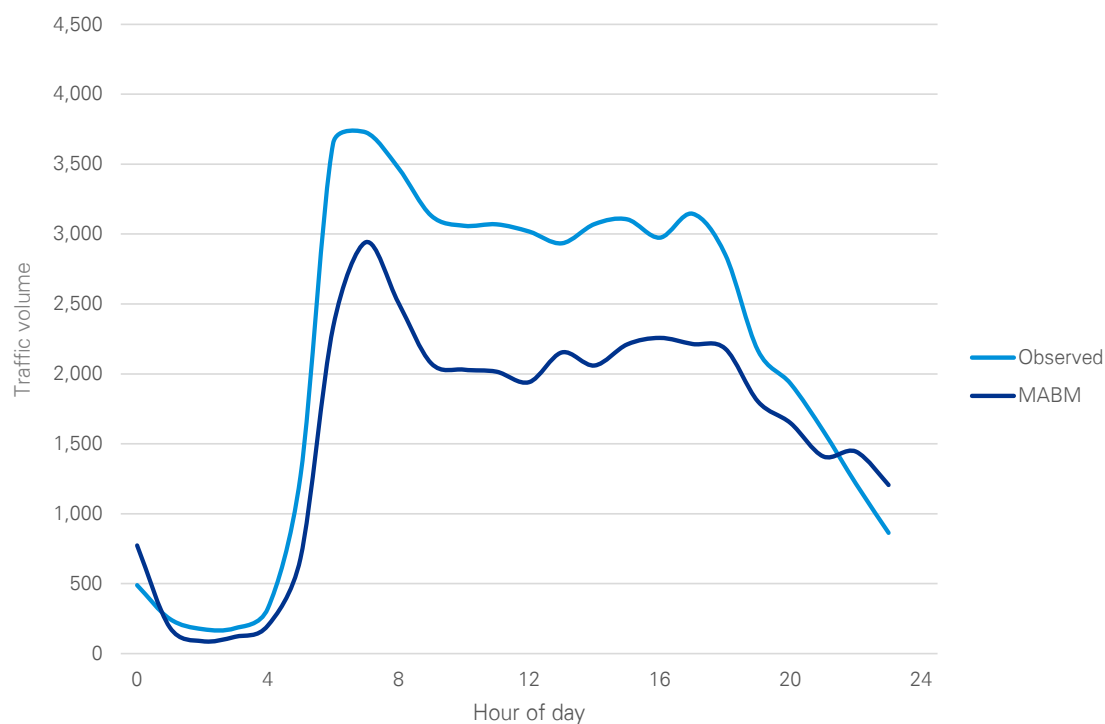


Figure 42: Toll road count location A, direction 2

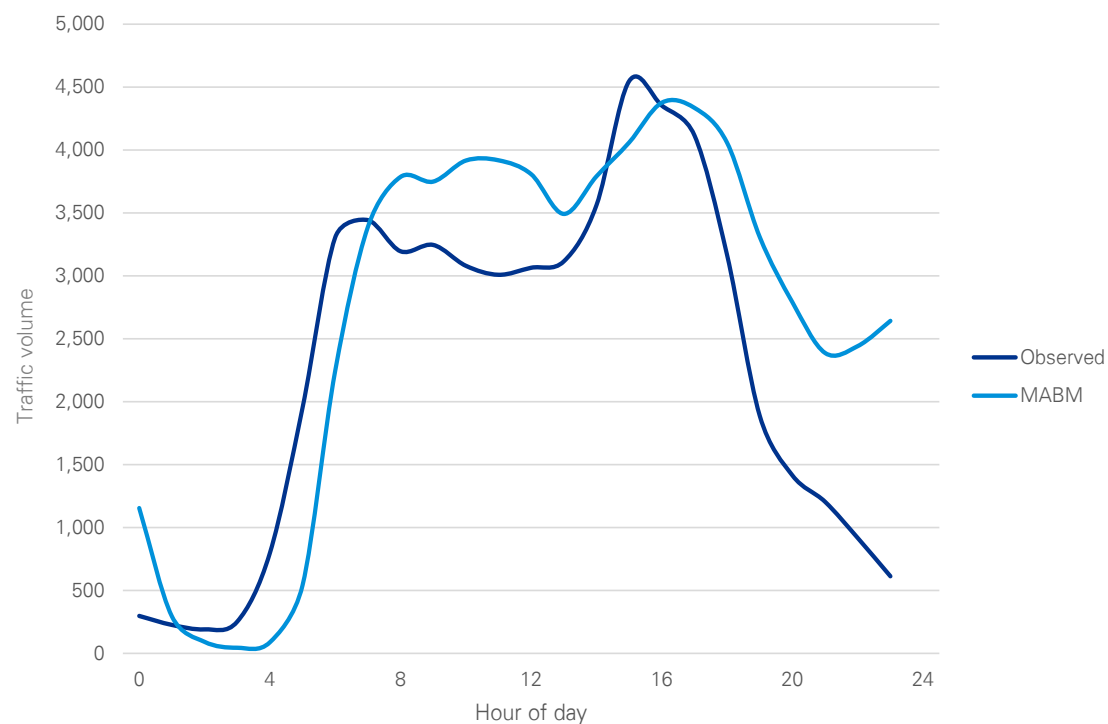


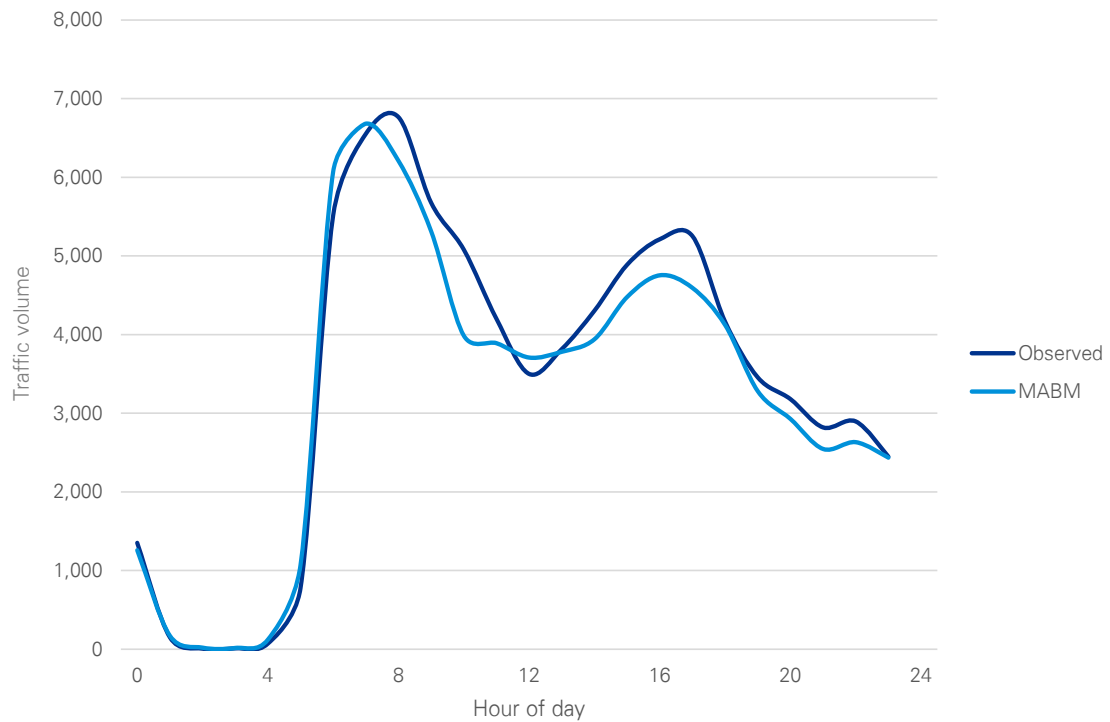
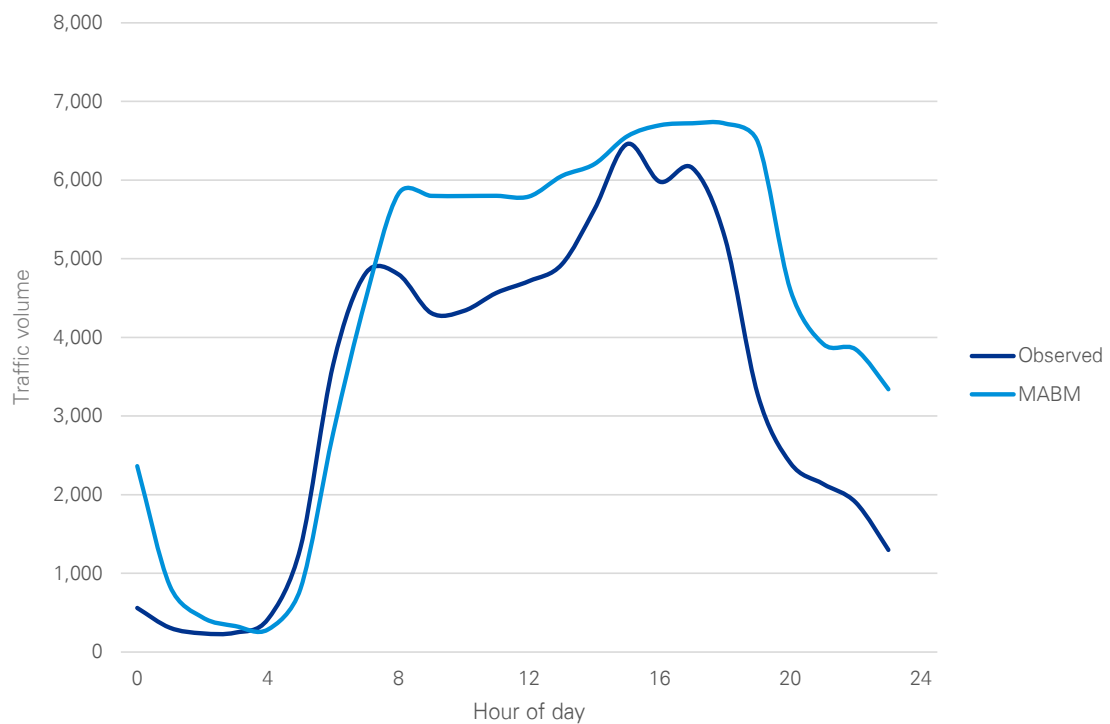
Figure 43: Toll road count location B, direction 1**Figure 44: Toll road count location B, direction 2**

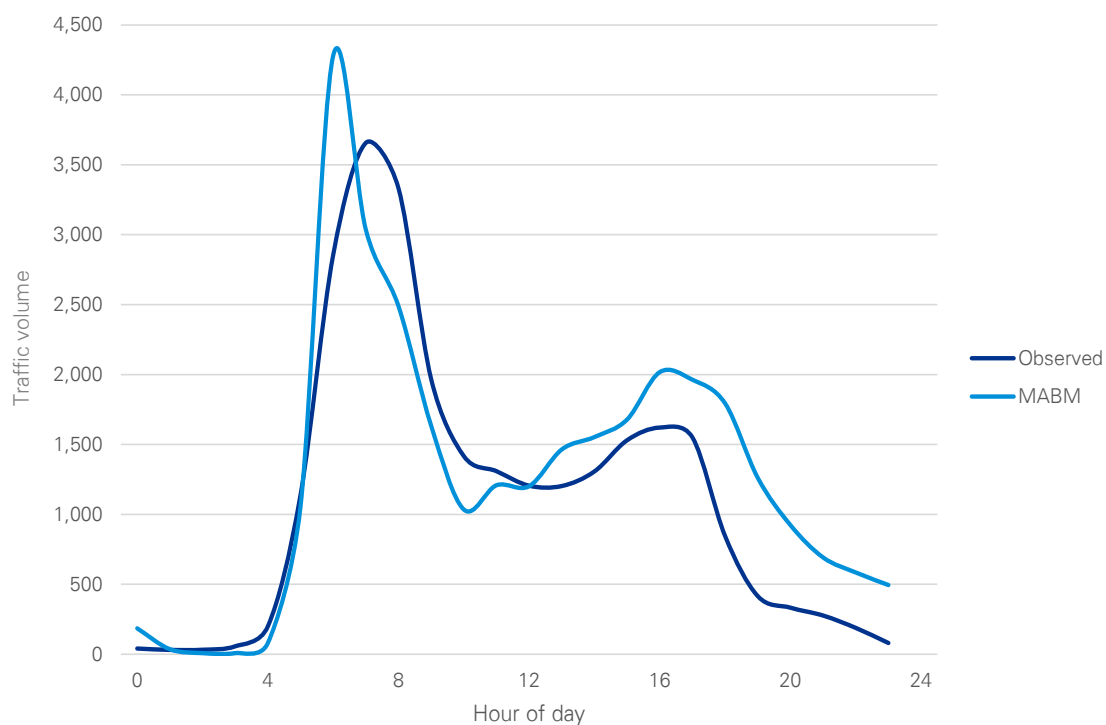
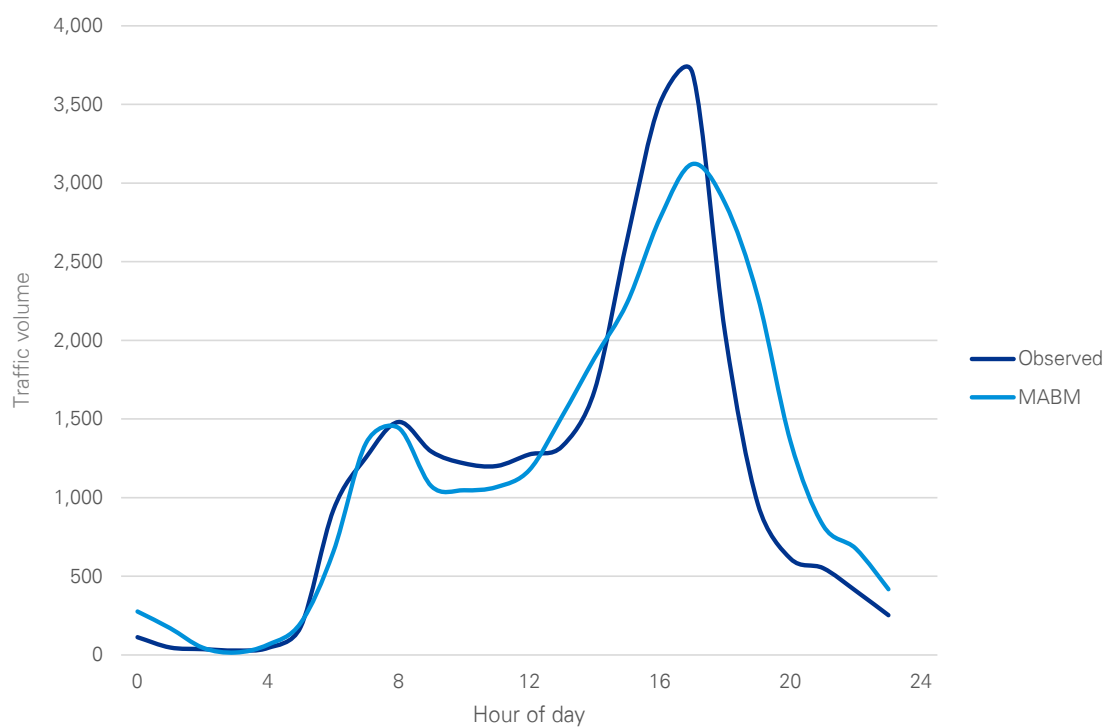
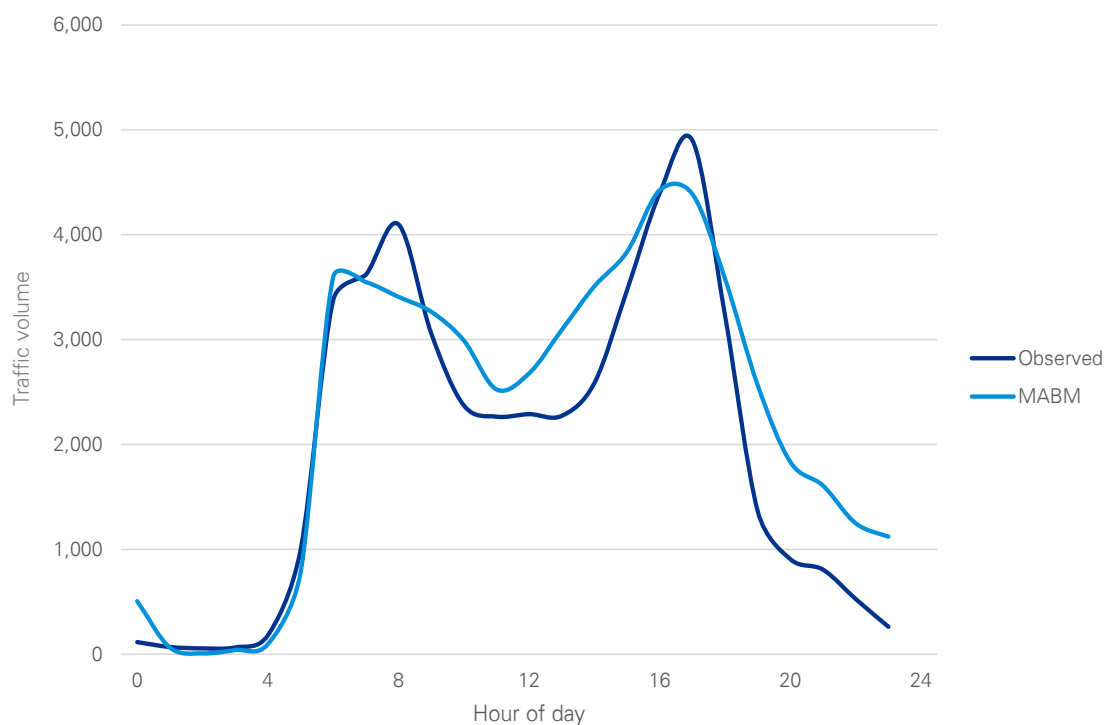
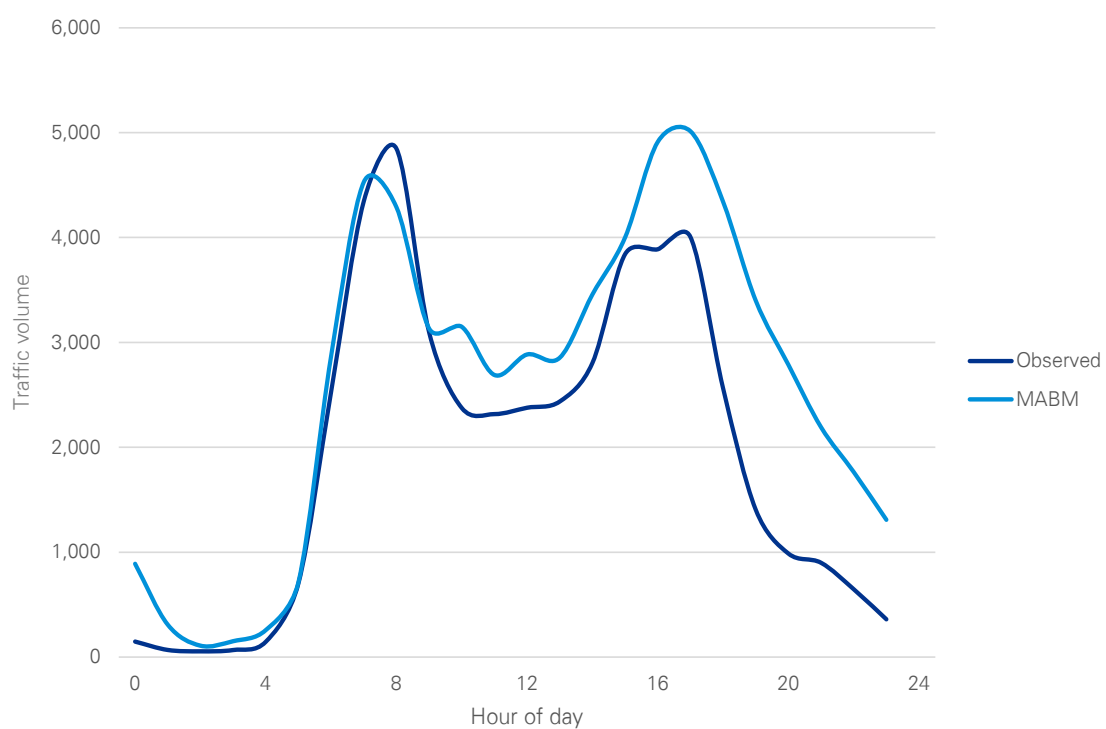
Figure 45: Toll road count location C, direction 1**Figure 46: Toll road count location C, direction 2**

Figure 47: Toll road count location D, direction 1**Figure 48: Toll road count location D, direction 2**

5.5 Public Transport

5.5.1 Train station entries & CBD cordon loads

Rail station entries have been assessed rather than rail boardings, to align with the available observed data. Limitations of the observed data used for model validation are outlined in Section 4.3. Daily train station entries are summarised in Table 14, comparing modelled station entries against PTV entries derived from ticketing data. The table demonstrates that the modelled train station entries across the whole of Melbourne is estimated at 5% of the observed entries, well within the desired criterion of 20%. Different lines however have some variance with Clifton Hill line group in particular having significantly higher difference of ~60%.

Modelled and observed train loadings, comparing to Public Transport Victoria load surveys and broken down by line group at the CBD cordon, are summarised in Table 15. CBD cordons are of particular interest as they represent the point of highest load on the rail network during critical peak periods. In all cases, modelled train loads meet the desired validation criteria (within 20% of observed).

Modelling of train patronage within MABM meets the desired validation criteria and is considered to suitably replicate observed passenger behaviour.

Table 14: 24 hour train station entries by line group

Line Group	Observed PTV ticketing data	Modelled	% Difference
Burnley	114,849	118,780	3%
Caulfield	162,774	165,000	1%
Clifton Hill	68,550	111,476	63%
Northern	132,589	154,744	17%
Inner Core	286,615	250,512	-13%
All Stations	765,377	800,512	5%

Table 15: Train loads (passengers) at CBD cordon

Period	Cordon	Observed PTV load surveys	Modelled	% Difference
AM	Northern	45,639	41,384	-9%
	Clifton Hill	19,960	23,452	17%
	Burnley	32,264	32,856	2%
	Caulfield	43,440	43,136	-1%
PM	Northern	51,829	47,832	-8%
	Clifton Hill	22,401	22,444	0%
	Burnley	36,255	30,280	-16%
	Caulfield	47,745	39,832	-17%

5.5.2 Bus and Tram boardings

Observed (PTV ticketing data) and modelled boardings for both bus and tram are shown in Table 16. The modelled daily bus boarding volume is 2% less than observed, well within the desired validation criteria (within 20% of observed). Tram boarding replication is less accurate however, with total modelled boardings 22% less than observed. This is likely due to the current inability of MABM to model the free tram zone, substantially reducing modelled tram boardings within the CBD. This is further discussed in Section 7.1.

Given that the omission of the free tram zone is a known limitation of MABM and that modelled boardings are reasonably close to meeting the desired validation criteria, tram passenger behaviour is considered to be suitably well replicated.

Table 16: 24 hour bus and tram boardings

Mode	Observed	Modelled	% Difference
Bus	421,462	430,572	2%
Tram	652,385	503,140	-22%

5.6 Road travel times

5.6.1 Network wide performance

Figure 49 shows total vehicle kilometres travelled (VKT) and vehicle hours travelled (VHT) by hour of day according to the MABM. Private and freight vehicles are included.

Figure 49: Vehicle kilometres travelled (VKT) and vehicle hours travelled VHT) by hour of day

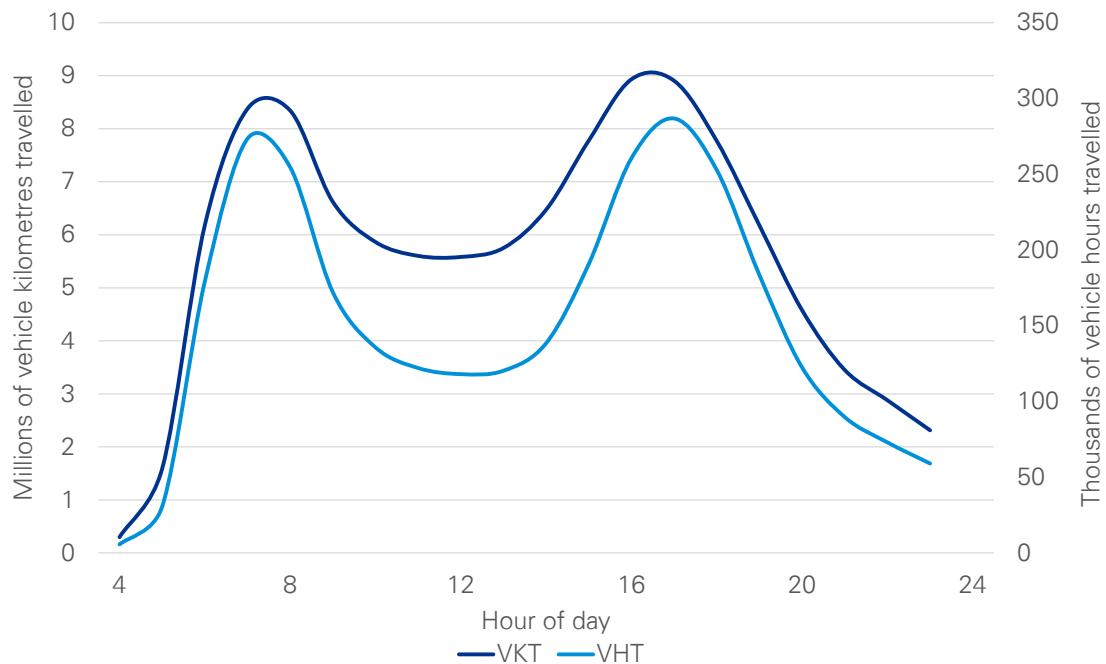


Figure 50 shows average network speed by time of day according to the MABM. Average speeds drop to approximately 30 km/h during the morning and afternoon peaks. VicRoads formerly released a Traffic Monitor report which reported a similar statistic (VicRoads, 2014). The average travel speed chart for the most recent report is shown in Figure 51. Comparison of the two charts demonstrates that average network speeds for the MABM correspond reasonably well with observed data.

Note that the VicRoads travel speeds in Figure 51 are for their monitored network, which includes 100% of freeways and a sample of arterials. Local roads are not included, unlike the MABM data. VicRoads estimates that this covers 47% of overall travel on freeways and arterials. By contrast, the MABM results cover all roads. Given that speed limits are generally lower on local roads, it is therefore likely that VicRoads data would overestimate the average travel speed for all roads. With this context, the average network speed for MABM is considered a good match with observed data.

The MABM also shows slower average speeds late at night compared to in the middle of the day. This is unlikely to be reflective of reality. This is attributed to the performance of the MABM degrading throughout the course of the day as bottlenecks occur on isolated sections of the network. These bottlenecks then have flow-on impacts which propagate through the remainder of the day. This is a limitation of the current version of the MABM and is discussed further in Section 7.1.

Figure 50: Average network speed (km/h) by hour of day

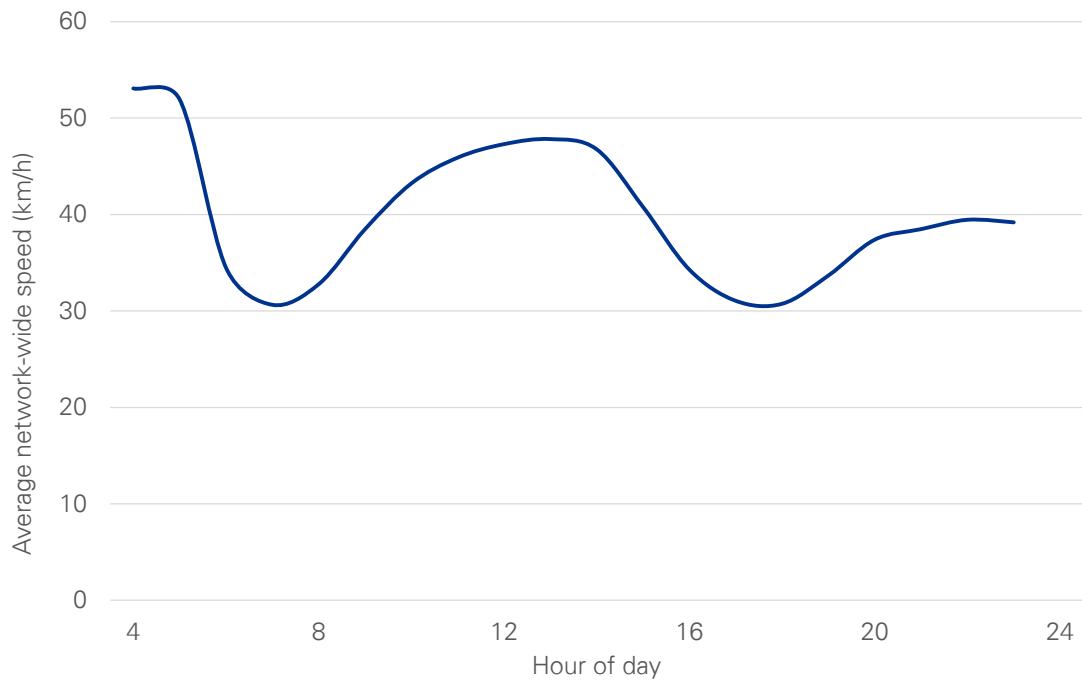


Figure 51: Network wide average speed, VicRoads observed



Source: VicRoads Traffic Monitor, 2012-13.

Note: AM Peak is 7:30am to 9am, PM Peak is 4:30pm to 6pm, Off peak is 10am to 3pm

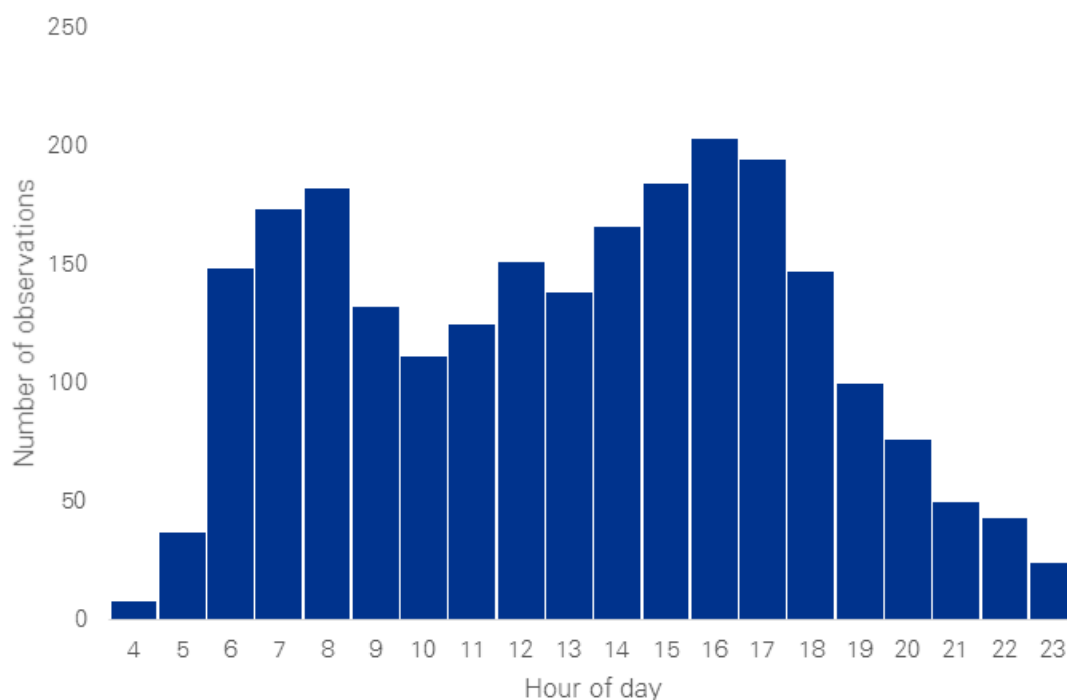
5.6.2 Trip-level travel time performance

In order to test the performance of MABM with respect to travel times at a trip-level, 2,500 car trips were randomly selected from the MABM baseline run. The travel times for these trips

were compared to the HERE Maps API. HERE Maps uses a proprietary methodology to predict travel times based on recent historical data. The data sets used here was generated from the public APIs. Predicted travel times were collected for Tuesday the 29th of August 2017 (in advance of that date) for the departure time of the randomly selected MABM trip.

The departure times of the randomly selected trips are shown in Figure 52.

Figure 52: Departure times of 2,400 randomly selected MABM trips

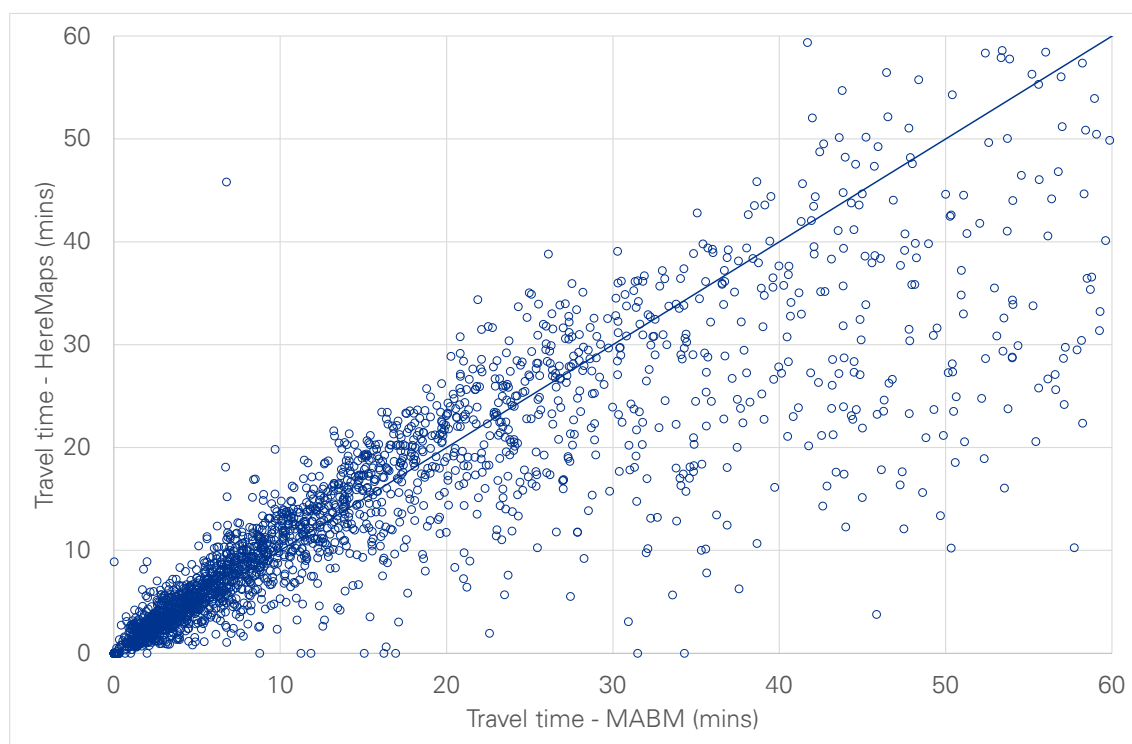


A scatter plot showing the correlation between MABM and HERE Maps are shown in Figure 53 for travel times under sixty minutes. Table 17 shows the proportion of randomly selected trips which fall within 20% and 50% of the predicted travel time for HERE Maps.

The plot and table demonstrate a reasonably good fit between modelled and observed for most trips for both data sources. However, a proportion of trips have substantially greater modelled travel times than observed. This is also true of a small proportion of trips to the right of the charted area in Figure 53 (i.e. not shown).

The MABM exhibits a 'long tail' of travel times relative to observed data. This is caused by large queues forming on small sections of the network which take a long time to clear. In the worst cases, these queues can take several hours to clear. This causes a small proportion of trips to have their travel times significantly overestimated. This is a limitation of the current version of the MABM and is discussed further in Section 7.1.

To illustrate the effect of the long tail, Figure 54 shows the cumulative percentage of the randomly selected trips below a given travel time for MABM and HERE Maps. As demonstrated, a small but significant number of trips are influenced by these queues. According to HERE Maps, 96.3% of the randomly selected trips have travel times less than sixty minutes. According to MABM, only 90.5% of the same set of trips have travel times less than sixty minutes.

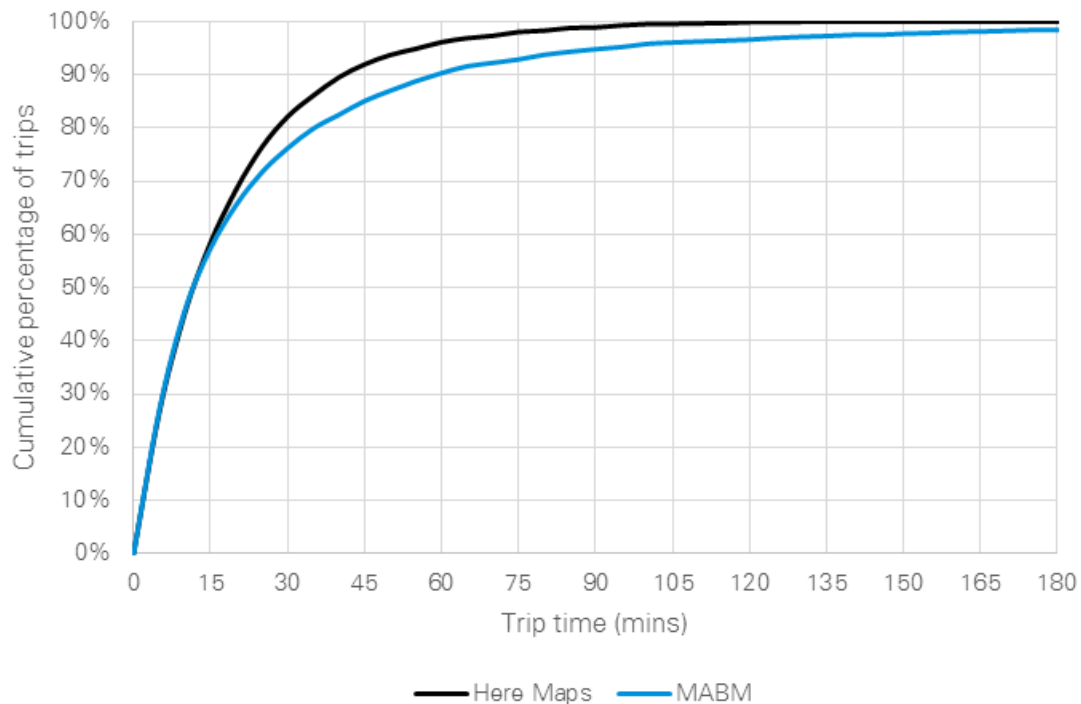
Figure 53: MABM vs HERE Maps trip travel times

Source: MABM and HERE Maps API

Table 17: Percentage of travel times within thresholds of observed data

Data source	Within 20% of predicted	Within 50% of predicted
HERE Maps	46%	75%

Figure 54: Cumulative percentage of trips less than a given trip time, MABM vs HERE Maps



Source: MABM and HERE Maps API

5.7 Model response and elasticity testing

5.7.1 Elasticity analysis

Four elasticity tests have been specified to test the responsiveness of the MABM to changes in monetary costs. These tests represent analogous measures to potential road pricing schemes. Arc elasticities were calculated as shown in Equation 1.

$$(1) \quad e = \frac{\log(Q_2) - \log(Q_1)}{\log(P_2) - \log(P_1)}$$

where:

Q = quantity¹⁰

P = cost

1 is before and 2 is after the change in cost

The elasticities are compared to DEDJTR's elasticity guidelines (DEDJTR, 2015).

The tests include changes in fuel costs (analogous to a distance based charge), parking costs (analogous to an area based charge) and existing tolls on CityLink and EastLink. The fourth elasticity test was undertaken to assess the elasticity of public transport trips in response to

¹⁰ The quantity refers to the output measures as defined in Table 19

changes in public transport fares. The elasticities, including their precise definitions and results, are presented in Table 19.

It should be noted that this analysis uses guidelines which were designed for trip-based models. Trip-based models consider changes in generalised cost relating to a single trip. Activity-based models such as the MABM consider changes in score (utility) over the course of the day. As a result, activity-based models are likely to exhibit non-linearity of elasticities to a greater extent than trip-based models. This means that small changes in daily cost may have minimal effects on behaviour. This is a desirable characteristic of the MABM and is likely to be a realistic reflection of actual behaviour. Further work should be undertaken to assess the non-linearity of responses in MABM.

A large degree of uncertainty is inherent with elasticities, and direct comparisons with model results are inherently difficult. The DEDJTR guidelines implicitly acknowledge this uncertainty by providing a range of elasticity values. It should also be noted that short run elasticities tend to be lower than long run fuel elasticities (VTPI, 2012). This is consistent with the MABM result for fuel elasticities. As MABM does not allow destination change, it is more reflective of a short run elasticity. Four step models typically include destination choice, which include the possibility of changing activity locations in response to changes in generalised costs (e.g. moving house or changing job). As such, four step models are more comparable to long run elasticities.

In addition, the MABM allows elasticities to be calculated separately for different segments of the population. Further work should be undertaken to assess differences in response to charges for different demographic groups.

5.7.1.1 Fuel

The MABM is less responsive to change in fuel costs than the DEDJTR guidelines specify, with an elasticity value of -0.03. The DEDJTR guideline range is -0.15 to -0.30.

The elasticity test is undertaken by increasing the monetary distance rate from 17.6 c/km by 10% to 19.4 c/km. This is a small change in cost in the context of a whole day, upon which scores are calculated in the MABM. For a person who drives 30 km in a day, this change amounts to about 50 cents over the course of the day. This is equivalent to a change of daily score of about 0.2% for an average person. This cost change is not enough to cause any significant mode shift from car to public transport in the MABM.

The current version of the MABM does not allow activities to be foregone or for their location to be changed, so there is no ability for people to reduce their trip lengths in response to the increase in fuel costs.

In addition, fuel costs are applied in the MABM purely on the basis of distance (the monetary distance rate), without consideration to how speeds impact fuel efficiency. As a result, increasing the fuel cost by a small amount primarily causes agents to minimise their distance when routing. This manifests in a decrease in freeway VKT and an increase in arterial and local road VKT as agents trade off longer travel times for reduced distances. This amounts to rat-running behaviour. To illustrate this dynamic, Table 18 shows the elasticity by road type.

Table 18: Fuel elasticities by road type, daily, all purposes

Road type	Elasticity
Freeways	-0.14
Arterials	+0.01
Local Roads	+0.02

This result should be considered when specifying distance based charges, as a similar effect is likely to occur.

5.7.1.2 Parking

The daily parking elasticity for commuting is -0.27. This falls in the middle of the DEDJTR elasticity guideline range of -0.10 to -0.40. This provides some assurance that the model will respond appropriately to area and cordon based charges (which have similar effects to parking charges).

5.7.1.3 Toll

The daily toll road elasticity is measured at -0.15. No DEDJTR guideline is applicable for comparison. The result demonstrates that the model is responsive to changes in toll values. This is an expected result. This provides some assurance that the model responds appropriately to link-based road pricing.

5.7.1.4 Fares

The MABM is less responsive to change in public transport fares than the DEDJTR guidelines specify, with an elasticity value of -0.10. The DEDJTR guideline range is -0.20 to -0.60.

The increase in charge is modest relative to a daily score. A capped daily public transport charge in the MABM is \$5.17 per day (accounting for concession and different ticket types). This means a 10% change amounts to about 50c per day, approximately 0.2% of a person's daily score. It is likely that a larger change in fares would yield a greater elasticity.

Table 19: Model response and elasticities for MABM

Attribute	Trip Purpose	Method	Change Amount (%)	Typical Change Amount (c)	Output Measure	DEDJTR Elasticity Guidelines	MABM Elasticity
Fuel	All	Increase monetary distance rate	+10%	~50 c/day	Car vehicle kilometres travelled, Daily	-0.15 to -0.30	-0.03
Parking	Commuting	Increase inner city parking rates and cap	+10%	~200 c/day	Car trips to CBD and inner areas, Daily	-0.10 to -0.40	-0.27
Toll	All	Increase tolls and cap	+10%	~75 c/day	Car volumes at toll road count stations, Daily	N/A	-0.15
Fares	All	Increase public transport fares and cap	+10%	~50 c/day	Public transport trips, Daily	-0.20 to -0.60	-0.10

5.7.2 Model response to other inputs

Several runs were undertaken which varied other inputs beyond the subject of the elasticity analysis discussed in the previous section. These tests were undertaken on earlier versions of the model and were not set up to provide formal elasticity analysis. However, these runs do provide insight into the responsiveness of the model to various changes in inputs. This section references the model run numbers defined in Attachment B.

More formal analysis of the impacts of changes to these inputs should be explored in future.

5.7.2.1 Value of time

Numerous runs were undertaken which varied the marginal utility of travel time for walk and public transport modes. The model responded as expected, with reductions in the marginal utility of travel time making agents systematically less likely to use those modes. Reductions in the marginal utility of walk travel time also impacted public transport usage, due to the walk legs that occur at each end of a public transport journey.

5.7.2.2 Boarding and transfer penalties

Numerous runs were undertaken which varied the boarding and transfer penalties by public transport submode (i.e. bus, train, tram). The model responded as expected, with increases in individual submodes causing agents to avoid that submode and favour the other submodes. In addition, increases in boarding and transfer penalties caused agents to shift away from public transport in favour of other modes.

5.7.2.3 Travel demand inputs

Several different variants of travel demand inputs were tested. The model was found to be very sensitive to the demand inputs, and in particular to trip distance distributions. For runs in which trip distance distributions for certain activity types were longer than observed, an increase in vehicle kilometres travelled and volume-capacity ratios was observed.

5.7.2.4 Mode specific constants

Various mode specific constants were tested for each mode in the model. The model was highly responsive to mode specific constants, as expected. Increasing the mode specific constant caused significant mode shift towards that mode.

5.7.2.5 Road capacities

Different assumptions regarding road capacity were tested. A test was undertaken in which arterial road capacity was increased by 20% and freeway capacity increased by 10%. This test (run 117) induced a modest increase in VKT on freeways and arterials. A moderate decrease in public transport boardings and cordon loads was observed.

5.7.2.6 Park and ride station capacities

A test was undertaken with unconstrained park and ride car park capacities (run 123). As expected, this test showed a significant increase in park and ride activities and train cordon loads.

5.7.2.7 Random seeds

A single run was undertaken on a late version of the baseline run (run 154) with an alternative random seed against an otherwise equivalent benchmark (run 146). There were no substantial differences between the validation results with different random seeds.

5.8 Summary and validation sign-off

In keeping with the strategic nature of the model, while some validation criteria have not been fully met, the MABM has been deemed to be fit-for-purpose for undertaking strategic level analyses of transport network demand management policies including analysis and impact assessment of potential road pricing policies:

- Overall travel demand patterns:
 - Scatter plot (Figure 22) shows excellent correlation between MABM and VISTA;
 - VISTA has a small sample size for individual Origin-Destination pairs – this means there will always be large margin of error when comparing disaggregated areas;
 - Modelled demand for important locations perform well; and
 - It is considered that the current performance is fit for purpose for this project.
- Toll road volumes:
 - The GEH statistic is a binary metric, a slight difference can mean that results either meet threshold criteria or are out;
 - Traffic volume profiles across the day have historically been very difficult to model well along toll roads; it is very important to replicate traffic volume profiles well for this project;
 - MABM tracks the traffic volume profiles along toll roads very well; and
- It is considered that the current performance is fit for purpose for this project.
- Road screenline volumes:
 - The target curve measure is binary, a slight difference can mean that results either meet threshold criteria or are out;
 - MABM is tracking volumes by time of day across screenlines very well, and this is also the case for screenlines that do not technically meet the criteria; and
 - It is considered that the current performance is fit for purpose for this project.

Based on this, IV signed-off on the model validation on 4 August 2017 and assessed it as being fit for purpose for assessing different transport network demand management policies, with a focus on road pricing options.

6 2031 Model Development and Performance

The 2031 MABM uses the same population synthesis methodology as the 2015 MABM, but uses demand and network assumptions based on 2031 forecasts. The key differences between the 2015 and 2031 MABM are:

- Network changes to incorporate infrastructure and service change between model years; changes in network in the 2031 model are described in Section 6.1.
- Synthetic population based on forecasted demographics and land use for 2031; changes in demand in the 2031 model are described in Section 6.2.

All parameter values used in MABM remain unchanged between 2015 and 2031. This means that all monetary costs such as vehicle operating costs, fares, fuel and parking are assumed to stay constant in real terms.

6.1 Network changes

To maintain consistency with the VITM, many of the inputs to the MABM align with the VITM Reference Case. The Reference Case is a suite of assumptions, interventions and future trends agreed across the transport portfolio, in relation to inputs required by the VITM.

Base and future year assumptions around the following demand elements were held consistent with the VITM Reference Case. This includes details on the volume of demand, its distribution across the day and its geographic location.

- Freight
- Airport
- External (regions outside of metropolitan Melbourne)

A range of road and public transport network additions and upgrades are assumed between 2015 and 2031. These reflect the Victorian governments VITM Reference Case, with modifications based on recommendations made by IV in their 30-year strategy.

Assumed additions to the road network include:

- North-East Link,
- Eastern section of the Outer Metropolitan Ring Road,
- Western Distributor,
- Mordialloc Bypass,
- Westall Road extension, and
- New connections within growth corridors.

Enhancements to the existing road network include:

- Upgrades to the M80, and the Tullamarine, Monash and Calder Freeways
- Upgrades to numerous arterial roads, including implementation of the committed 50 level crossing projects.

Assumed additions to the public transport network include:

- Melbourne Metro,
- Mernda Rail Extension,
- Fishermans Bend Tram Link, and
- Various growth area bus enhancements.

6.2 Demand generation

The 2031 synthetic population was generated in the same way as the 2015 synthetic population. The methodology is described in Section 3.1.2 of this report. There are two changes to the input data sources, as per the below.

- The 2015 Victoria in Future and Victorian Government's Small Area Land Use Projections (SALUP) are replaced with the 2031 equivalent. This accounts for expected growth in population and employment as well as changes in the demographic profile. Table 20 shows the change in population and worker numbers between MABM 2015 and 2031.
- The distribution of work activities is modelled using a synthetic version of the ABS Census 2011 Method of Travel to Work (MTWP) data. This is done in order to model the distribution of work trips in future years in the absence of Census data. The synthetic data is based on a gravity model and 2031 demographic projections. The methodology used to derive this data is described in Section 6.3.

Table 20: Population and worker growth in MABM 2015-2031

Measure	Region	MABM 2015	MABM 2031	CAGR
Population	Total¹¹	4,493,204	5,988,856	1.8%
	Outer Eastern	149,792	175,008	1.0%
	Inner Metro	327,888	479,620	2.4%
	Inner South East	529,884	606,576	0.8%
	Mid Eastern	730,268	847,664	0.9%
	Mid Northern	441,592	545,444	1.3%
	Mid South East	438,108	526,244	1.2%
	Mid Western	295,140	372,796	1.5%
	Outer Northern	446,980	678,576	2.6%
	Southern	535,192	786,004	2.4%
	Outer Western	533,856	841,580	2.9%
Workers¹²	Total	1,609,268	2,004,620	1.4%
	Outer Eastern	30,072	33,644	0.7%
	Inner Metro	472,360	613,028	1.6%
	Inner South East	149,120	175,372	1.0%
	Mid Eastern	250,436	304,108	1.2%
	Mid Northern	101,108	126,304	1.4%
	Mid South East	179,568	223,280	1.4%
	Mid Western	89,100	101,048	0.8%
	Outer Northern	119,148	152,100	1.5%
	Southern	97,716	118,840	1.2%
	Outer Western	111,260	145,316	1.7%

¹¹ Totals include population residing within the MABM coverage area and outside the 10 validation regions

¹² 'Workers' in this context refers to persons who travel to work on the modelled day in MABM

6.3 Work location synthesis

In order to model the distribution of work trips in future years it is necessary to estimate the change in trip distribution since the most recent available Census data from 2011. Worker demand in 2031 is generated using SALUP projections and 2011 ABS Census Method of Travel to Work (MTWP) data. The distribution of work trips is estimated using a custom gravity model calibrated to 2015 data.

6.3.1 Trip generation

Trip production and attraction factors for each SA2 were calculated using 2011 MTWP data and SALUP 2015 demographics. These factors represent respectively the number of people who travel to work per person who lives in the SA2, and the number of people who travel to work per job in the SA2.

The production factor for each SA2 is given by the ratio of MTWP trips by origin (*i*) to working age population, where working age population is defined as persons aged 18-65. The attraction factor is given by the ratio of MTWP trips by destination (*j*) to SALUP employment.

The definitions of the production factor and attraction factors are given in Table 21.

Table 21: Production and attraction factors

Factor	Definition
Production	$\frac{MTWP_{total,i}}{Population_{18-65}}$
Attraction	$\frac{MTWP_{total,j}}{Employment_{total}}$

Production attraction vectors were generated by applying the 2015 factors to the 2031 demographics. Attractions were then normalised such that total attractions were equal to total productions.

6.3.2 Trip distribution model

A production (home) constrained gravity model was used to distribute work trips across Melbourne. The form of the model is described by Equation 2.

$$(2) \quad T_{ij} = \frac{P_i A_j f(d_{ij})}{\sum_j A_j f(d_{ij})}$$

where:

P_i = number of productions at origin SA2 *i*

A_j = number of attractions at destination SA2 *j*

$f(d_{ij})$ = friction factor, dependant on network distance between zone *i* and *j*

6.3.3 Matrix balancing

The gravity model uses a negative exponential friction function to represent the impedance between each pair of SA2s. The network distance in kilometres between the centroid of each SA2 used as the measure of impedance. The friction function is described by Equation 3.

$$(3) \quad f(\text{distance}) = e^{-\lambda \cdot \text{distance}}$$

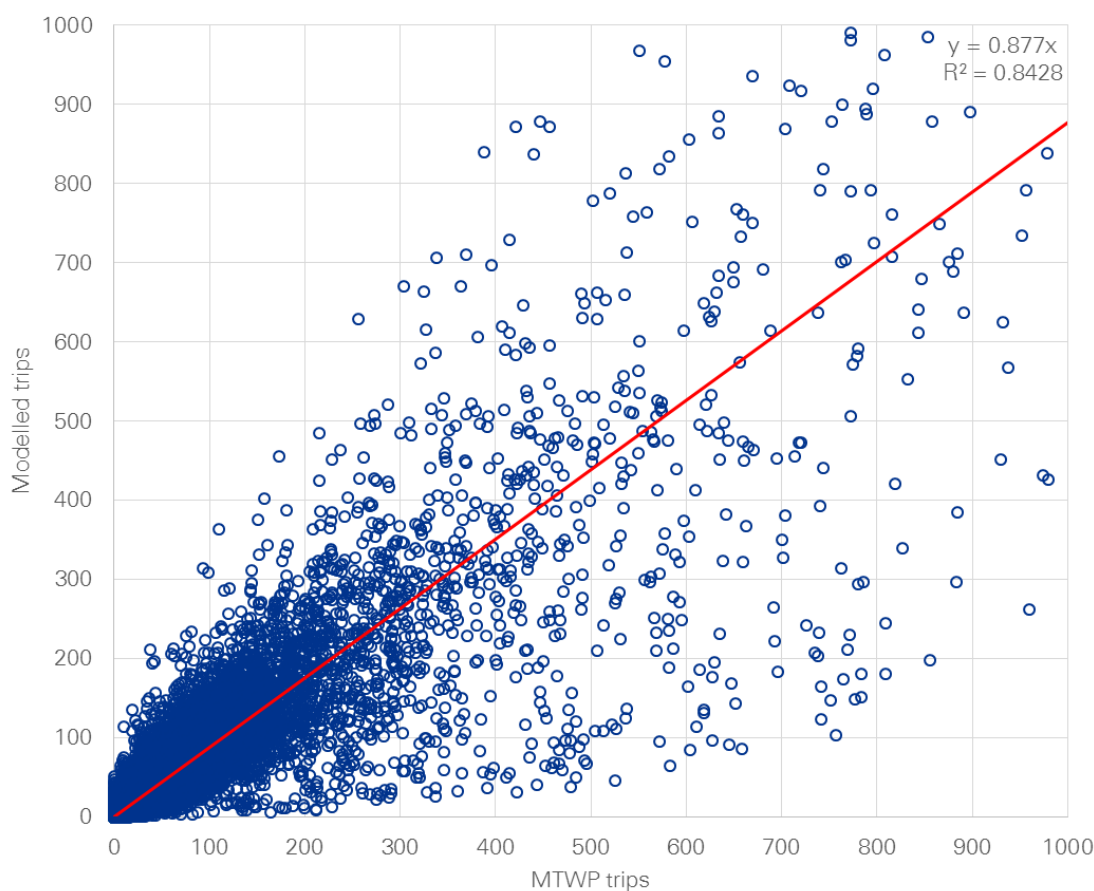
An initial trip matrix was generated using a value of $\lambda = 1$. The initial trip matrix is balanced iteratively until convergence.

The gravity model was calibrated by finding the value of λ such that the sum of squared difference between the modelled trips and MTWP total for each SA2 OD pair is minimised. This process yielded a parameter value for λ of 0.1.

6.3.4 Gravity model results

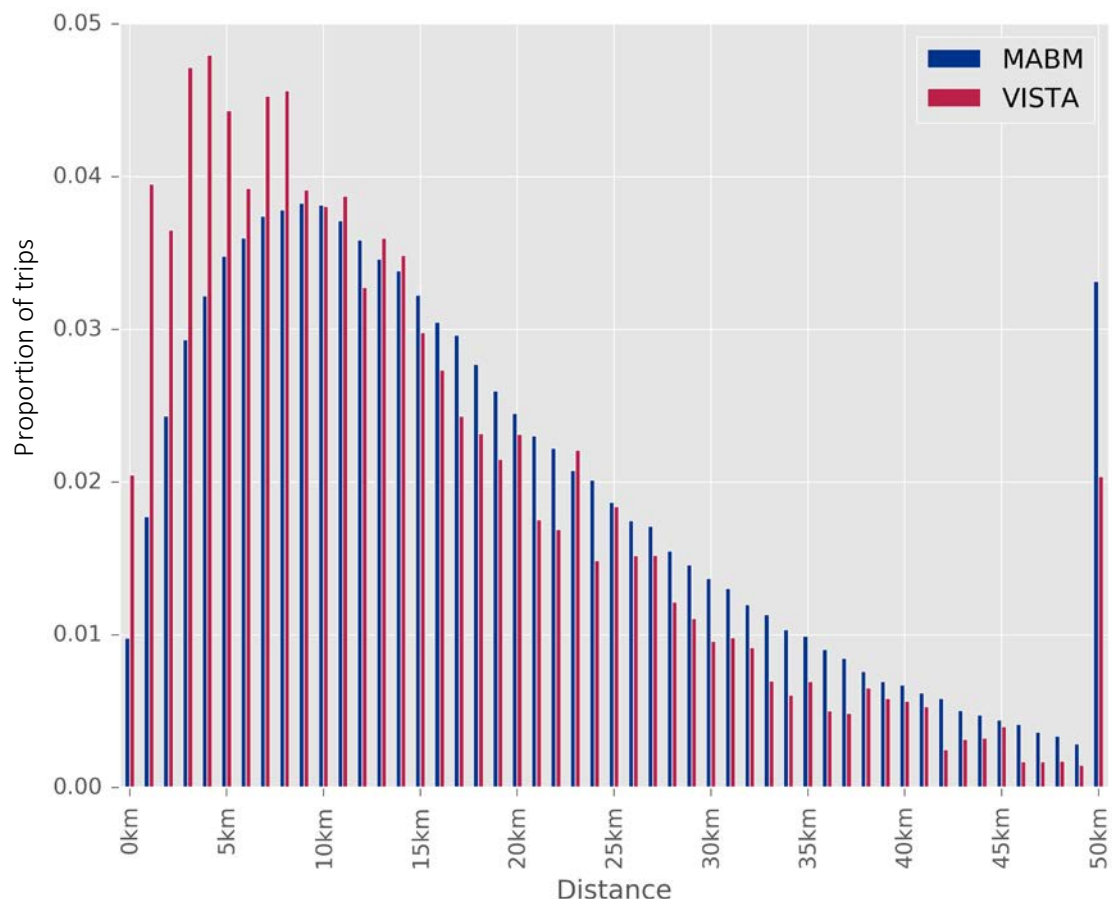
Figure 55 shows the output of the gravity model compared to the input census data, where each point represents a particular pair of SA2s. The gravity model recreates the data reasonably well. The R^2 value indicates that the model explains approximately 84% of the variation in trip volumes.

Figure 55: Modelled work trips - gravity model vs MTWP input for SA2 pairs



To generate worker demand in the 2031 MABM, the results of the gravity model were used in place of the Census inputs. Figure 56 shows the distance distribution for trips between home and work in the 2031 model compared with VISTA. When compared with VISTA, the distribution produced by the gravity model tends to underestimate trips that are shorter than 10km and overestimate trips that are longer than 10km. This is not necessarily a problem, as it is plausible that commuting lengths would get longer between 2015 and 2031 due to increasing separation between residential and employment locations. It is however important to keep this difference in mind when comparing the 2015 and 2031 MABM results.

Figure 56: Distance distribution - Home to Work - MABM 2031 vs VISTA



6.4 2031 MABM performance

The 2031 MABM uses the same benchmark model as the 2015 MABM with modifications to the demand and network based on projected changes in population, land use and infrastructure. Aside from these changes, the patterns of population and activity are comparable between the two models.

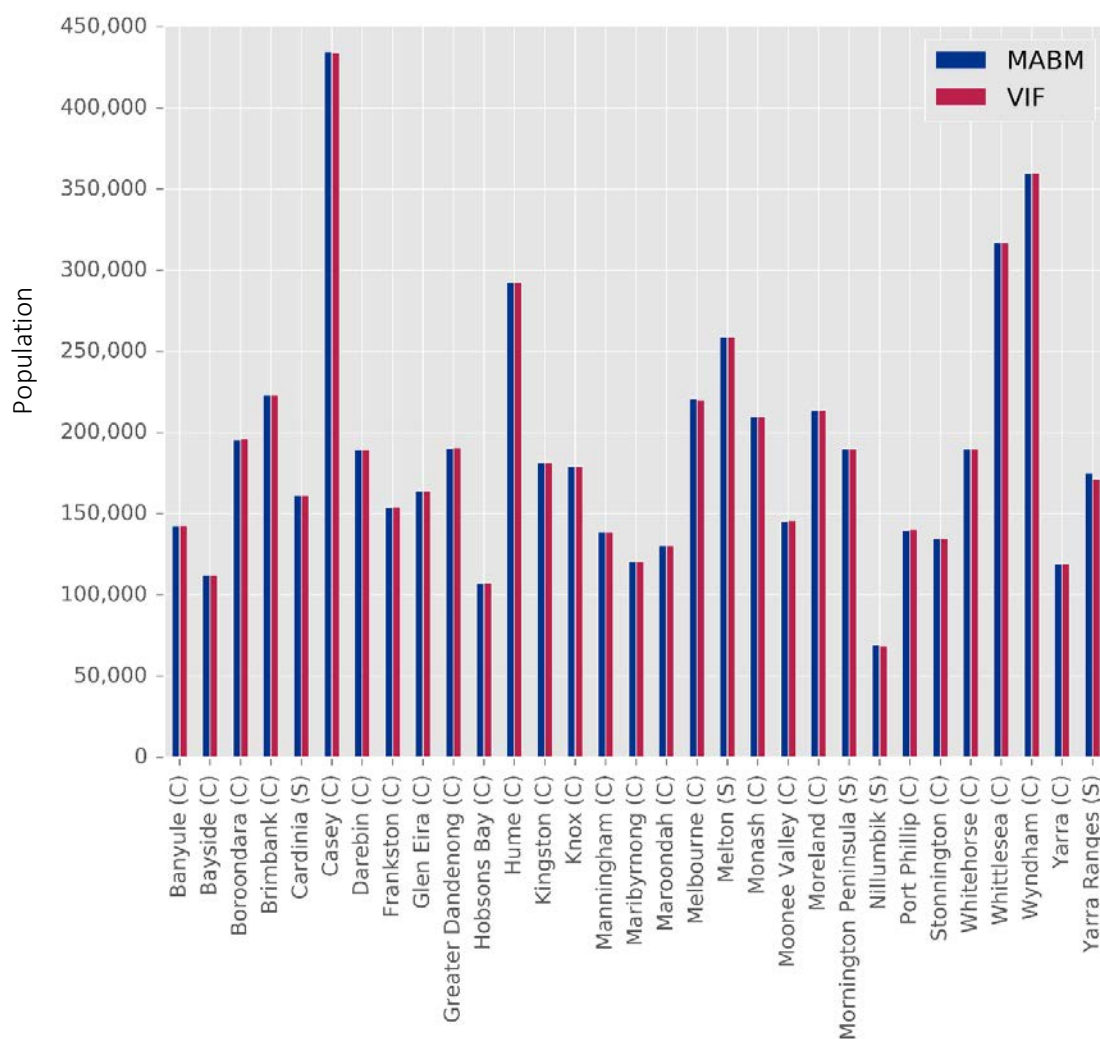
The performance of the MABM in 2031 is assessed by comparing the model behaviour against the validated 2015 model. As detailed in Section 5, the 2015 model accurately emulates observed patterns of demand and activity; this section compares the performance of the 2031 MABM to the 2015 model.

6.4.1 Activity Generation and Distribution

6.4.1.1 Modelled persons by Local Government Area

Figure 57 demonstrates how MABM accurately replicates the distribution of population across the study area in 2031 compared to VIF 2031.

Figure 57: Population (2031) by LGA



6.4.1.2 Total modelled trips

Table 22 and Table 23 show the growth in trip numbers by activity type and by region respectively. Across all regions, the number of modelled trips increases between 2015 and 2031 at an average annual rate of 1.5%. The Outer Western region has the highest rate of trip growth in Melbourne (2.6% annually). This is to be expected given Outer Western region also has the highest growth in population at 2.9% per year between 2015 and 2031.

Table 22: Growth in modelled trips by activity type

Activity type	MABM 2015	MABM 2031	CAGR
Home	4,953,992	6,423,088	1.6%
Work	1,869,032	2,323,716	1.4%
Business	380,940	479,152	1.4%
School	586,680	779,780	1.8%
University/TAFE	105,672	128,432	1.2%
School pickup/ drop-off	668,452	861,684	1.6%
Other	4,001,536	5,291,932	1.8%

Table 23: Modelled trips by region (origin)

Region	MABM 2015	MABM 2031	CAGR
Outer Eastern	453,432	528,516	1.0%
Inner Metro	1,535,508	2,124,268	2.0%
Inner South East	1,533,240	1,783,092	0.9%
Mid Eastern	2,122,652	2,497,728	1.0%
Mid Northern	1,075,292	1,344,756	1.4%
Mid South East	1,340,628	1,621,864	1.2%
Mid Western	746,488	948,868	1.5%
Outer Northern	1,160,284	1,699,044	2.4%
Southern	1,362,276	1,912,084	2.1%
Outer Western	1,205,956	1,827,564	2.6%

6.4.1.3 Activity start times

Figure 58 through Figure 61 show the distribution of activity start times in MABM 2015 and 2031. In all cases, the distribution is nearly identical in the two modelled years. This demonstrates that the 2031 MABM is performing as expected, given that activity patterns are generated in the same way for both years.

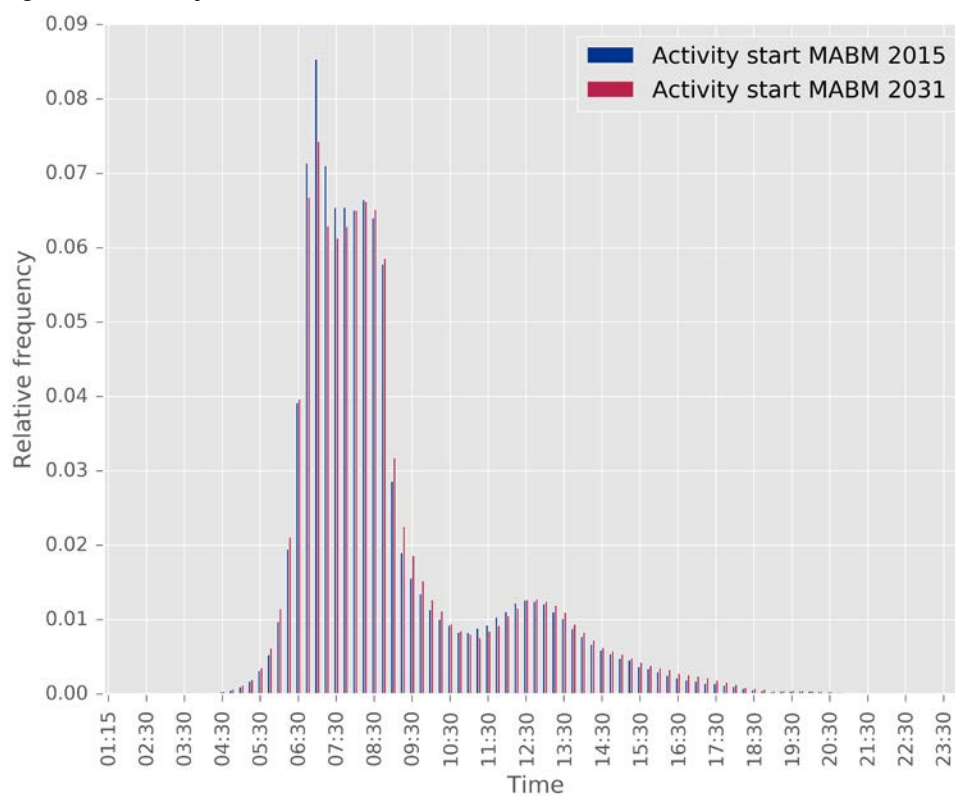
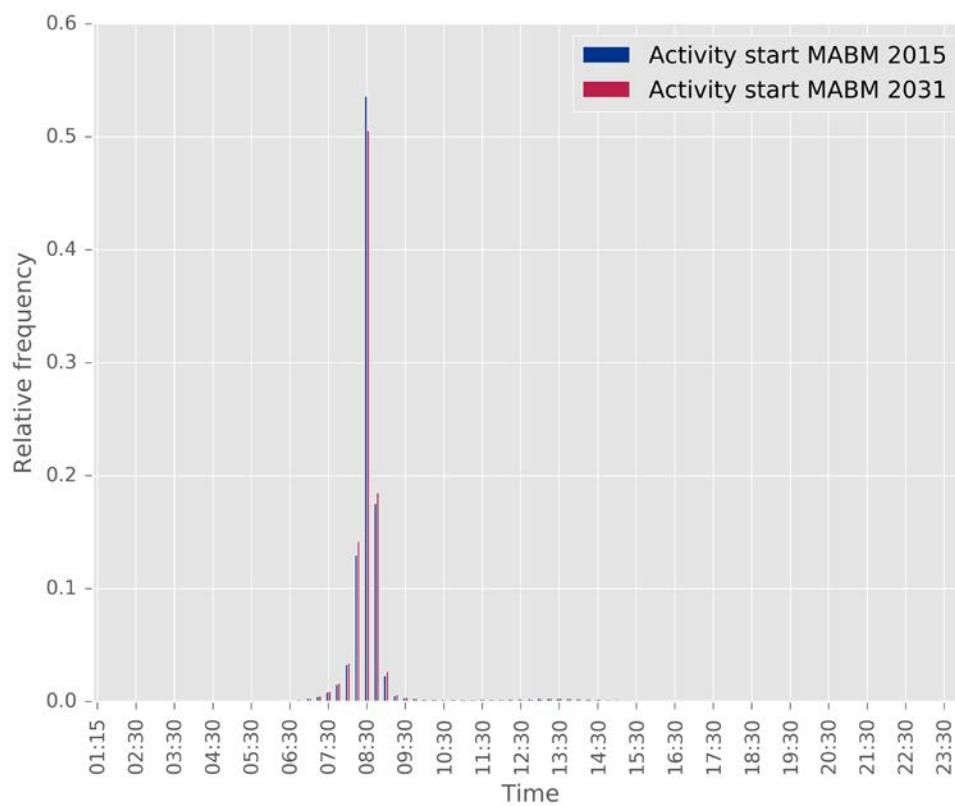
Figure 58: Activity start time - Work**Figure 59: Activity start time - School**

Figure 60: Activity start time - business

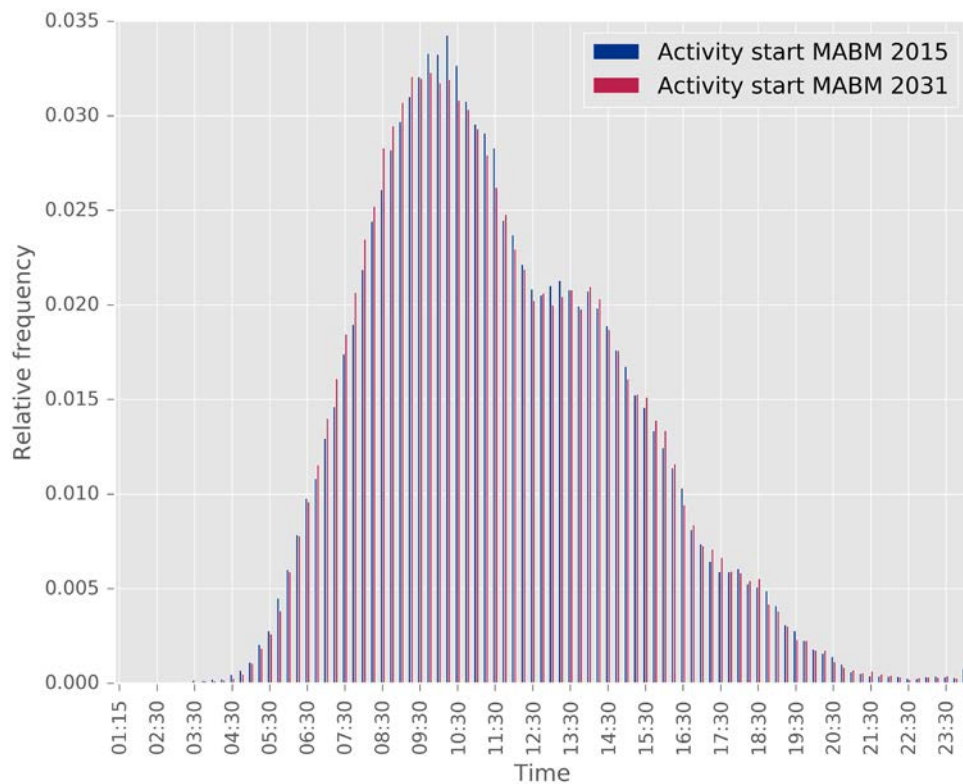
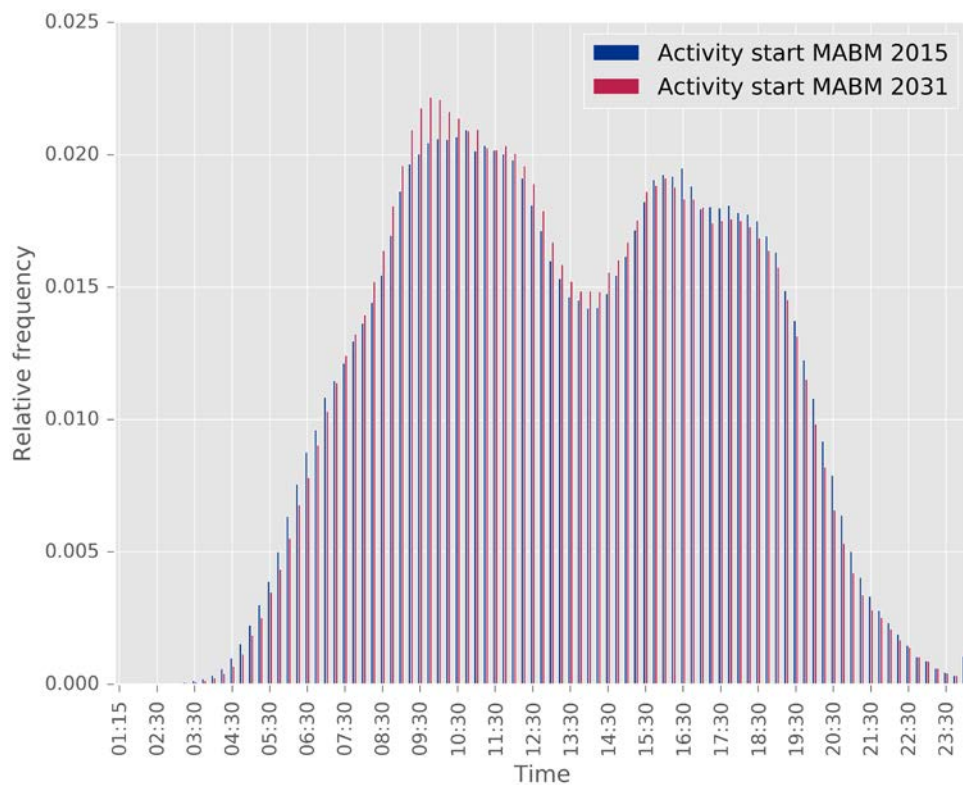


Figure 61: Activity start time - Other activities (shopping, leisure, social)



6.4.1.4 Activity durations

Figure 62 – Figure 65 show the distribution of activity start times in MABM 2015 and 2031. In all cases, the distribution is nearly identical in the two modelled years. This demonstrates that the 2031 MABM is performing as expected, given that activity patterns are generated in the same way for both model years.

Figure 62: Activity duration – Work

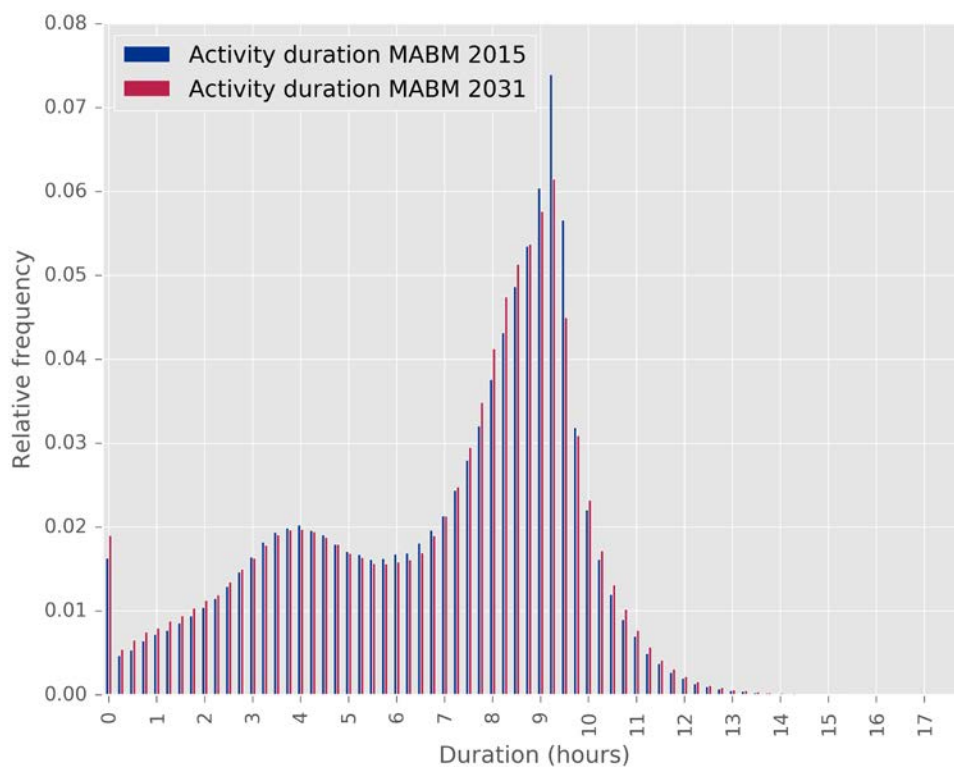


Figure 63: Activity duration - School

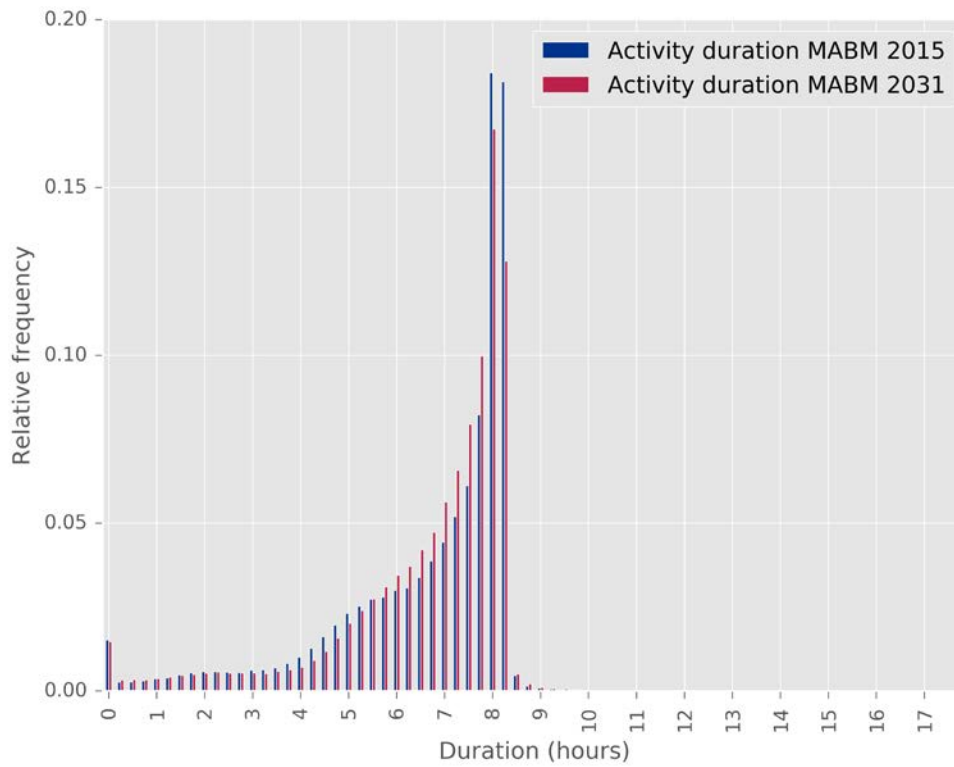


Figure 64: Activity duration - Business

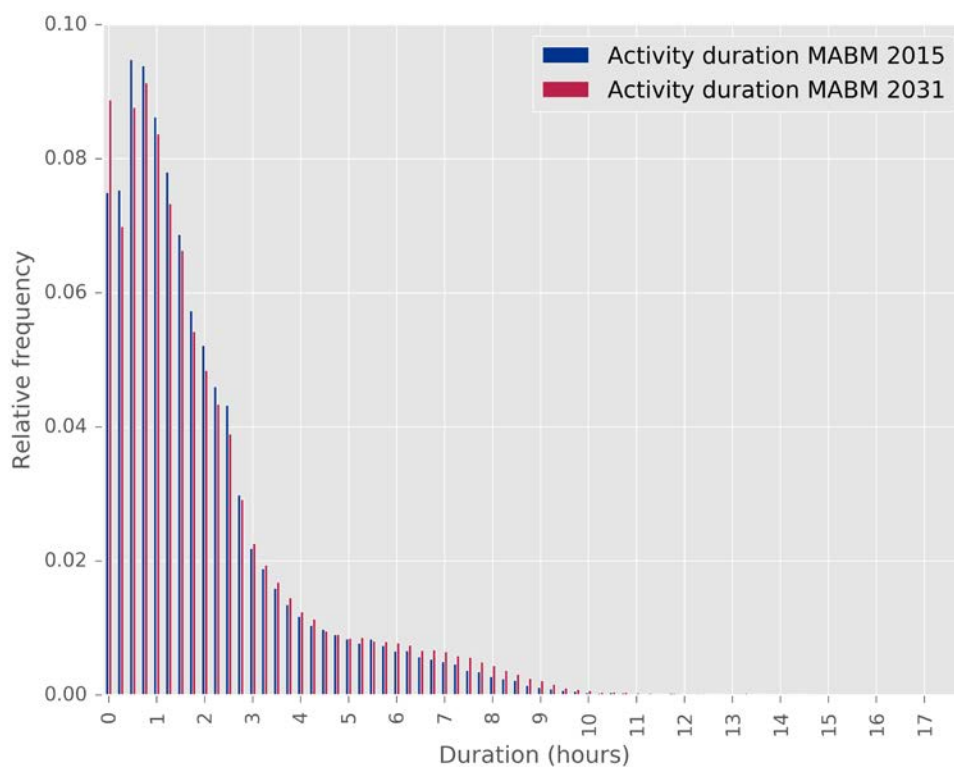
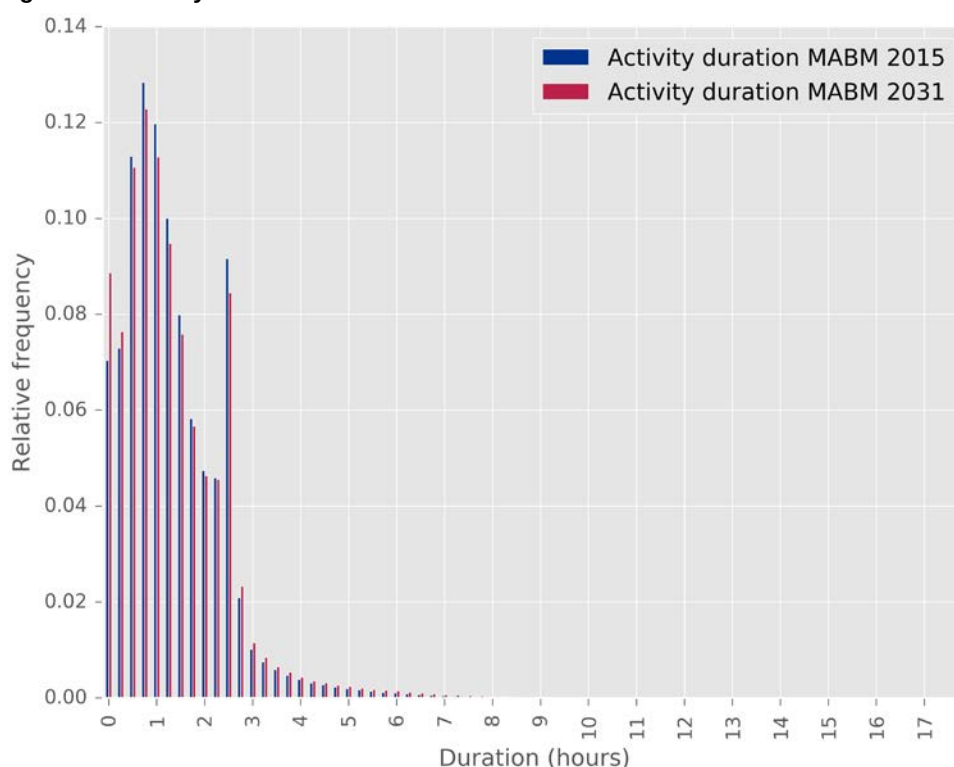


Figure 65: Activity duration - Other

6.4.1.5 Activity frequency

Activity frequency is the average number of occurrences of an activity per person. The frequency of activities in MABM is generated based on daily activity plans from VISTA.

The distribution of activity frequency in MABM 2031 is compared against 2015 for key activities in Table 24. With the exception of University/TAFE, the number of activity occurrences per person decreases slightly in 2031. The frequency of work decreases the most of any activity (-6%). These small shifts are the result of demographic changes between the modelled years; for example an ageing population is expected to cause the frequency of work trips to decline as the proportion of retirees in the population increases.

Table 24: Activity occurrences per person

Activity type	MABM 2015	MABM 2031	% Change
Work	0.39	0.37	-6%
Business	0.08	0.08	-1%
School	0.13	0.13	-4%
University/TAFE	0.02	0.02	1%
School pickup/ drop-off	0.14	0.14	-2%
Other	0.86	0.85	-1%

6.4.1.6 Travel distance to activity location

As in the 2015 model, travel distance between most activities in MABM are assigned to agents based on survey responses from VISTA. Each trip in VISTA has a corresponding travel distance,

which is used in MABM to assign locations to all activities with the exception of Home and Work. Trips between home and work are based on the gravity model described in Section 6.3, which replaces the Census data used in the 2015 model.

Figure 66 - Figure 70 show the distribution of activity start times in MABM 2015 and 2031. For all cases except Home – Work trips, the distance distribution is virtually identical in 2015 and 2031. The distribution for work trips produced using the gravity model tends to understate the prevalence of commuting trips shorter than 10km and overstates the prevalence of trips longer than 10km as previously described.

Figure 66: Distance distribution – All activity types

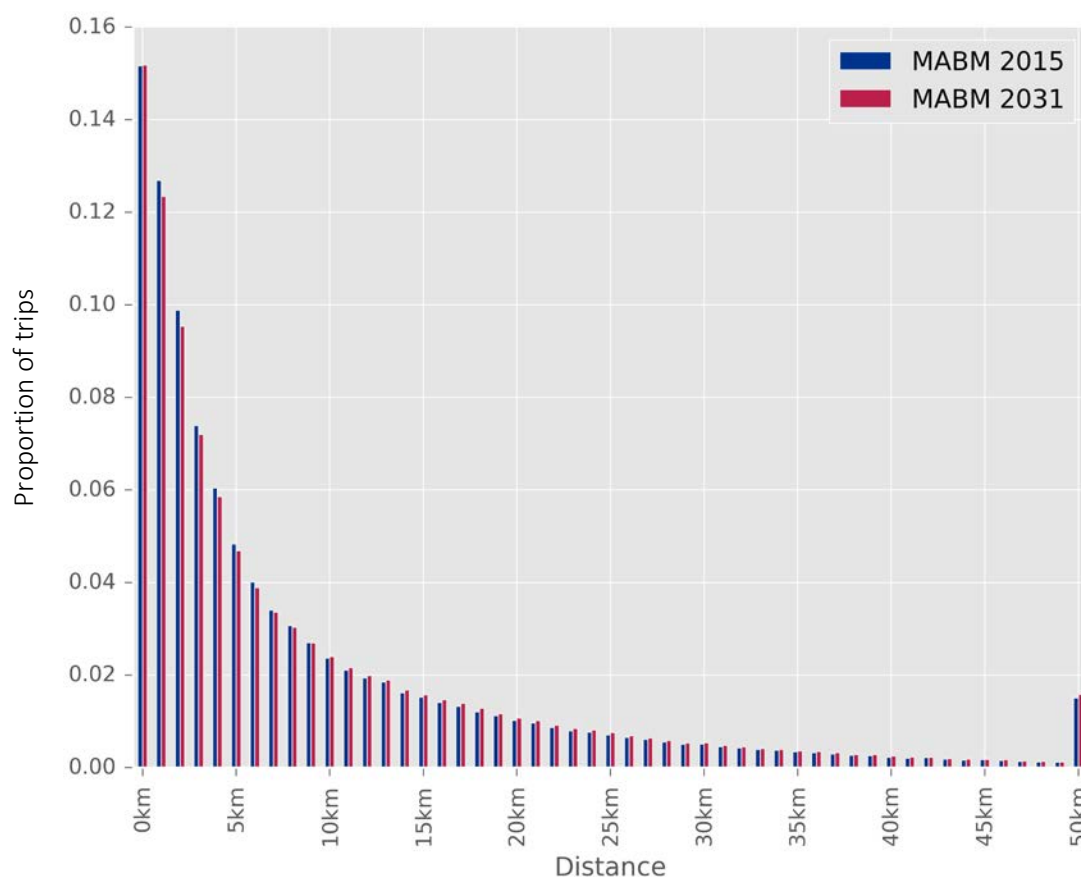


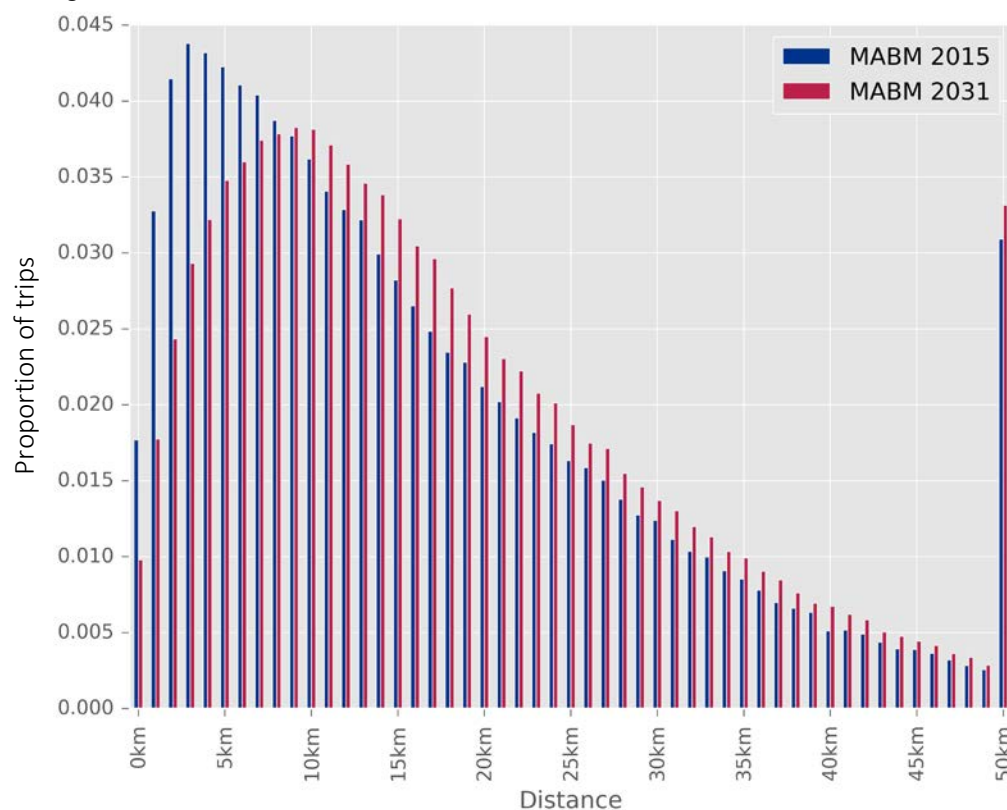
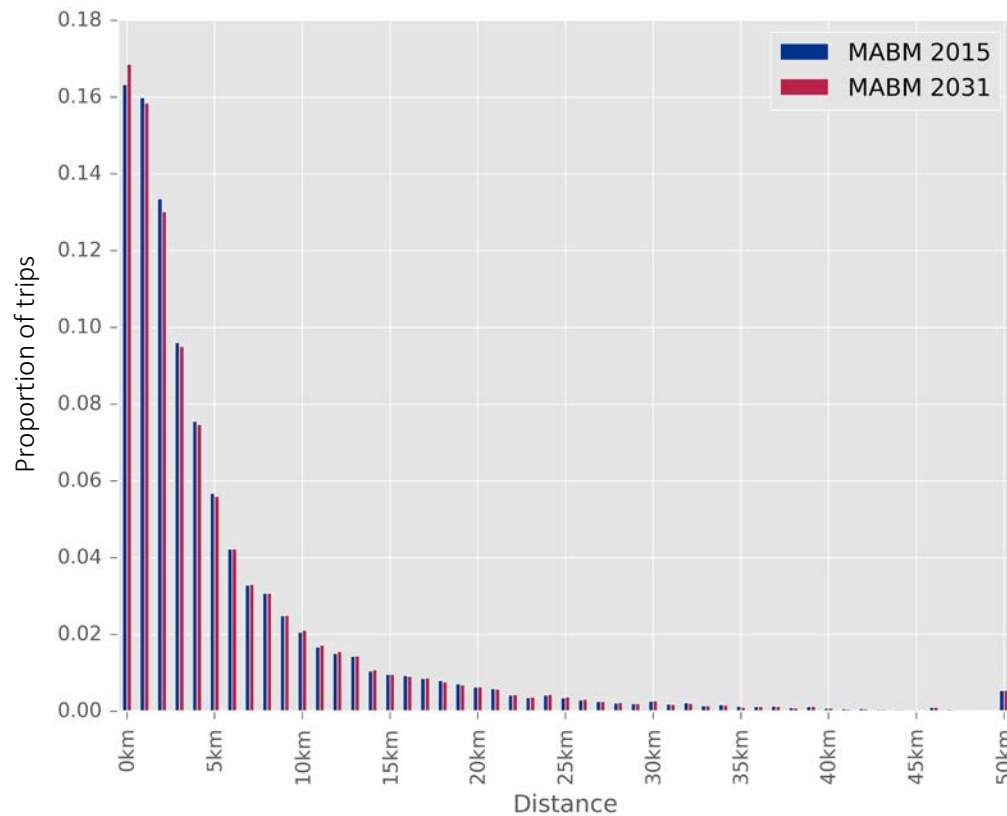
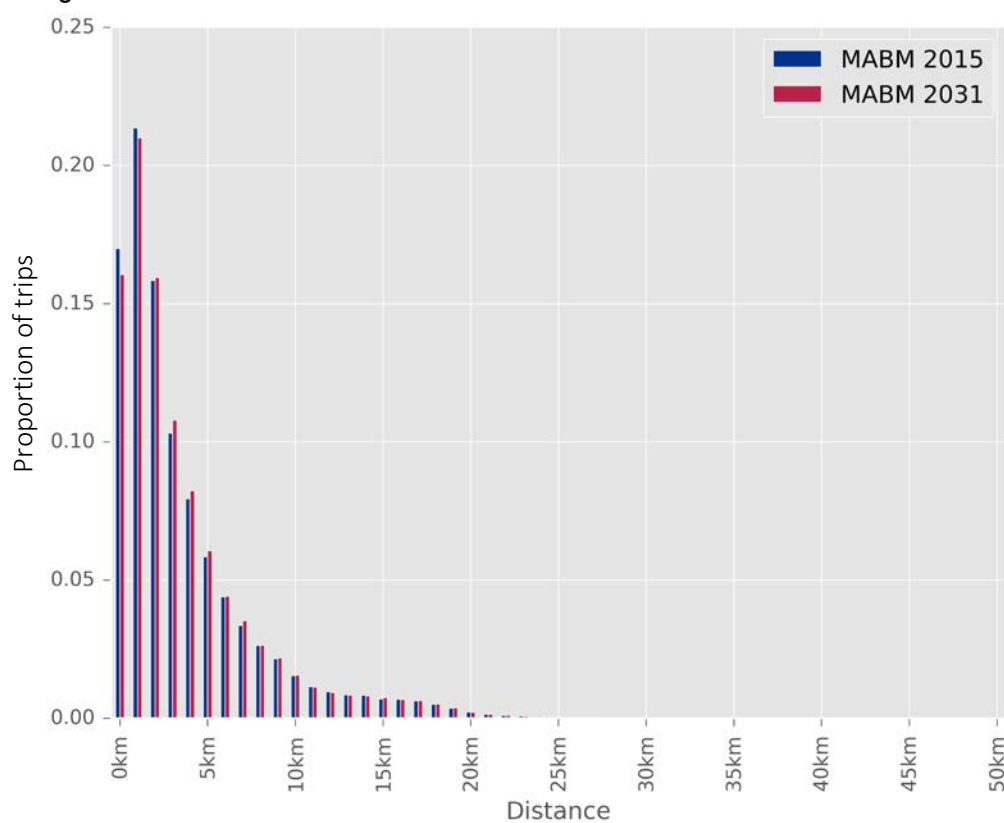
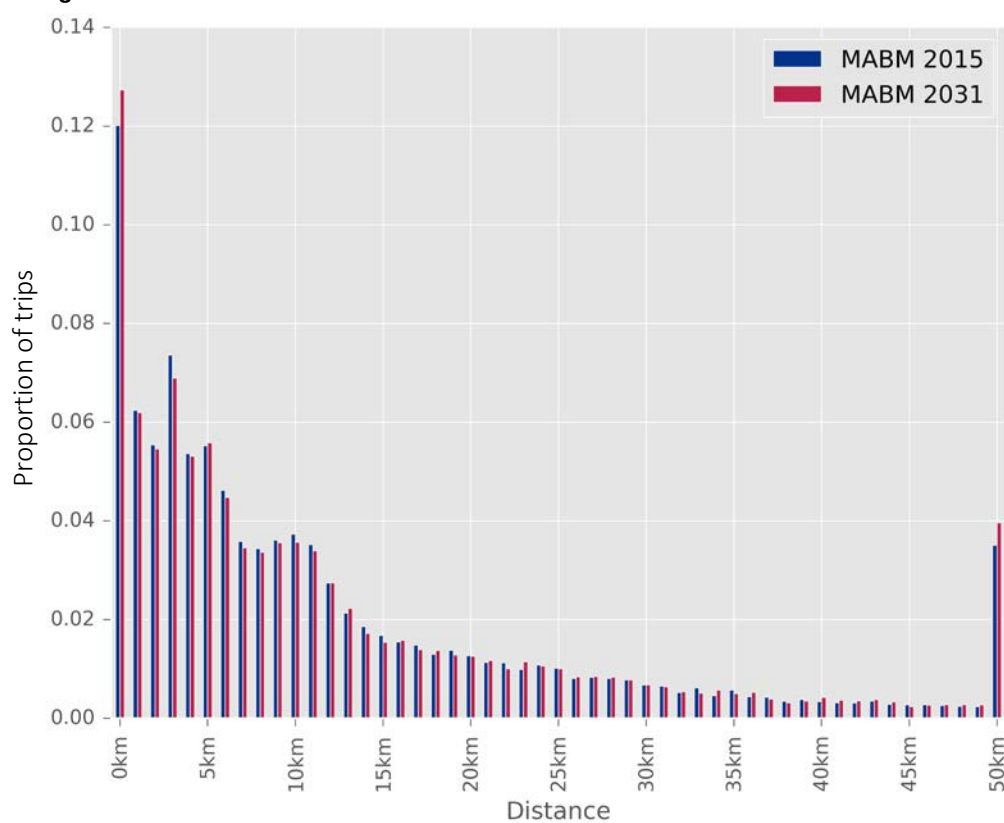
Figure 67: Distance distribution – Home to Work**Figure 68: Distance distribution – Home to Other (shopping, leisure, social)**

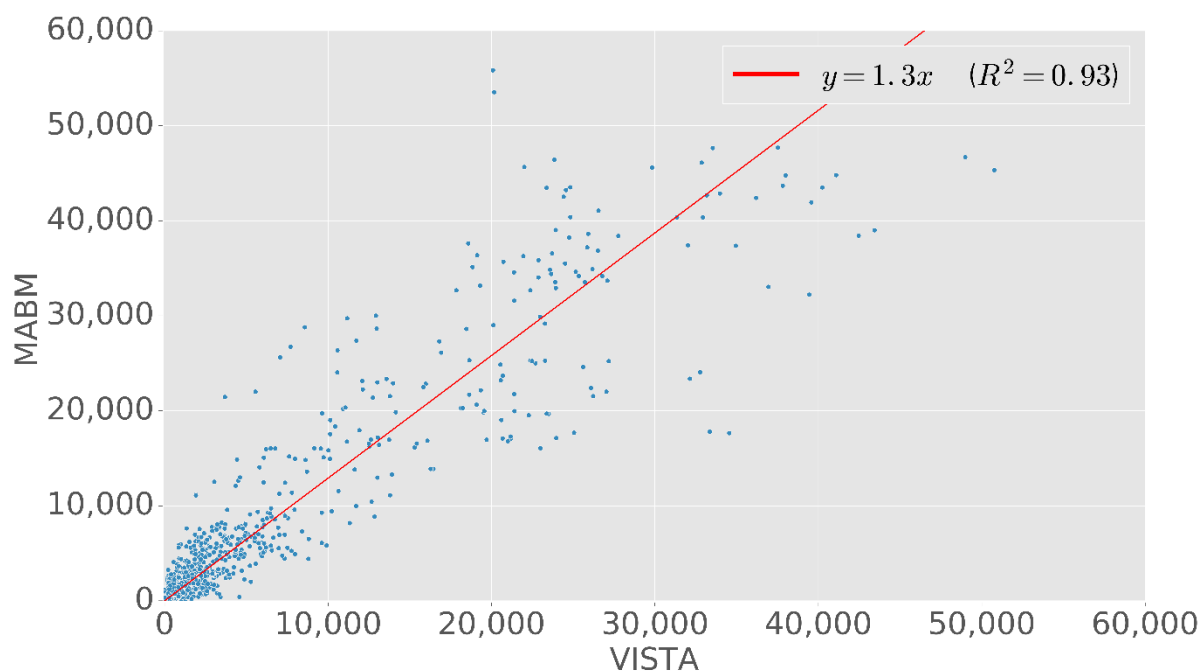
Figure 69: Distance distribution – Home to School**Figure 70: Distance distribution – Work to Business**

6.4.1.7 Travel demand patterns

To assess travel demand patterns, the 2031 MABM is compared to VISTA as for 2015. Because activity patterns in both model years are derived from VISTA, it is expected that travel demand patterns at an LGA level will be similar but with a generally higher level of demand in 2031.

Figure 71 shows the 2031 MABM modelled trips plotted against the weighted VISTA values. The scatter plot demonstrates a close linear correlation between 2031 MABM and VISTA. The linear regression coefficient of 1.3 indicates that on average the 2031 model predicts about 30% more trips for a given origin-destination pair than the 2012-14 VISTA sample.

Figure 71: MABM 2031 - Travel demand for LGA pairs compared to VISTA (2012-14)



Travel demand patterns for LGAs that contain National Employment and Innovation Clusters (NEIC) are presented in Figure 72 – Figure 78 below. For each selected LGA, the travel demand in 2031 MABM from each origin LGA is compared to 2015 MABM. In general, the pattern for LGAs is consistent between the two modelled years with higher demand in 2031.

Figure 72: Travel demand to Melbourne (C) by LGA

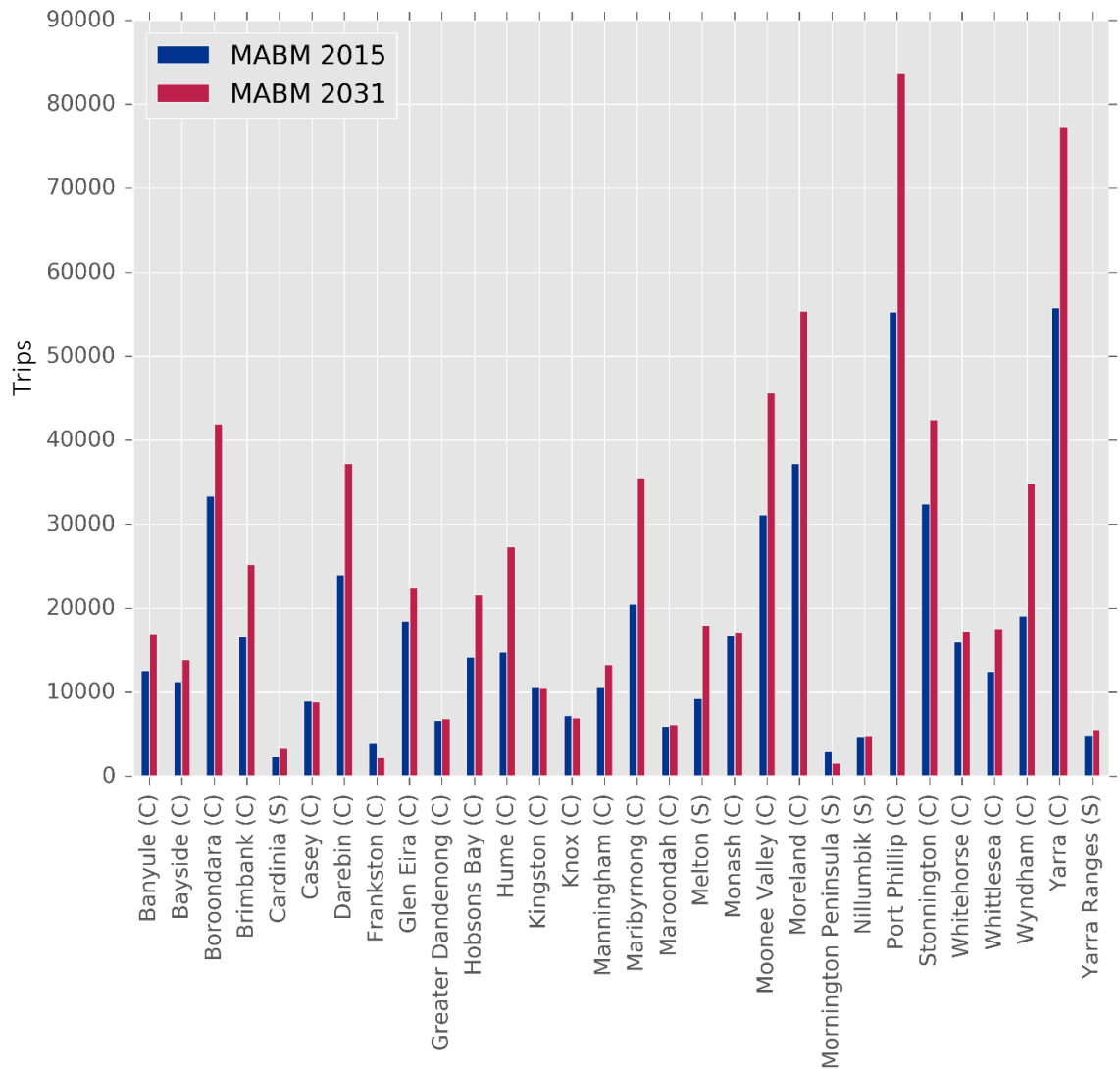


Figure 73: Travel demand to Monash (C) by LGA

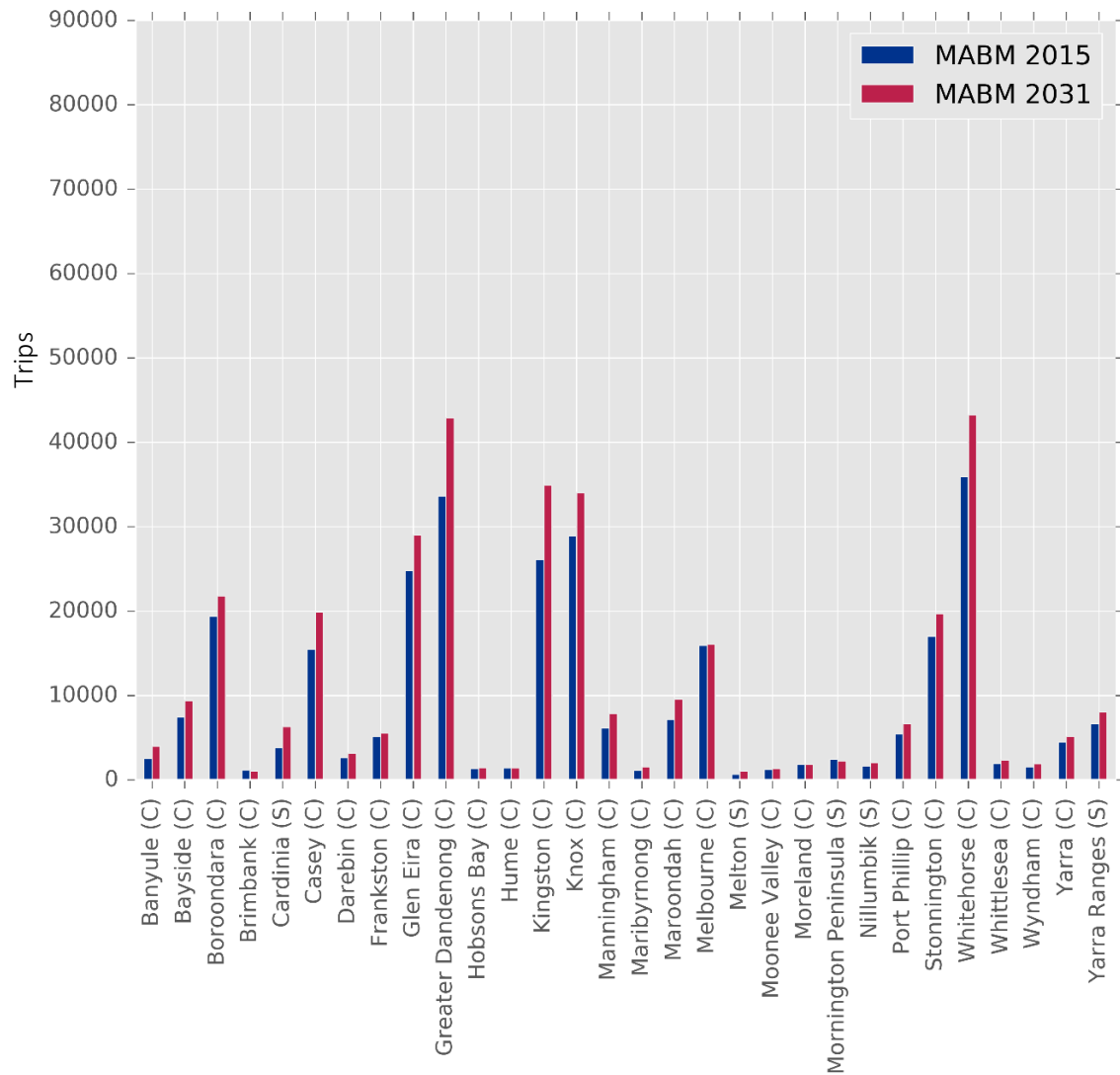


Figure 74: Travel demand to Port Phillip (C) by LGA

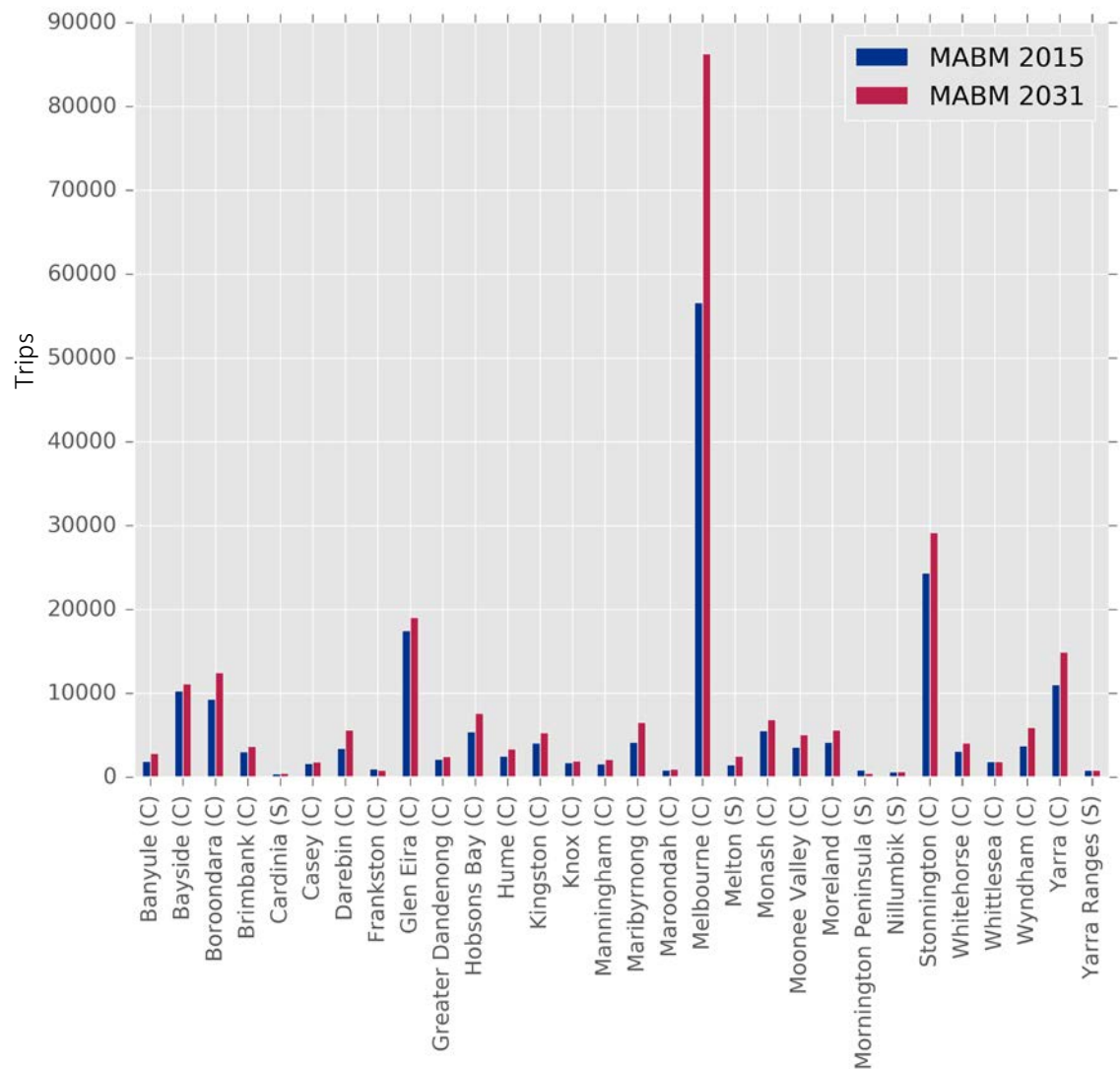


Figure 75: Travel demand to Greater Dandenong (C) by LGA

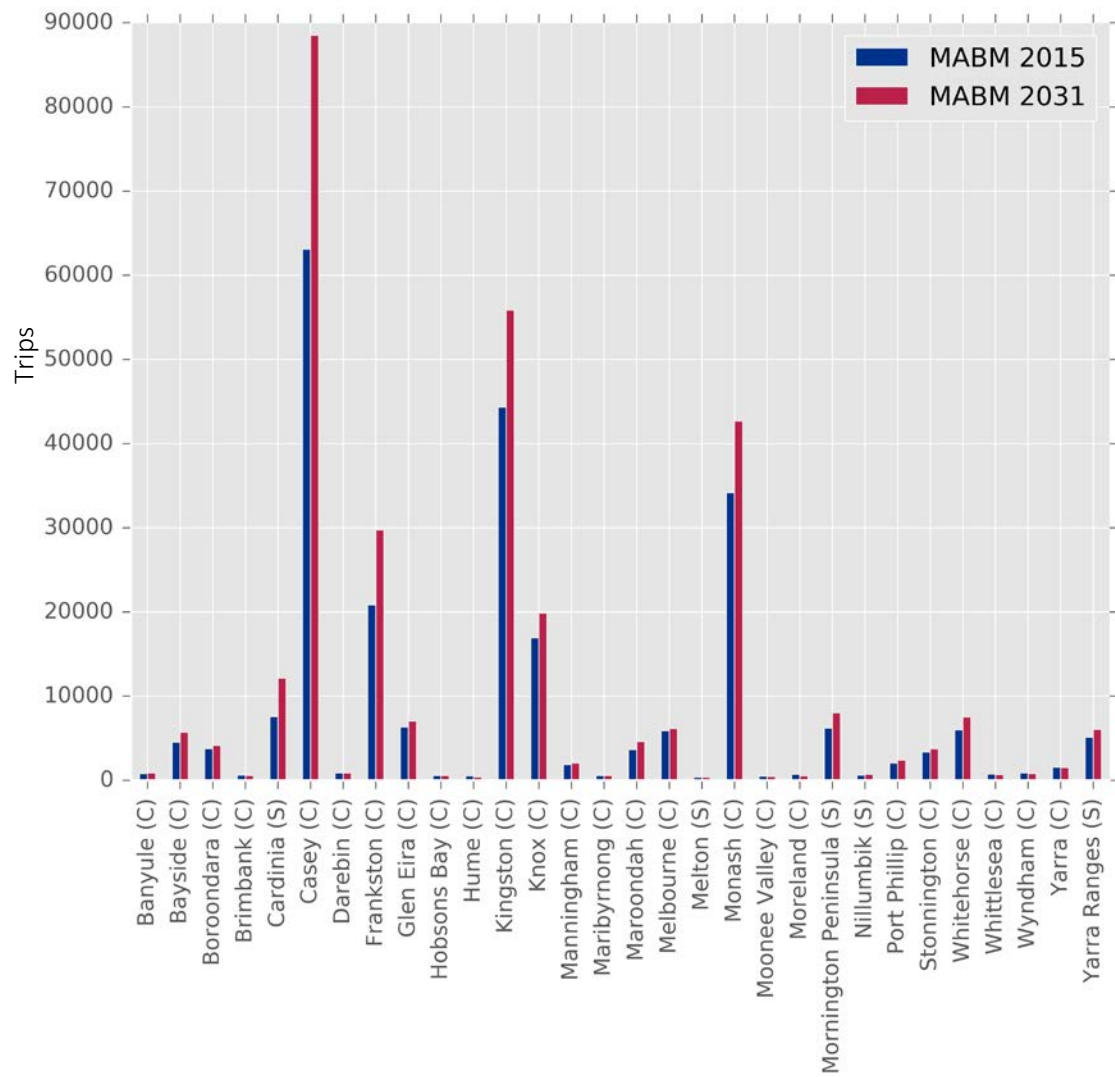


Figure 76: Travel demand to Darebin (C) by LGA

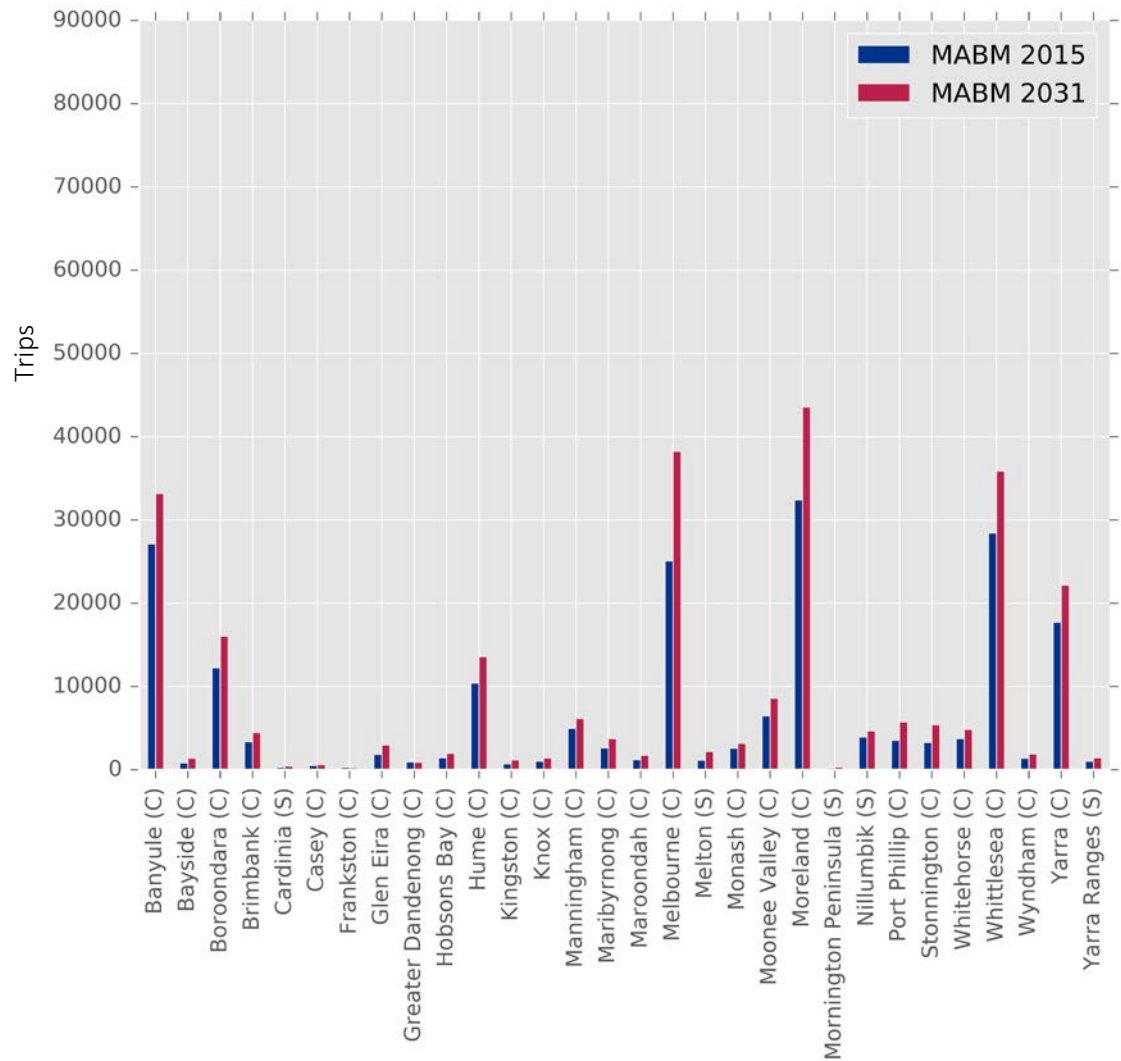


Figure 77: Travel demand to Brimbank (C) by LGA

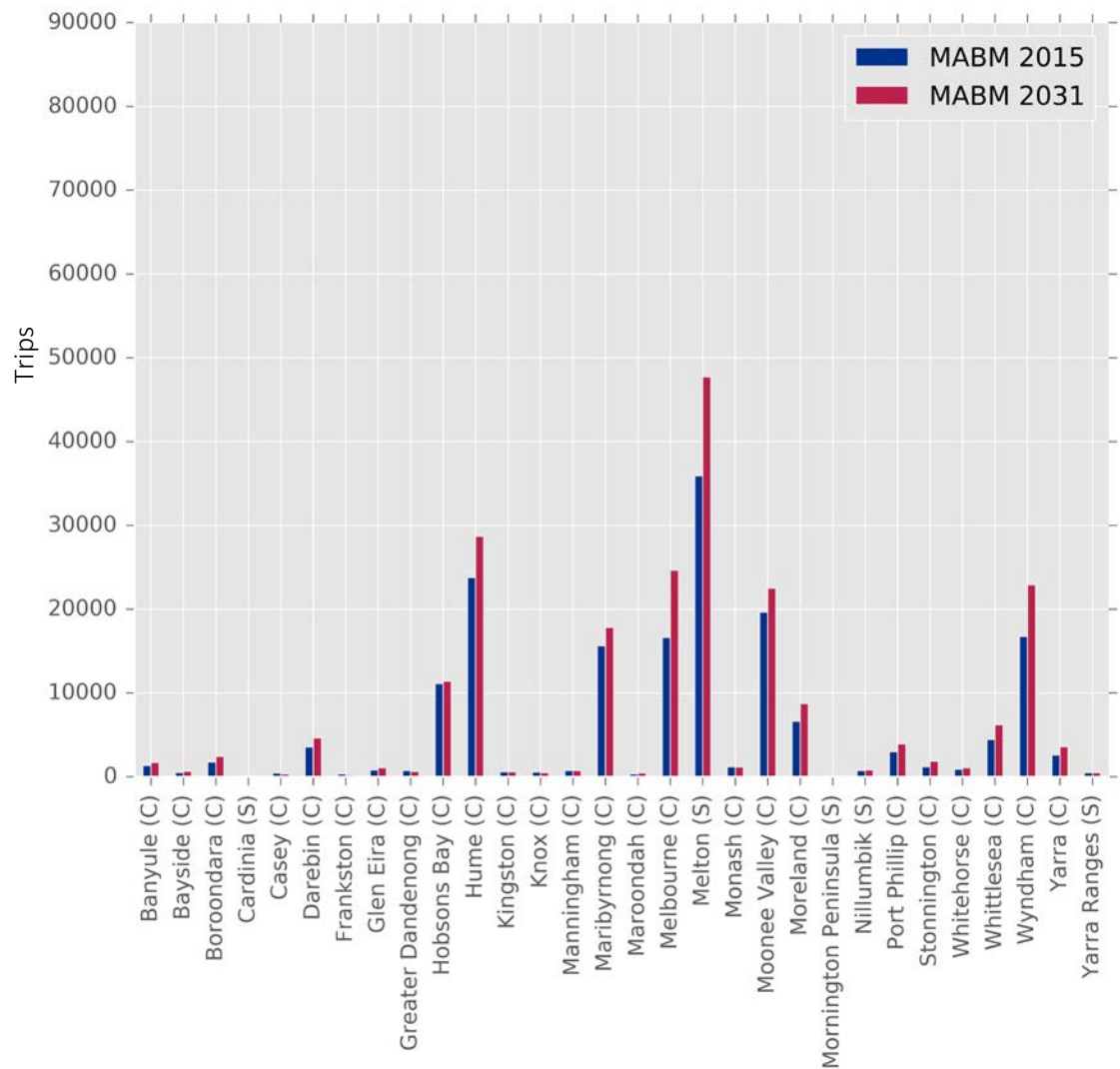
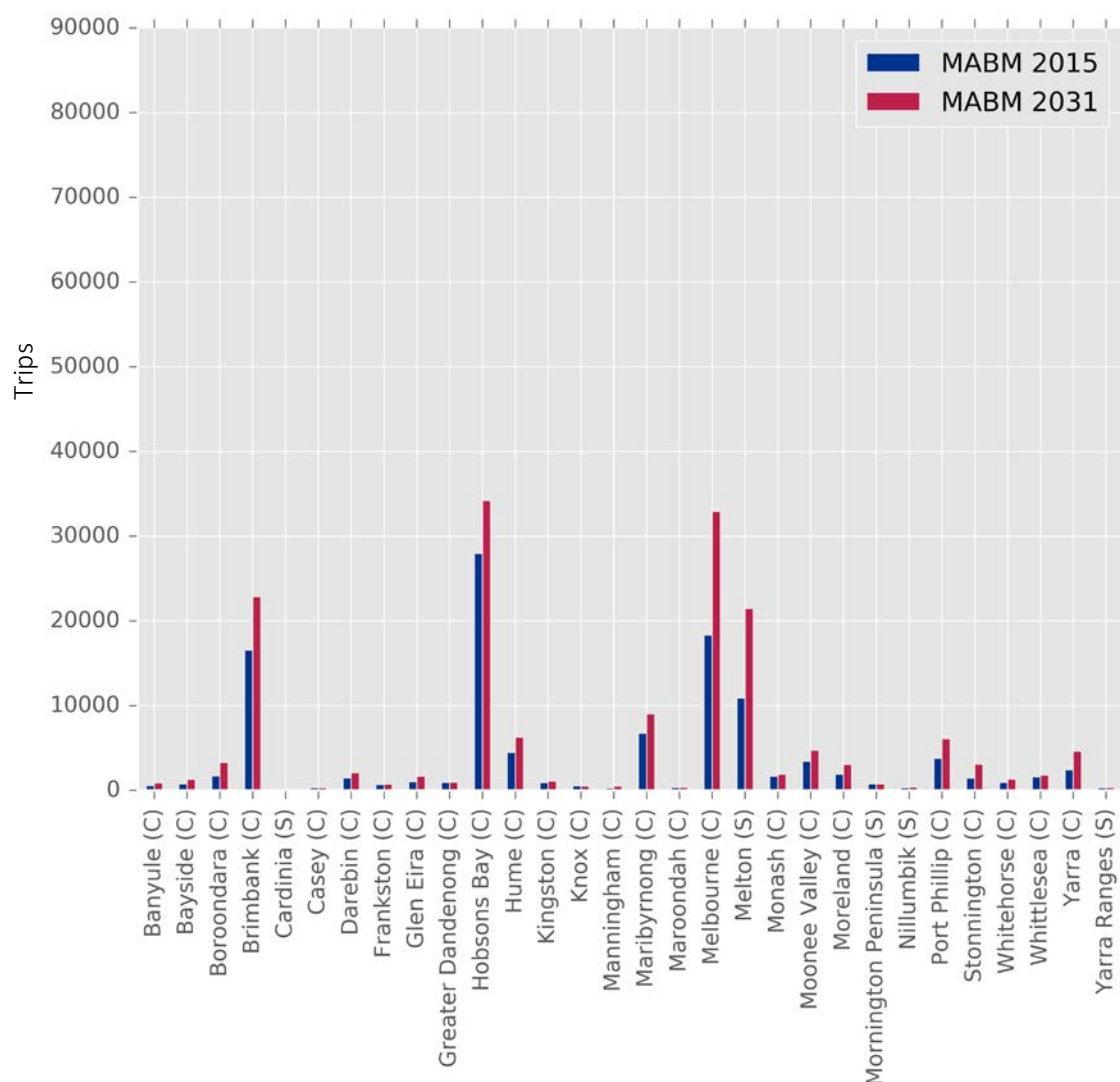


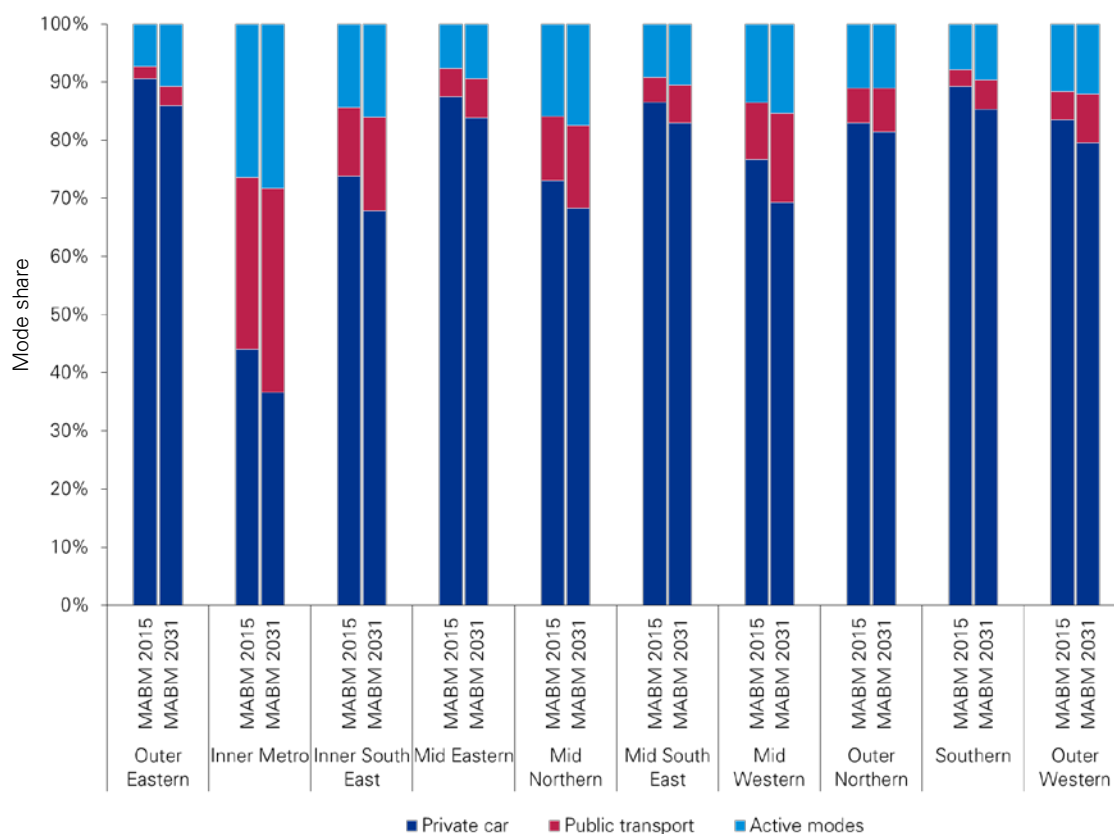
Figure 78: Travel demand to Wyndham (C) by LGA



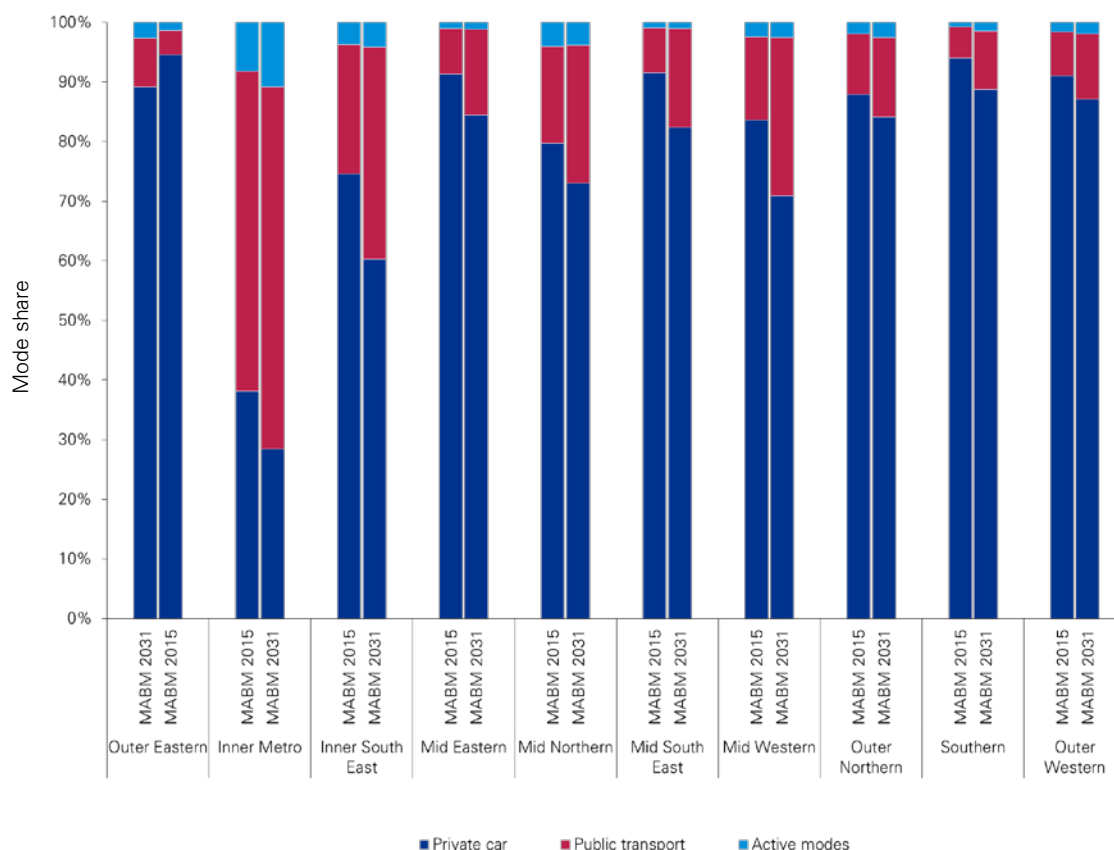
6.4.2 Mode Share

Mode share in the 2031 MABM is compared by region against the 2015 values. Figure 79 shows how the overall proportion of public transport trips increases in all regions. As shown in Table 25, the inner metro experiences the largest swing toward public transport of any region, with a 17% reduction in car mode share in the 2031 MABM.

Figure 80 and Table 26 show the change in mode share for commuters by workplace region. Again the inner metro experiences the largest proportional reduction in car mode share in 2031.

Figure 79: Mode share - all trip purposes by origin**Table 25: Car mode share (driver and passenger) in MABM 2015 and 2031**

Region	MABM 2015	MABM 2031	% Change
Outer Eastern	90%	85%	-5%
Inner Metro	44%	36%	-17%
Inner South East	73%	67%	-8%
Mid Eastern	87%	83%	-4%
Mid Northern	72%	67%	-7%
Mid South East	86%	82%	-4%
Mid Western	76%	69%	-10%
Outer Northern	82%	80%	-2%
Southern	88%	84%	-4%
Outer Western	83%	79%	-5%

Figure 80: Work mode share by destination, MABM 2031 vs 2015**Table 26: Car mode share for work trips by destination, MABM 2031 vs MABM 2015**

Region	MABM 2015	MABM 2031	% Change
Outer Eastern	95%	89%	-5%
Inner Metro	38%	29%	-23%
Inner South East	74%	61%	-18%
Mid Eastern	91%	85%	-7%
Mid Northern	80%	74%	-7%
Mid South East	91%	83%	-10%
Mid Western	84%	71%	-14%
Outer Northern	88%	85%	-3%
Southern	94%	89%	-5%
Outer Western	91%	88%	-4%

6.4.3 Highway

6.4.3.1 Screenline volumes

A key benefit of the MABM's 24 hour continuous simulation is the ability to replicate the profile of traffic volumes across the whole day. Figure 81 to Figure 86 show a comparison of screenline volumes across the day in MABM 2015 and MABM 2031. The screenline numbers correspond to the locations indicated in Section 5.4.1. The traffic patterns in 2031 mimic the patterns in 2015 but with generally higher demand throughout the day.

Note that the profiles presented only account for roads which exist in both the 2015 and 2031 networks. This means that the 2031 volumes are likely to be understated as they don't include traffic on new infrastructure. Despite this limitation, the profiles demonstrate that the patterns of demand in 2031 MABM closely align with the 2015 model.

Figure 81: Screenline 901, inbound, number of vehicles by time of day

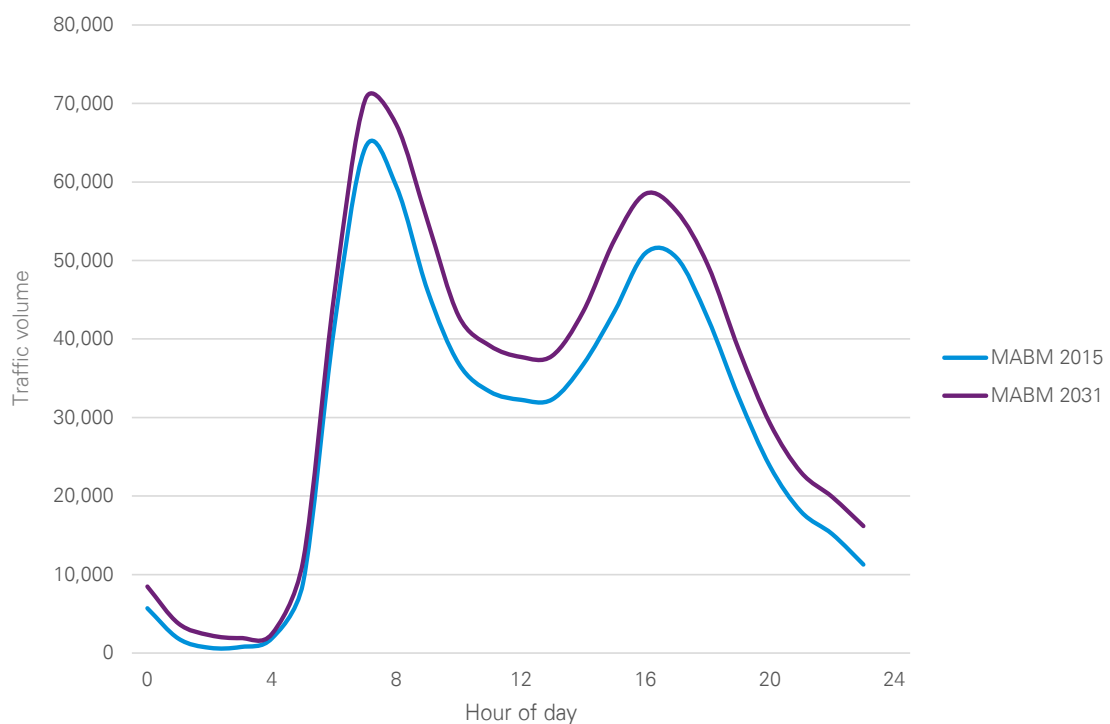


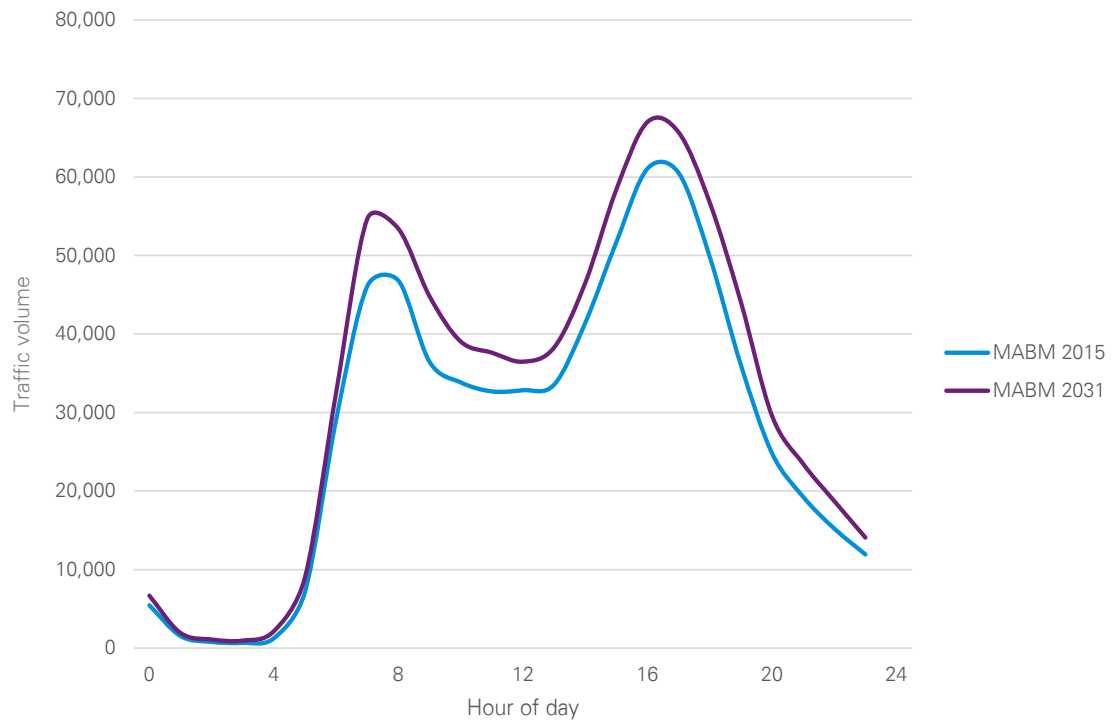
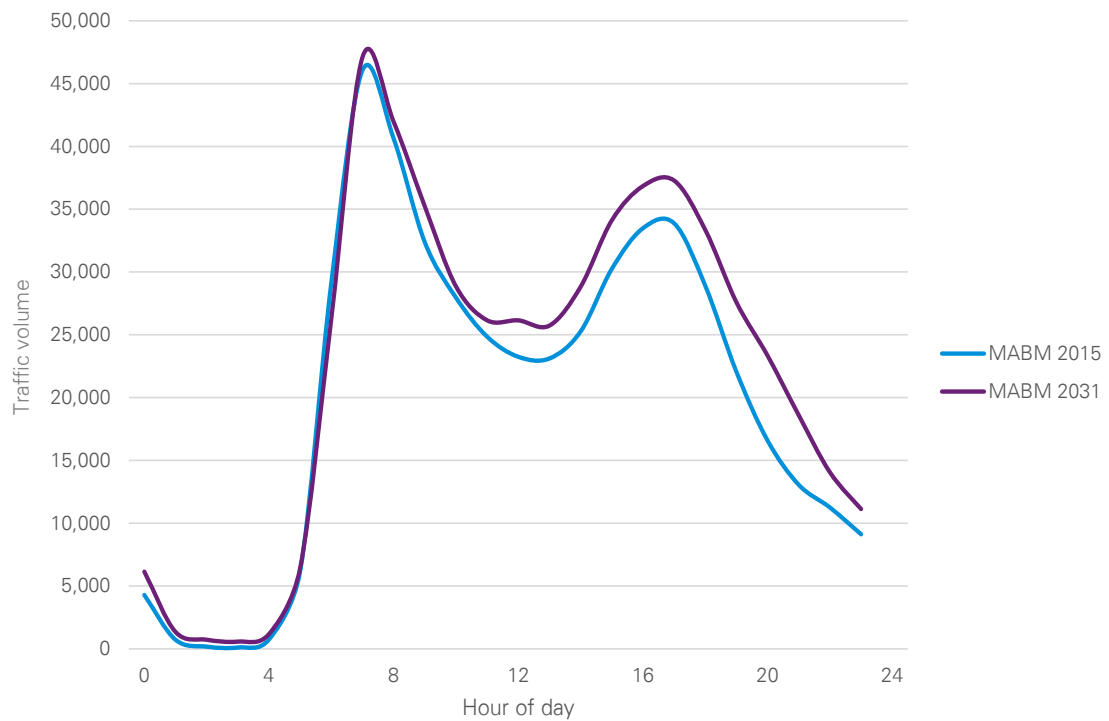
Figure 82: Screenline 901, outbound, number of vehicles by time of day**Figure 83: Screenline 902, inbound, number of vehicles by time of day**

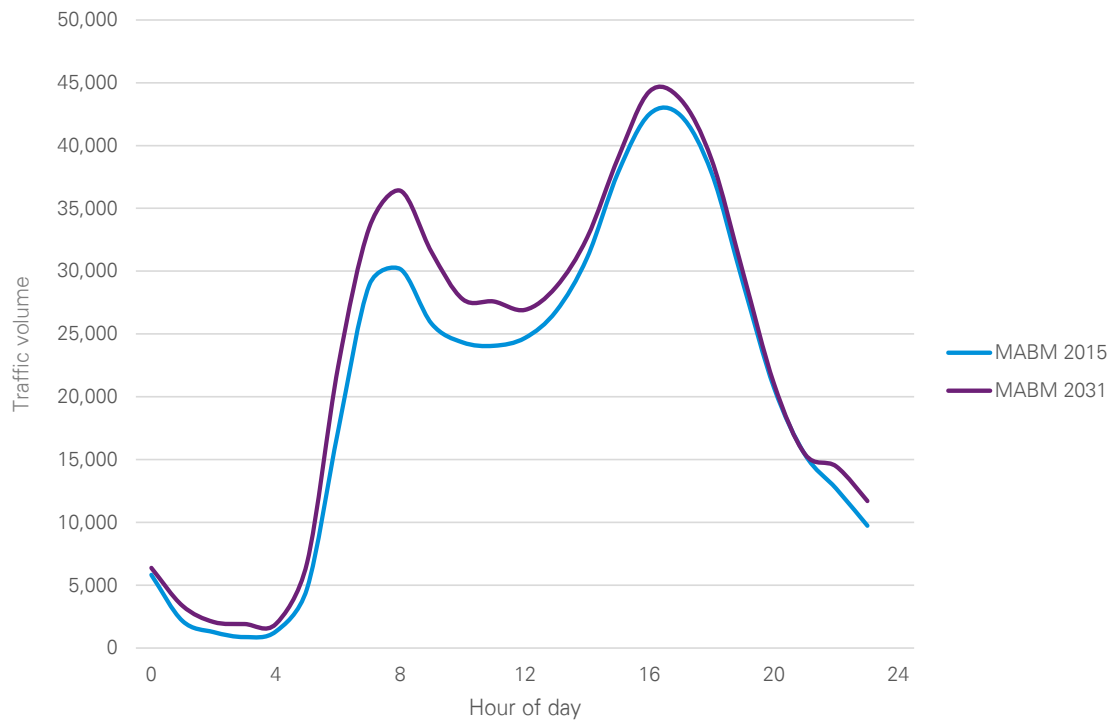
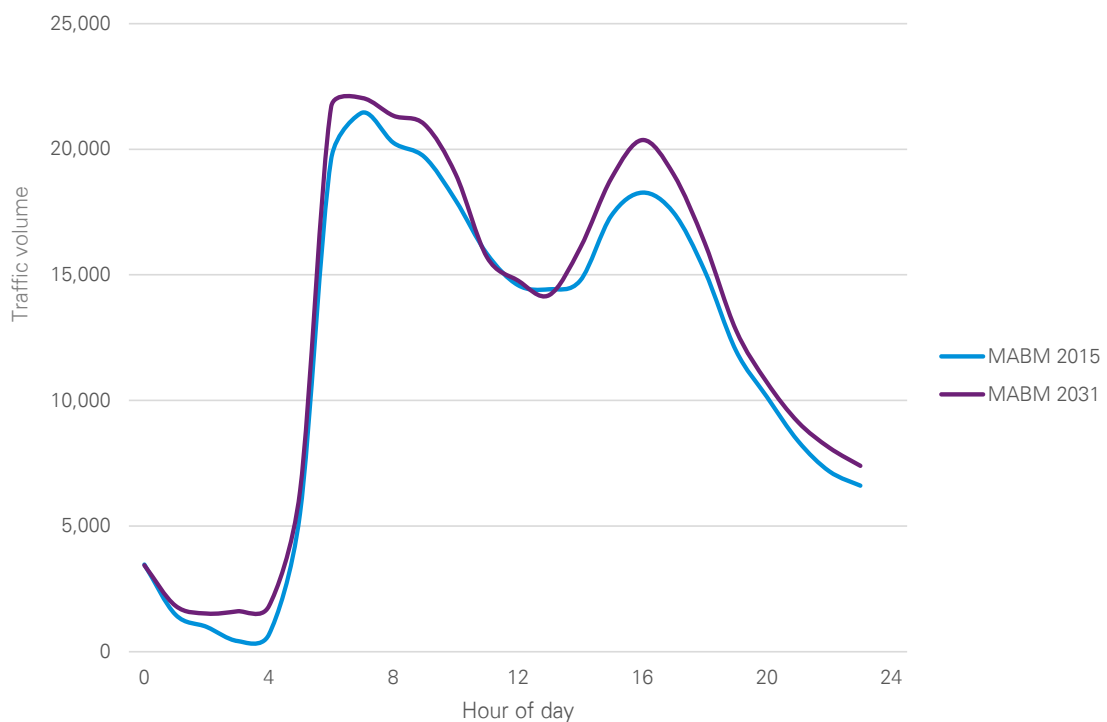
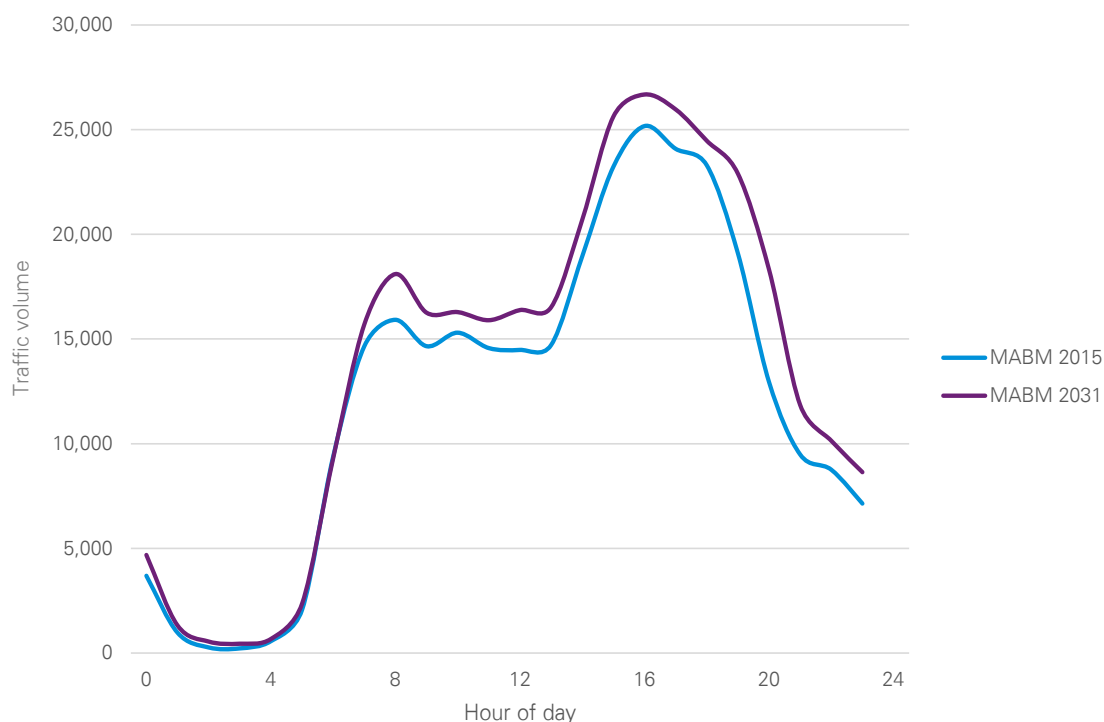
Figure 84: Screenline 902, outbound, number of vehicles by time of day**Figure 85: Screenline 908, inbound, number of vehicles by time of day**

Figure 86: Screenline 908, outbound, number of vehicles by time of day



6.4.3.2 Toll roads

Time of day profiles for the selected toll road count stations are shown comparing MABM 2031 to MABM 2015 in Figure 87 to Figure 94. The toll road count data was reproduced for MABM 2031 using the same locations displayed in Section 5.4.2. Note that the volumes and locations are de-identified due to the confidential nature of the data.

The demand patterns in 2031 generally mimic those of 2015 for most locations. Only toll roads that exist in 2015 are profiled which means users of new tolled infrastructure are not represented below. Where new infrastructure draws demand away from existing infrastructure, the traffic volumes on the profiled toll roads may grow more slowly, or not at all, despite an overall growth in road demand.

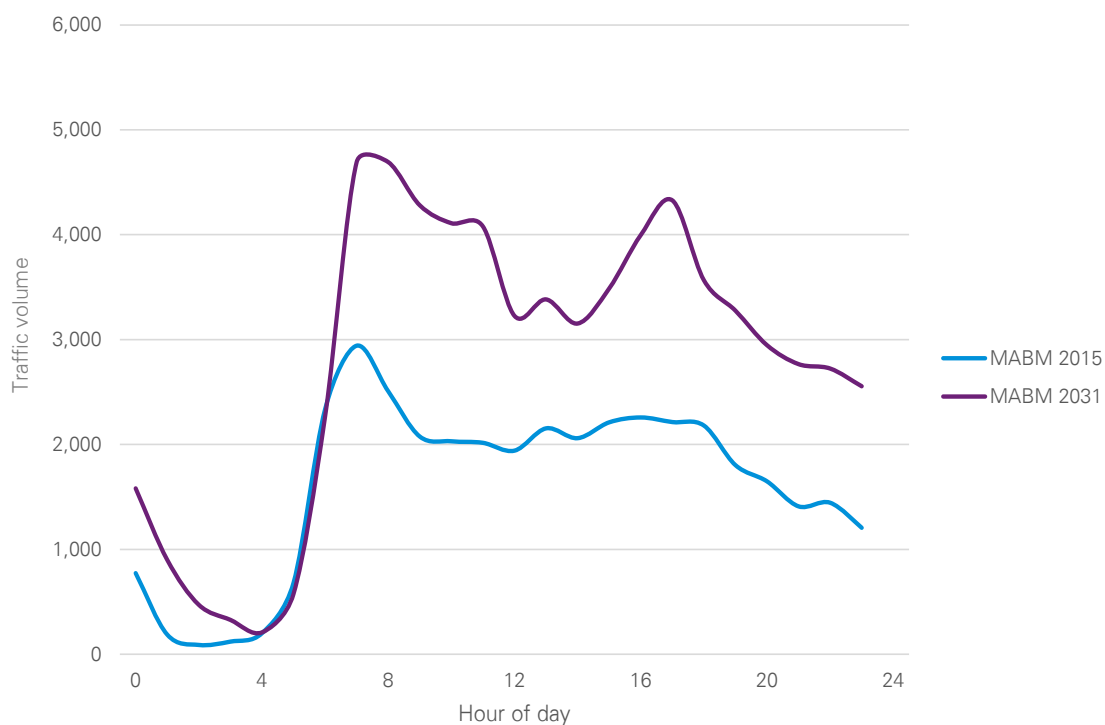
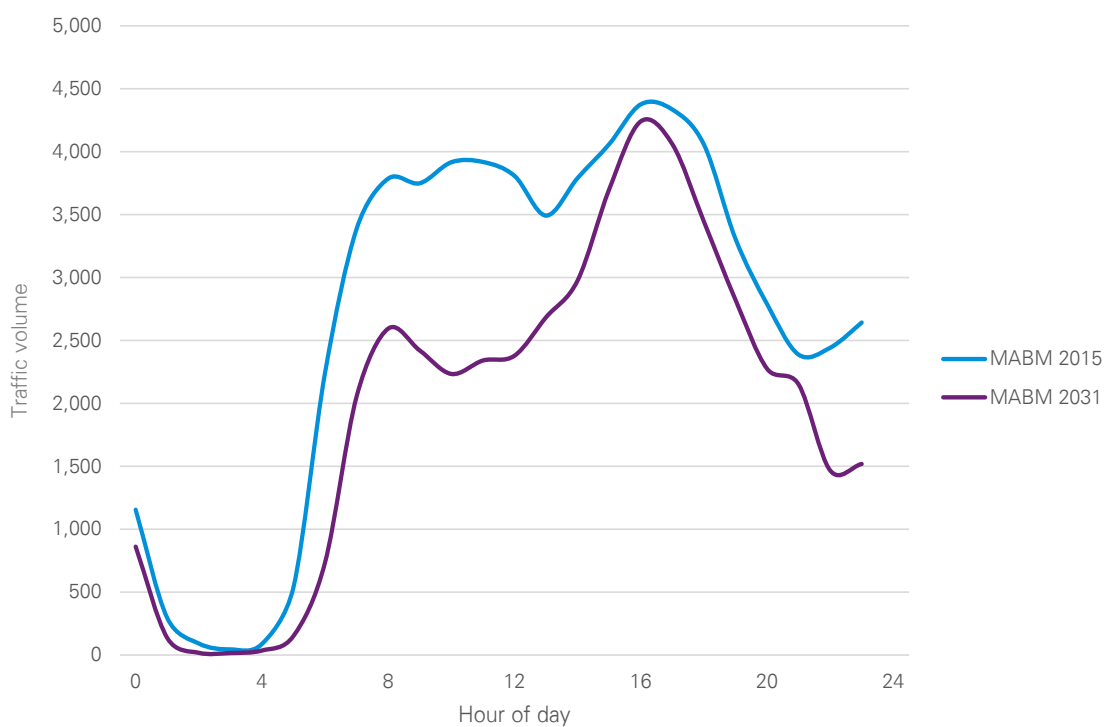
Figure 87: Toll road count location A, direction 1**Figure 88: Toll road count location A, direction 2**

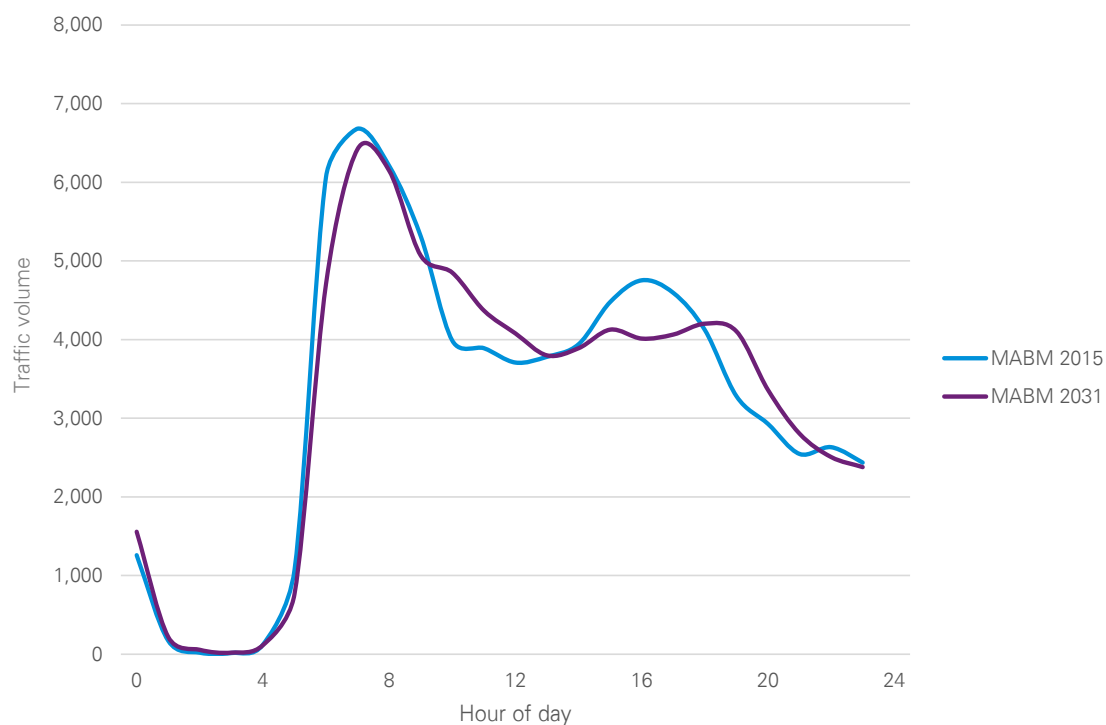
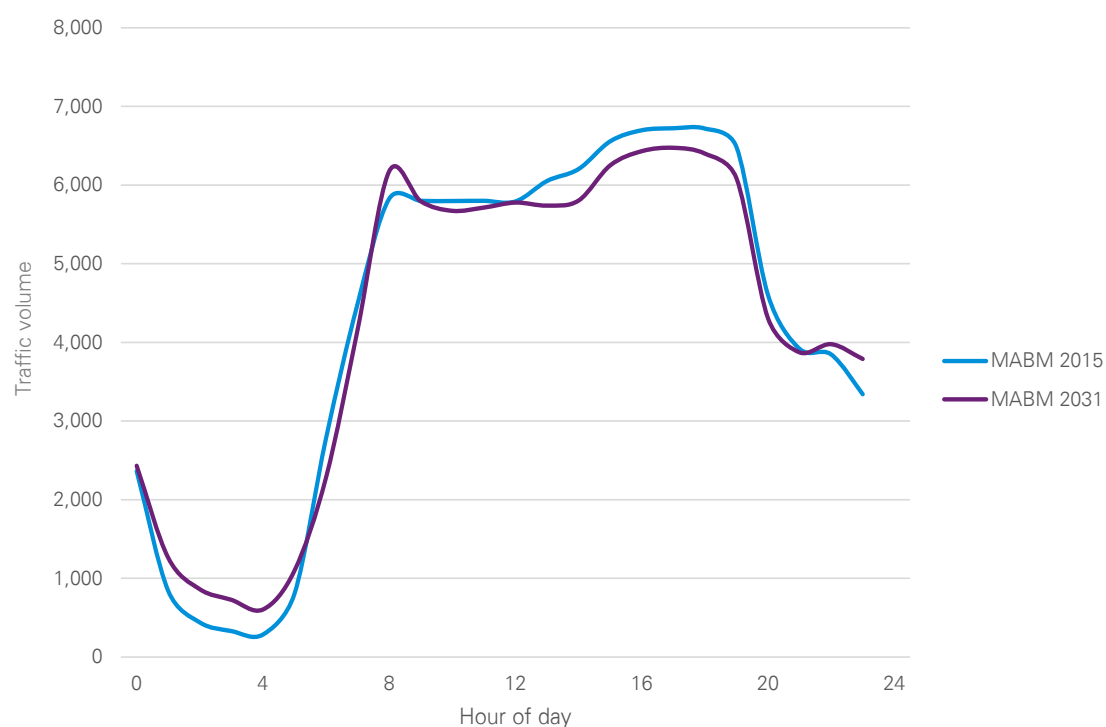
Figure 89: Toll road count location B, direction 1**Figure 90: Toll road count location B, direction 2**

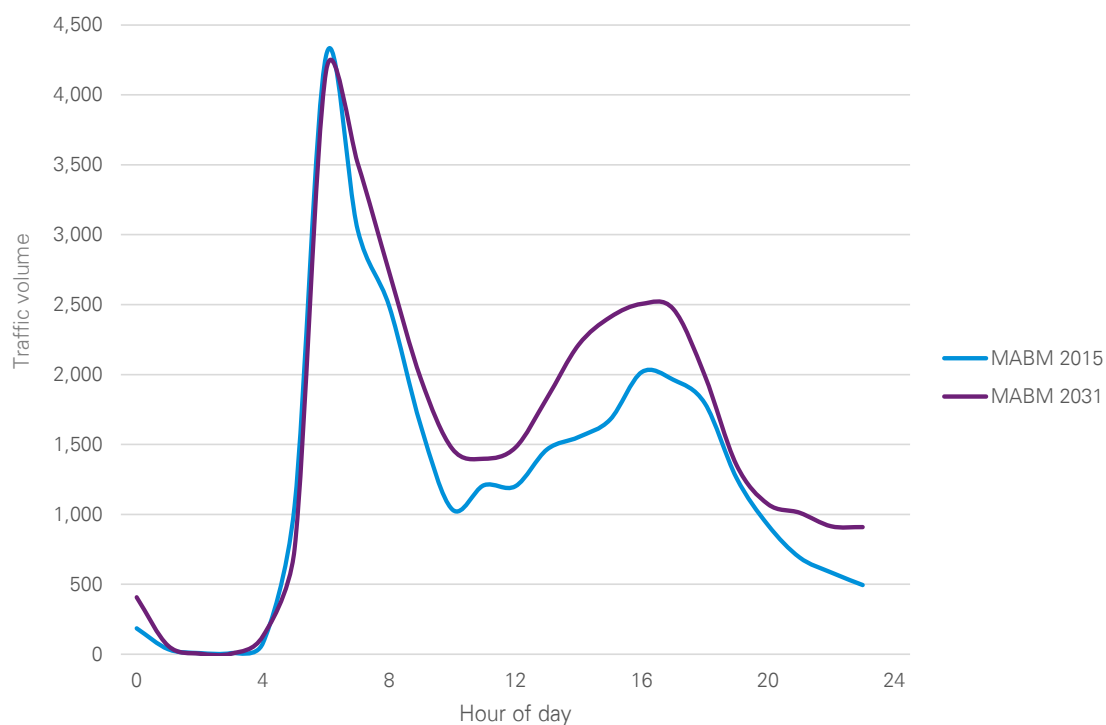
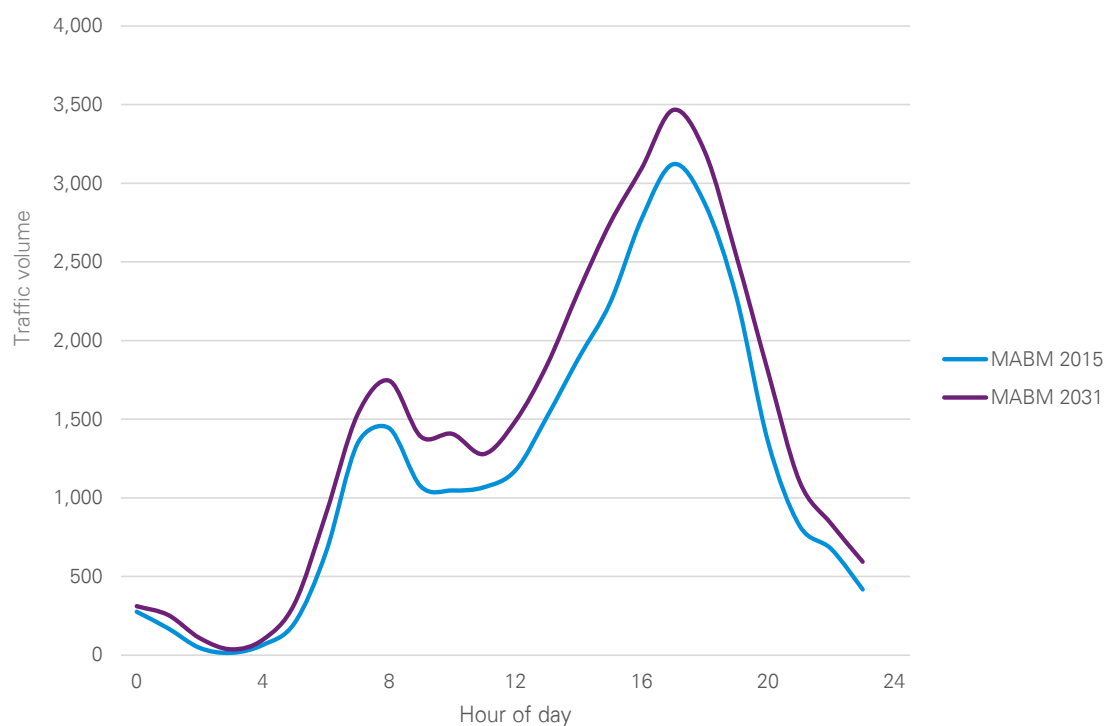
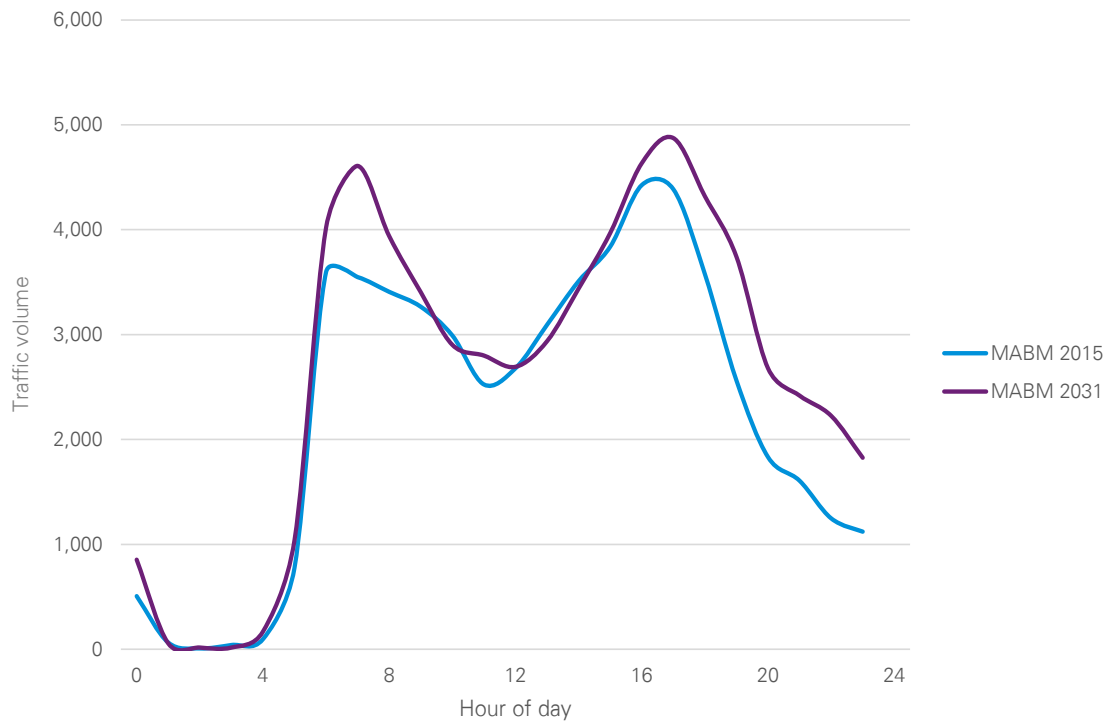
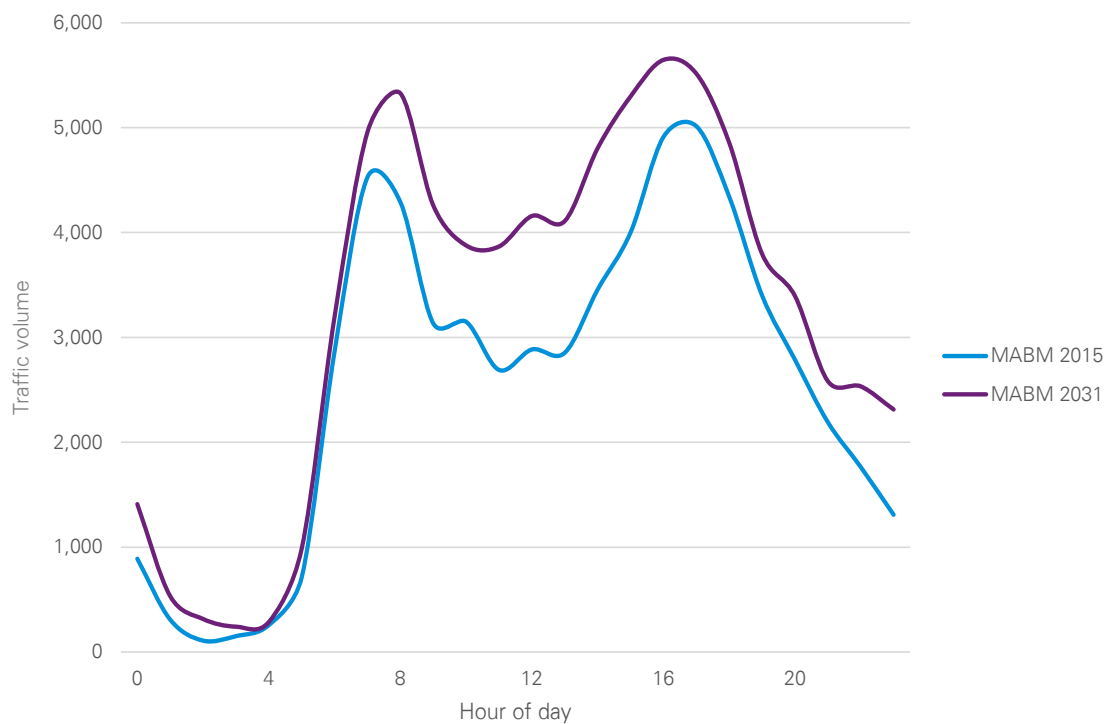
Figure 91: Toll road count location C, direction 1**Figure 92: Toll road count location C, direction 2**

Figure 93: Toll road count location D, direction 1**Figure 94: Toll road count location D, direction 2**

6.4.4 Public Transport

6.4.4.1 Train station entries & CBD cordon loads

Table 27 – Table 30 show the change in train patronage in the 2015 and 2031 models. Train cordon loads and boardings are projected to grow faster than population growth of 1.8% average annual growth rate. Caulfield group is expected to experience a marginal decline with commencement of Melbourne Metro which takes some load off the Caulfield and Northern rail groups.

Table 27: Modelled cordon loads AM Inbound, MABM 2015 and 2031

AM Inbound	MABM 2015	MABM 2031	CAGR
Northern	41,384	55,512	1.9%
Clifton Hill	23,452	41,612	3.6%
Burnley	32,856	37,404	0.8%
Caulfield	43,136	38,980	-0.6%
Melbourne Metro (Domain)		19,324	
Melbourne Metro (Arden)		27,032	
Total	140,828	219,864	2.8%

Table 28: Modelled cordon loads PM Outbound, MABM 2015 and 2031

PM Outbound	MABM 2015	MABM 2031	CAGR
Northern	47,832	61,792	1.6%
Clifton Hill	22,444	43,128	4.2%
Burnley	30,280	37,388	1.3%
Caulfield	39,832	34,380	-0.9%
Melbourne Metro (Domain)		19,876	
Melbourne Metro (Arden)		32,944	
Total	140,388	229,508	3.1%

Table 29: Modelled station entries, MABM 2015 and 2031

24hr Period	MABM 2015	MABM 2031	CAGR
Burnley	118,780	180,752	2.7%
Caulfield	165,000	300,768	3.8%
Clifton Hill	111,476	222,252	4.4%
Inner Core	250,512	444,464	3.6%
Northern	154,744	323,948	4.7%
Total	800,512	1,472,184	3.9%

6.4.4.2 Bus and Tram boardings

Table 30 shows a comparison of modelled tram boardings in 2015 and 2031 MABM. Total tram boarding are projected to grow at an average annual rate of 3.1%, faster than projected population growth of 1.8%.

Table 30: Modelled tram boardings, MABM 2015 and 2031

24hr Period	MABM 2015	MABM 2031	CAGR
CBD	147,256	234,392	2.9%
Docklands	11,696	30,552	6.2%
East	49,136	72,036	2.4%
Inner North-West	33,132	50,300	2.6%
Inner South-East	62,276	84,076	1.9%
Inner-East	56,112	105,588	4.0%
Inner-North	49,376	74,392	2.6%
North	14,728	26,920	3.8%
North-West	6,112	11,336	3.9%
South	35,912	60,220	3.3%
South-East	37,404	68,336	3.8%
Total	503,140	818,148	3.1%

Table 31 shows a comparison of modelled bus boardings in 2015 and 2031 MABM. Total tram boarding are projected to grow at an average annual rate of 5.5%, faster than projected population growth of 1.8%.

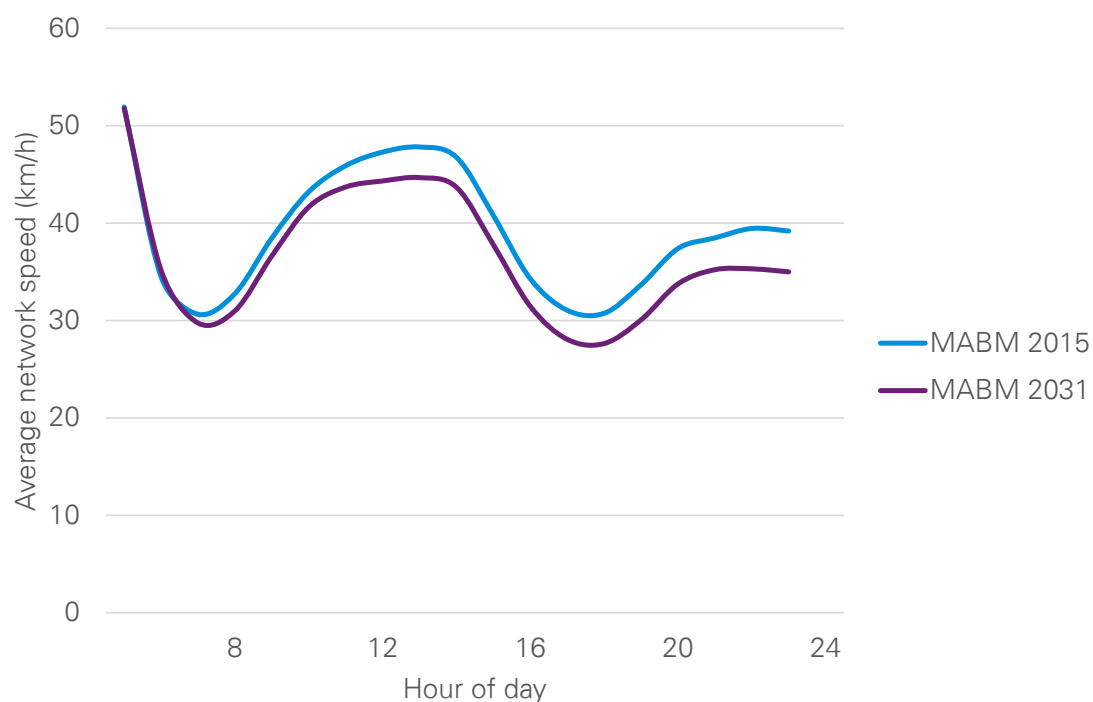
Table 31: Modelled tram boardings, MABM 2015 and 2031

24hr Period	MABM 2015	MABM 2031	CAGR
Inner Metro	53,624	101,568	4.1%
Inner South East	41,800	91,840	5.0%
Mid Northern	49,164	86,124	3.6%
Mid Eastern	88,880	167,116	4.0%
Mid South East	44,228	108,224	5.8%
Mid Western	35,276	94,116	6.3%
Outer Northern	56,964	123,784	5.0%
Outer Eastern	5,244	7,640	2.4%
Southern	17,676	71,460	9.1%
Outer Western	37,560	155,392	9.3%
Total	430,424	1,009,484	5.5%

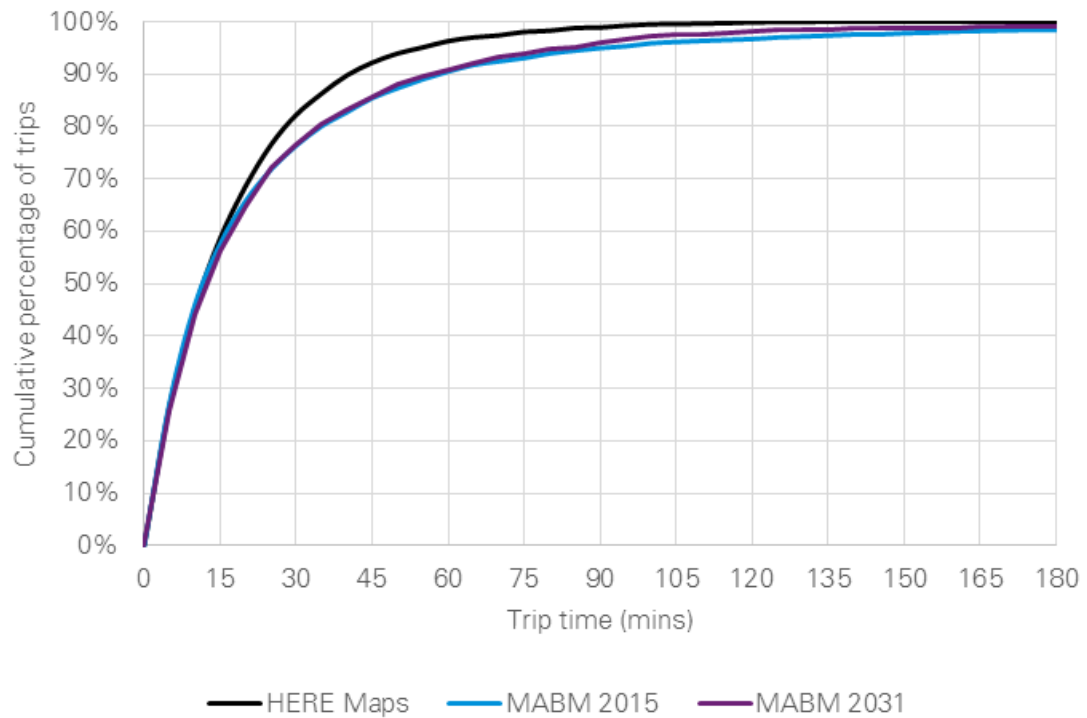
6.4.5 Road travel times

Across all time periods, the average network speed in MABM is lower in 2031 than in 2015, which reflects increased congestion across the network. The 24 hour average speed falls from 36.4km/h in 2015 to 34.4 in 2031. The average network speed across the day for MABM 2015 and 2031 is shown in Figure 95. The network speed across the day shows a similar profile in both model years.

Figure 95: Average network speed, MABM 2015 and 2031



As in the case of the 2015 model, travel times in the 2031 MABM are subject to a 'long tail', as a small proportion of agents get stuck in bottlenecks for extended periods of time. Figure 96 shows the cumulative distribution of travel times in both modelled years compared to the HERE Maps travel time. Importantly the proportion of trips with very high travel times (greater than 100 minutes) is virtually identical in both model years. This suggests that the 2031 MABM does not suffer from the 'long tail' effect to a greater extent than the 2015 scenario.

Figure 96: Cumulative travel time distribution, MABM 2015 and 2031

Source: MABM and HERE Maps API

7 Application

This section considers the limitations arising from the MABM validation presented in this report for analysing the impacts of transport network demand management and/ or pricing policies. It also considers the general strengths and limitations of the MABM approach relative to the traditional four step modelling approaches.

It should be noted that the MABM is still in the early stages of development. While it is considered that the model is fit for purpose for analysis of transport network demand management and road pricing policy options at a strategic level, further development and testing is required to increase confidence in the model and improve its range of applicability.

7.1 Limitations for analysis

The following limitations of this version of the MABM are noted. These do not fundamentally impact the fitness of the model, however they should be considered when specifying scenarios and interpreting results from the model.

- The model underestimates car mode share for work trips accessing the inner city relative to ABS Census data (refer Figure 31). This arises from the difficulty with modelling the perceived costs of parking at a disaggregated level for individuals. This needs to be considered when testing options which have significant impacts on public transport mode share for workers to and from the inner city. This is not an issue for overall congestion in the inner city as car mode share by destination for *all* trips is not underestimated.
- The model is prone to having work activities begin earlier than observed data. This moves the morning peak a little earlier than observed. However, examination of traffic volume profiles (refer to Figure 35 – Figure 40) suggests that this does not significantly impact on peak times. This should be considered when specifying and interpreting time of day pricing scenarios.
- The response of the model to changes in monetary costs appears to be highly non-linear. Small changes in costs appear to have lower elasticities than larger changes in costs. This should be verified and explored with further analysis for future work. For this study, care should be taken that pricing options impart reasonably significant charges, as very small changes in prices are unlikely to meaningfully impact behaviour.
- The MABM is prone to developing queues which can in some instances take an unrealistically long time to clear. This causes a very small proportion of travel times to be significantly overestimated. It also causes the quality of the model to degrade over the course of the modelled day, as the queues create flow on effects. Care should be taken when interpreting absolute travel times as well as effects that occur towards the end of the modelled day (i.e. after the PM peak).
- The 2031 model relies on a gravity model to artificially produce home and work locations for workers. The 2015 model relies on observed data for trip distance distributions. While we consider that this approach is fit for purpose, this should be considered when interpreting outputs related to commuting trip distances for the 2031 model.
- The model underestimates the number of tram boardings across the city by 22%. This is partly due to the fact that the free tram zone in the CBD is not explicitly modelled. This may have a marginal impact on the results of demand management scenarios that are focussed on inner city travel.

- The model overestimates the durations of school activities (primary and secondary school). This is unlikely to have a significant impact on any network demand management scenario, as pick up and drop off activity timings are not impacted.

7.2 Modelling approach

The MABM varies in many significant ways from the traditional four step modelling approach. Some selected key differences and their implications for transport network demand management and pricing policy analysis are discussed in Table 32. These differences need to be considered in using and interpreting results of the MABM.

The MABM has the ability to complement four step modelling approaches. The MABM is well suited for high level policy analysis due to its person-centric approach and its ability to produce rich visualisations for communicating outcomes to non-technical audiences. In the longer term, the MABM may be used as a secondary tool on business cases where a two model approach is desired to provide a higher degree of confidence in the appraisal process.

Table 32: Selected key differences between the MABM and a four step modelling approach

Aspect	Key difference	Implications
Unit of analysis	The unit of analysis for MABM is the <i>person</i> , whereas the unit of analysis for four step models is the <i>trip</i> .	A person-based approach is more suited to understanding of social impacts and winners and losers of policy responses. Trip-based models need to make assumptions to be able to attribute impacts to individuals or groups.
Time periods	The MABM has a continuous timescale, allowing for small changes in activity and trip timings. Four step models rely on arbitrarily defined aggregate time periods.	A continuous time scale is more suited to analysing the impacts of <i>peak spreading</i> . Peak spreading may occur due to time of day pricing regimes and/or increasing levels of congestion.
Spatial resolution	The MABM has activities occur at discrete coordinates in space. Four step models rely on arbitrarily defined geographical zones. Intrazonal trips are generally not assigned to the network in four step models.	A higher level of spatial resolution means the MABM is more suited to modelling the nature and characteristics of short trips, for example walk and cycle trips.
Chaining of activities and trips	The MABM considers the utility of all trips and activities over the course of a single simulated weekday. Four step models typically do not link trips or tours and therefore consider each trip in isolation.	The MABM is more suited to analysis of how decisions earlier in the day affect later decisions. For example, choosing to pay an area-based charge in the morning might mean that the person has access to that area for free for the remainder of the day.

Aspect	Key difference	Implications
Traffic dynamics	The MABM uses a simplified queue simulation, while four step models typically use volume delay functions based on speed flow curves.	The MABM in theory should provide a closer representation of actual traffic dynamics than volume delay functions. However, the implications of this model in the Melbourne context needs further exploration.
Public transport dynamics	The MABM simulates individual public transport vehicles and their capacities. Four step models typically use crowding generalised cost curves (analogous to the volume delay functions used for road traffic). Four step models may have unassigned trips for certain periods where demand exceeds capacity.	The MABM does not allow public transport vehicles to exceed capacity. Where there is a mismatch between supply and demand, MABM will use peak spreading and mode shift to resolve the discrepancy. Four step models increase generalised costs exponentially as capacities are reached and exceeded. This can lead to unassigned trips in certain time periods. While it is possible for public transport users to be unassigned ('stuck') in MABM, this is less of an issue than four step models due to the ability of agents to change activity timing. The implications of this in the local context needs further exploration.
Convergence process	The MABM uses a co-evolutionary algorithm, meaning simulated persons make small changes to their plans and 'learn' what works best for them over hundreds of simulated days. Individuals stop 'learning' late in the simulation, allowing the network to achieve equilibrium. Four step models typically use iterative processes to balance origin-destination matrices (e.g. gravity models) and iterative assignment procedures to achieve network equilibrium.	The outcome of MABM modelling is sensitive to the number of model iterations and the size of the population sample. These dynamics need to be explored further in the local context.
Testing and proving	Four step models have been used in practice in Australian transport planning for several decades. The MABM is the first metropolitan scale model of its kind in Australia.	Further testing and application of MABM is required in the local context to improve understanding of its dynamics, strengths and limitations.
Model run times	A model scenario of a given size and scope is likely to run more quickly and on cheaper hardware	Longer run times means model development and scenario analysis timeframes need to be longer for MABM than an equivalent four step

Aspect	Key difference	Implications
	for a four step model compared to the MABM.	model. Higher specification hardware is also required.

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Attachment A: Derivation of calibration parameters

This section sets out the methodology that was used to estimate the initial calibration parameters for the MABM. A process of multinomial logistic regression was undertaken using existing travel data for Melbourne to estimate utility functions that could be adapted for use with MABM.

Scoring Functions

MABM compares alternative travel plans by scoring them using utility functions. The overall score for a plan is the sum of the utility from performing an activity, and the (dis)utility of travelling to that activity (Agarwal & Kickhoffer, 2016, pp. 1-25).

The utility of an activity q is defined as (Horni, et al., 2016, p. 25):

$$(1) \quad S_{act,q} = \beta_{dur} \cdot t_{typ,q} \cdot \ln(t_{dur,q} / t_{0,q})$$

where β_{dur} is the marginal utility of activity duration, and $t_{typ,q}$ and $t_{dur,q}$ are the typical¹³ and actual durations of activity q . The duration at which utility begins to be positive is given as $t_{0,q}$.

The travel disutility for a leg q is defined as (Horni, et al., 2016, p. 26):

$$(2) \quad S_{trav,q} = C_{mode(q)} + \beta_{trav,mode(q)} \cdot t_{trav,q} + \beta_m \cdot \Delta m_q + \beta_m \cdot \gamma_{d,mode(q)} \cdot d_{trav,q} + \beta_{transfer} \cdot x_{transfer,q}$$

where $C_{mode(q)}$ is a mode specific constant;

$\beta_{trav,mode(q)}$ is the direct marginal utility of time spent travelling by a specific mode in addition to the marginal utility of time as a resource;

$t_{trav,q}$ is the travel time between activities, β_m is the marginal utility of money, and Δm_q is the monetary change in budget caused by fares or tolls;

The distance between activities is given by $d_{trav,q}$;

$\gamma_{d,mode(q)}$ is the mode specific monetary distance rate;

$\beta_{transfer}$ is the public transport transfer penalty; and

$x_{transfer,q}$ is the number of transfers.

Methodology for Calibration

Data Sources

A process of multinomial logistic regression was used to estimate the parameters presented in Equations 1 and 2. Data to inform the regression was utilised from the sources below.

¹³ Typical durations for activities are an input to MATSim. They are derived from average activity durations in VISTA.

Victorian Integrated Survey of Travel and Activity (VISTA)

Revealed preference data tables for person and household travel information from 2012-14 were used to collect the following information for the journey to work leg of home-work-home trips:

- Household income;
- Household size;
- Mode taken for journey to work (car, PT, walk or cycle only);
- Home location (SA1);
- Work location (SA1); and
- Departure time and day.

Journey to work trips were used for the calibration as they represent a significant proportion of travel demand. In addition, the project team considered that using work trips was appropriate to achieve a high quality validation during peak periods.

Fuel costs

Fuel costs were estimated using the route distance, and fuel consumption coefficients for the interrupted flow model presented in the Australian Transport Assessment and Planning (ATAP) guidelines (ATAP, 2017).

The average travel speed for each trip was calculated, and a threshold of 60km/h was used to select between the stop-start model and the free-flow model. The fuel consumption coefficients for a 'medium car' were adopted from Table 36 of the ATAP Road Parameter Values guidelines.

Estimated fuel consumption was converted into monetary terms using the 2013 retail price for ULP in Melbourne of 144.8c/L listed in Table 1 of the ATAP guidelines (ATAP, 2017).

Public Transport Fares

Public transport fares were estimated using 2012 fare prices on the previous three zone system. 2012 fares were used to match the observed VISTA data. Each SA1 area was assigned to a fare zone, with the fare estimated based on the origin and destination SA1 and hence fare zone for each home-work-home trip recorded in VISTA. The fare price used is displayed in Table 33.

Table 33: 2012 Public transport fare prices by zone

Trip by Zone	Zone 1	Zone 2	Zone 3	Zones 1-2	Zones 1-3	Zones 2-3
2 Hour Adult Fare (PTUA, 2012)	\$4.00	\$3.00	\$3.00	\$6.50	\$6.50	\$3.00

It is recognised that the fares presented in the above table represent a single fare type for what in practice was a complex fare structure depending upon concessions, and the duration of the ticket purchased. These fares are at the upper range of prices that were likely to be experienced by commuters at this point in time. This will have had the effect of slightly decreasing the marginal utility of money (β_m) than if a full range of fare options and discounts had been assigned.

Regression Analysis

Using the travel data outlined above, a multinomial logistic regression was undertaken using the following formulas:

$$(3) \quad V_{car} = -\beta_m \cdot \frac{Cost_{car}}{y_j} + \beta_{trav.car} \cdot Time_{car}$$

$$(4) \quad V_{PT} = -\beta_m \cdot \frac{Cost_{PT}}{y_j} + \beta_{trav.PT} \cdot Time_{PT}$$

$$(5) \quad V_{walk} = \beta_{trav.walk} \cdot Time_{walk}$$

$$(6) \quad V_{cycle} = \beta_{trav.cycle} \cdot Time_{cycle}$$

where V_{mode} is the utility function of the given mode as a function of travel cost and time; and

y_j is daily household income per person j .

Income y_j is obtained by the following calculation (Kickhoffer, 2014, p. 65):

$$(7) \quad y_j = \frac{y_{year,HH}}{n_{HH} \cdot 240}$$

where $y_{year,HH}$ is the household income reported in VISTA annualised by 52 weeks; and

n_{HH} is the number of persons in the household and 240 is the number of working days per year.

Incorporating an income parameter in the form of y_j into the utility function for car and public transport effectively allows the marginal utility of money to vary depending on an individual's income. This allows individuals to respond to price signals such as fares and tolls according to their income, and consequently their willingness to pay. A model such as the MABM is uniquely suited to incorporating income dependent travel behaviour at an individual level.

To ensure that the effective value for the marginal utility of time (β_m) is not excessively high for a given individual, an income floor of \$65 / workday or \$15,600 annual household income per person has been implemented. This value was selected as the 10th percentile income per person, and ensures that workers with very low income are not unreasonably sensitive to costs such as public transport fares.

The probability of travel by a particular mode for any trip given the utility functions shown above can be represented as:

$$(8) \quad P_{mode,q} = \frac{e^{V_q}}{\sum_{i=1}^n e^{V_i}}$$

where n is the number of alternative modes, and V is the utility function for a given mode outlined in Equations 3 to 6.

Results of Analysis

Table 34 presents the results of the regression analysis, and the level of significance of each coefficient:

Table 34: Results of multinomial logistic regression

Parameter	Coefficient	t-value	Probability ($> t $)
β_m	28.299	-11.968	$< 2.20E-16$
$\beta_{\text{trav,car}}$	-2.139	-4.996	5.85E-07
$\beta_{\text{trav,PT}}$	-8.779	-20.540	$< 2.20E-16$
$\beta_{\text{trav,walk}}$	-3.114	-13.674	$< 2.20E-16$
$\beta_{\text{trav,cycle}}$	-4.567	-14.208	$< 2.20E-16$

The regression was undertaken using a value for time in minutes. The coefficients in the above table have been converted into an hourly value as this reflects that requirements of the MABM scoring function parameters.

The low probability values associated with each of the coefficient presented in Table 34 indicates that all coefficients are statistically significant to well below the 1% significance level.

A value for transfer penalties was not estimated as part of the regression process as the journey to work trips recorded in VISTA showed a positive correlation between the number of transfers and public transport usage. While it is understandable that the proportion of trips by public transport in the morning peak would be greater for longer trips than those that do not require transfers across services, adopting a positive coefficient for this parameter is not reasonable.

Boarding penalties were assigned by public transport sub-mode (bus, train and tram). The values were based initially on VITM boarding and transfer penalties, and later calibrated directly in MABM. The adopted values are shown in Table 35.

A mode specific constant of 0.2 utils was applied to all public transport trips. Please note this constant only applies once for each trip, regardless of how many transfers occur.

Table 35: Sub-mode specific boarding penalties

Sub-mode	Value
Train	-0.1 utils / boarding
Tram	-0.15 utils / boarding
Bus	-0.45 utils / boarding

Calibration Parameters

Based upon the methodology outlined, the calibration parameters adopted in MABM are presented in Table 36.

Table 36: Calibration parameter values

Parameter	Calibration Value
β_m	28.30 utils / \$
β_{dur}	2.14 utils / h
$\beta_{tt,car}$	0 utils / h
$\beta_{tt,PT}$	-0.98 utils / h
$\beta_{tt,walk}$	-2.43 utils / h
$\beta_{tt,cycle}$	-6.64 utils / h
$\beta_{late,ar}$	-6.42 utils / h
$\gamma_{d,car}$	17.6 c / km

As outlined previously, β_m is to be divided by the individual daily household income per person with an income floor of \$65 / day.

β_{dur} was selected as the prefactor of car travel time from the regression analysis, with the parameter sign changed to a positive value (Horni, et al., 2016, p. 32).

$\beta_{tt,car}$ was set to zero, recognising that travelling by car will be implicitly punished by the opportunity cost of time (Horni, et al., 2016, p. 32). The marginal utility of travelling for other modes were similarly offset relative to the value for travel by car.

$\beta_{late,ar}$ was set at a scale of three times the marginal utility of activity (β_{dur}) as per the default value.

The monetary distance rate for travel by car ($\gamma_{d,car}$) was calculated to be 17.6c/km from the fuel price estimated using the ATAP guidelines.

Value of Travel Time Savings

From the initial calibration parameters, the Value of Travel Time Savings (VTTS) used in the MABM behavioural model can be calculated using the equation below:

$$(9) \quad VTTS = \frac{\beta_{dur} - \beta_{trav}}{\beta_m / y_j}$$

where the duration of the activity matches the typical duration (Horni, et al., 2016, p. 28).

Equation 9 shows that the value of time differs for individuals according to their household income and number of occupants. The average value for the household income parameter y_j from the VISTA trips used in the analysis was \$185.3 for an individual per day.

From Equation 9 the average VTTS for trips by car is \$14.01 / hour, and the VTTS for trips by public transport is \$20.39 / hour.

These values are comparable to those provided in the ATAP guidelines, with the recommended value for travel time for car occupants listed as \$14.99 / hour (2013 dollars) (ATAP, 2017, p. Table 12).



The value of travel time savings presented above are solely intended for use as inputs to the MABM behavioural model to inform mode and route choice. These values are not intended for use in economic evaluation of transport initiatives.

Attachment B: Run log summary

Run numbers	Comments
1 – 26	Initial exploratory testing and debugging
27 – 36	Testing and finalising model functionality, including fares, parking, toll functionality
37 – 51	Fine tuning and testing of population synthesiser
52 – 90	Introduced and tested Singapore public transport router, followed by custom Melbourne router. Also included a number of tests for a simplified 'matrix based' public transport router.
91 – 112	Model response testing – (boarding penalties, mode specific constants, marginal utilities of travel time, parking costs, fares)
113 – 119	Introduction and testing of park and ride functionality.
120 – 121	Testing of alternative specifications for 2031 (for comparison to 2015 runs)
122 – 132	Testing of park and ride station capacities, additional fine tuning of demand and testing of mode specific constants and marginal utilities of travel time.
133 – 145	Elasticity testing (fares, fuel parking), 2031 runs and testing of alternative sample sizes and performance on alternative hardware.
146 – 160	Fine tuning of mode specific constants, tests against different random seeds and testing of changes in parking assumptions. Baseline validation run (158) presented to IV on 31 st July. In addition an alternative random seed was tested.
161 – 165	Fine tuning of freight inputs and further fine tuning of parking assumptions. Final baseline validation run (162) for this report selected.
166 – 171	Final elasticity tests for validation report (fare, toll, parking), run time optimisations tests and final 2031 runs.

Attachment C: Network conversion

Highway Network

The highway network represents a key input to the MABM. This section details the process used to translate the VITM transport network¹⁴ into the format required by the activity-based model. Both the VITM and MABM represent their networks as graph systems comprised of nodes and links.

A python script was created to take the node and link attributes from VITM network input files and translate them into the MABM format. Attributes such as node location, link length, number of lanes and capacity could be directly transferred. Other attributes required specific processes, outlined as follows:

- *Link free-flow speed:* In the VITM, each road link has a posted speed limit attribute. In addition, each class of link in the VITM is paired with a free-flow speed factor. These two sources of information were combined to produce the free-flow speed (e.g. a link with posted speed of 80km/h and free-flow factor of 0.75 would have a free-flow speed of 60km/h). Train and tram-only link speeds were derived from a separate input into the VITM.
- *Link modes:* MABM requires a list of allowable modes for each link in the network. For pedestrians, cyclists, cars, trucks and trains this information was derived from each link's class. Determining whether buses or trams were allowed to travel on a link was achieved by analysing a VITM network that had assigned public transport volumes on it. If buses or trams had been shown to travel on a link, it was allowed on that link in MABM.

Public Transport

This section details the processes used to convert the public transport system representation within the VITM into a form that MABM can interpret. MABM requires two files to correctly define a public transport network:

- *Transit Schedule:* A breakdown of public transport stop facilities, routes and departure times.
- *Transit Vehicle Definitions:* Attributes of public transport vehicles such as seated and standing capacity. This file also contains a list of all transit routes and which specific vehicle is used on each.

In the VITM, this information is provided by the public transport line file and system file respectively. A python script was created to translate both of these files into MABM-compatible formats. With the transit schedule however, representations of certain attributes in the VITM differed compared to what MABM required. The following list describes these differences:

¹⁴ Master_170206_0004_3090_DOT.NET

- The VITM line file describes departure times in terms of defined headways during the four main time periods of a day. For example, a train service might have headways of 10 minutes during the AM period, meaning one train every 10 minutes between 7 and 9am. MABM requires explicit departure times for each service, i.e. 7:00am, 7:10am, 7:20am etc. Thus, in converting the departure times from the line file to the MABM transit schedule format, uniformly distributed departure times during each time period were specifically generated using the line file headways.
- For buses and trams, the VITM simulates dwell time at stops by artificially reducing the speed of the vehicle along its route by a calculated factor to emulate a certain stopping time at defined intervals. MABM requires the dwell time of each stop to be explicitly defined. These dwell times were calculated as a function of link length to replicate the behaviour seen in the VITM. Trains have a defined constant dwell time in both the VITM and MABM thus not requiring this special provision.

Attachment D: Synthetic population and activity patterns

The total number of individuals and households for the synthetic population compared to the 2016 ABS Census is shown in Table 37. Please note that the synthetic population is for 2015 and the ABS comparison data is for 2016. The population control totals are generated from Victoria in Future estimates for 2015 which are projected from 2011 Census data. This confirms that the total population size is similar to observed data.

There are fewer households in the synthetic population compared to 2016 ABS Census data by approximately 5%. This is likely a product of sample bias in the VISTA survey, as household structures in the synthetic population are derived from the VISTA survey. The synthetic population implies an average household size of 2.57 persons per household compared to 2.45 in the ABS 2016 Census.

Table 37: Synthetic population vs 2016 ABS Census, total population and households

	Synthetic population (2015)	ABS 2016 Census	Difference
Population	4,493,248	4,485,211	-0.2%
Households	1,746,882	1,832,043	4.9%

The age group distribution of the synthetic population relative to the ABS 2016 Census for metropolitan Melbourne is shown in Table 38. The age group distribution matches closely with Census data. This confirms that the distribution of age groups in the synthetic population is similar to observed.

Table 38: Synthetic population vs 2016 ABS Census, age group distribution

Age group	Synthetic population	ABS 2016 Census	Difference
0-4	6.4%	6.5%	+0.1%
5-11	8.5%	8.4%	-0.1%
12-17	6.7%	6.9%	+0.2%
18-25	11.6%	11.2%	-0.4%
26-64	52.7%	53.1%	+0.4%
65+	14.0%	13.8%	-0.2%

The proportion of households in each household income group is shown in Table 39. The household income data in the synthetic population is generated from VISTA data and is therefore subject to sample biases in the VISTA. The income distribution is reasonably similar to observed. The correspondence between observed and synthetic population is deemed to be fit for purpose for the current work.

Table 39: Synthetic population vs 2016 ABS Census, household income distribution

Income group	Synthetic population	ABS 2016 Census	Difference
\$0-\$26k	14.0%	11.9%	-2.1%
\$26k-\$52k	18.0%	20.0%	+2.0%
\$52k-\$104k	30.1%	27.3%	-2.8%
\$104k-\$208k	29.5%	35.7%	+6.2%
\$208k+	8.4%	5.1%	-3.3%

The proportion of individuals undertaking each activity plan is shown in Table 40 for the synthetic population compared to the VISTA sample. The VISTA sample is weighted using the Department of Economic Development, Jobs, Transport and Resources' standard person-weighting approach to generalise from the sample to the entire population.

In total, the VISTA sample contains 1,378 unique activity patterns and the synthetic population contains 1,158 unique patterns. The reason for the discrepancy is that the population synthesiser removes plans with airport and external trips before assigning plans to agents, as these trips are modelled separately in MABM.

The synthetic population has the top ten activity patterns account for 66.9% of all activity patterns. The equivalent number for the weighted VISTA sample is 67.5%. Overall, the synthetic population closely matches the observed weighted VISTA data.

Table 40: Synthetic population vs 2016 ABS Census, activity pattern distribution

Activity pattern	Synthetic population	VISTA 12-14	Difference
home	21.2%	21.1%	-0.1%
home-work-home	14.5%	16.3%	+1.8%
home-o-home	12.7%	10.1%	-2.5%
home-e1-home	6.0%	7.1%	+1.1%
home-o-home-o-home	3.5%	3.0%	-0.5%
home-o-o-home	3.1%	2.4%	-0.6%
home-work-home-o-home	2.4%	2.6%	+0.3%
home-work-o-home	1.6%	1.7%	+0.2%
home-o-o-o-home	1.5%	1.1%	-0.4%
home-e1-home-o-home	1.1%	1.4%	+0.2%
all other plans	32.5%	33.1%	+0.7%

Attachment E: Peer review letter

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Praveen Thakur
Director, Advisory
KPMG Australia
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15 November 2017

Subject: Independent Peer-Review of the MABM Calibration and Validation Report

Dear Praveen,

I have reviewed the provided Melbourne Activity-Based Model (MABM) Calibration and Validation report.

Introduction

The study detailed in the report includes development, calibration and validation of an activity-based model for Melbourne for a preliminary assessment of various transport network demand management schemes as contracted by Infrastructure Victoria. It is my assessment that KPMG and ARUP, the primary contractors for this work, have followed generally accepted professional standards in carrying out the transport model development and analysis.

The remaining of the letter is structured as follows. The next two sections describe the scope of this review and the exclusions. I then describe a summary of my technical evaluation of the MABM followed by a section providing a more detailed assessment of the model and identified issues and their significance along with my suggestions and areas for improvement.

Scope

The scope of this independent review was to evaluate the technical quality of the MABM development, calibration and validation including, but not limited to, data sets, model structure and specification, estimation of model parameters and model validation results.

Scope Exclusions

The conducted peer-review was limited to the information provided in the report, with no access to the data and model original files.

Technical Evaluation

Developing an activity-based model is a very complex task. Moreover, calibration and validation of an activity-based model is highly data-intensive and requires significant skills and resources. The conducted project by KPMG and ARUP and the provided report meets generally accepted standards for travel demand modelling in practice. However, several areas for further improvement of the model have been identified. The improvements will help provide more reliable forecasts and assessments. Below is a summary of the identified areas, which will be discussed in details in the following section:

1. Calibration of model parameters is conducted based on work trips only. For non-work trips, the same model parameters are used.
2. No destination choice model is developed and included. The current model only allows individual travellers to change their activity duration, departure time, route, and mode including park and ride.
3. No correlation between activity patterns of individuals in the same household is considered.
4. MATSIM uses an over-simplified traffic assignment for route choice. This calls for integration of MABM with a more sophisticated dynamic traffic assignment model in future.
5. Some of the estimated elasticities are not within the range as specified in the DEDJTR modelling guidelines and may require further exploration. Note that the DEDJTR guidelines have been developed based on the outcomes of a 4-step model and not an activity-based model.
6. The estimated value of travel time saving for car trips is reasonable and consistent with previously estimated values. However, the estimated value of travel time saving for public transport trips is higher than expected.
7. Some of the parameters used in the model are directly borrowed from the VITIM and other existing models and guidelines. This requires further investigation, as use of the same values may not be appropriate for an activity-based model.
8. The majority of the validation results are acceptable. However, a few critical measures including temporal distribution of work and school start times and durations, link traffic volumes, and origin-destination travel times may require further improvement.

As highlighted earlier, a full calibration of an activity-based model is highly data-intensive. It is my assessment that the calibrated MABM as it currently stands is fit for purpose for higher-level strategic analysis of policy and infrastructure options and forecasting changes in travel demand driven by demographic changes under ‘business as usual’ scenario. However, the model still requires further improvement and continuing investment for detailed and comprehensive assessment and implementation advice for transport demand management policies and infrastructure options. Given the major well-known limitations of 4-step models, further study of and investment in activity based modelling is highly recommended.

Detailed Assessment

The following table provides a more detailed assessment of the report along with their significance level and suggestions.

#	Issue	Suggestion	Significance	KPMG response	KPMG action	Status
1	A general comment on section 2.1. Theory: Some of the statements here are more related to the way MATSIM is working. For example, the queue simulation described in section 2.1.4 is specific to MATSIM. A different ABM platform/model can model queue formation and propagation differently.	Please reframe the discussion with a focus on MATSIM.	Minor	We have reframed the section to focus more on the specific MATSim theoretical framework rather than the 'activity-based' framework. This reflects that activity-based is only one feature of MATSim among others (i.e. agent-based, co-evolutionary algorithm) and also to note that some features in other activity-based models do not appear in MATSim (eg. Activity adding, dropping, reordering).	Text amended.	Closed
2	Section 3.1.2.1 Can you please share some of the results related to how representative the synthesized population is?	Please further clarify in the report.	Moderate	A new attachment (Attachment D) has been produced which compares the age and income profiles of the synthetic population with new ABS 2016 Census data, and the activity patterns with the 2012-14 VISTA data.	New Attachment D produced.	Closed
3	Section 3.1.2.1 How are you calculating the inflation factor for some of the new fringe suburbs that had zero or almost zero population in 2011 but in 2015, they had grown significantly in population?	Please further clarify in the report.	Minor	For SA2s with zero population in 2011, the MTWP proportions of a neighbouring SA2 were applied to the VIF2015 forecast to estimate the 2015 mode split.	Text amended.	Closed
4	Section 3.1.2.2 More information on the number and identified activity patterns need to be provided.	Please further clarify in the report.	Minor	This is covered in the new Attachment D.	New Attachment D produced.	Closed
5	Section 3.1.2.2 This is unclear a little bit. What exactly are you	Please further clarify in the	Minor	The demographic signature is created using the individual attributes associated with the	Text amended.	Closed

	using here? Are you randomly assigning an activity chain to an individual based on his/her income, age, etc? Are you considering the connection between individuals from the same household?	report.		individual including age (for non-workers), household location at an SA4 level, and employment status. SA4 is selected to provide a large enough bank of persons to ensure heterogeneity of activity patterns and timing within small areas. This is critical to avoiding high concentrations of activities which can lead to gridlock when traffic is assigned. Person weights from the VISTA sample are also applied to account for known sample biases.		
6	Section 3.1.2.2 This is perhaps one of the most important steps in ABM. We need to make sure the generated activities make sense and follow the same patterns as in reality. The statements here need to be supported with some evidence. Comparing distributions of distance traveled and distribution of activity locations among other measures could provide some evidence.	Please provide evidence in the report.	Moderate	These are already considered to a high level of detail later in the report (Section 5).	No action.	Closed
7	Section 3.1.2.3 Given the complexity of the problem here, you may need to look into latent-variable modelling.	Possible direction for future work.	Minor	Noted as an avenue for future work.	No action.	Closed
8	Section 3.1.2.3 This needs a bit of more exploration. This is a grey area in theory of choice	Possible direction for future work.	Minor	Acknowledged. The fuel price is commonly used in Australian state Government models so we have used it here. This assumption could be	No action.	Closed

	models. Whether we should use the direct out of pocket fuel price cost or consider a more complete cost estimates such as \$0.66 AUD per kilometer as the reimbursement rate set by ATO.			explored in more detail in future work.		
9	Section 4.1.4 Using the same reduction factors previously used in a 4-step model (MITM/VITM) may not be appropriate here. Now, that you are working with an ABM, applying the same reduction factor to PT cost is a bit arbitrary. What this basically does, it increases the "attractiveness" of public transport by artificially reducing the travel cost. The ABM should technically capture the higher attractiveness of the PT without the need for applying such reduction factor.	Possible direction for future work.	Moderate	The reduction factors are meant to adjust for perceived costs to account for certain individuals having longer term passes and/or concession rates. Agree that this assumption should be tested and explored more thoroughly in future work. For this work, noting the focus is road pricing, we do not consider that this fundamentally impacts the fitness for purpose of the model.	No action.	Closed
10	Section 4.4 Hopefully with the release of the new 2016 Census data, you could update this.	Possible direction for future work.	Minor	Agreed – area for future work.	No action.	Closed
11	Table 7 How many trips in total are you modeling? 12 million trips for the entire day? How are you weighting up the VISTA trips	Please further clarify in the report.	Minor	Weighted up to represent population according to VISTA methodology. Have added a footnote to the table to that effect.	Text amended.	Closed

	here?					
12	Figure 9 While the general patterns reported are fine; some of the measures including the activity start times in the ABM model for the morning are clearly off. This could significantly affect the model outcomes given the importance and number of the morning commutes.	Please further clarify in the report. Possible direction for future work.	Moderate	Acknowledged and agreed as an area for future improvement. This could be addressed by altering opening times for work activities. However we also note that time of day profiles for screenlines and toll road profiles are generally close to observed, so this doesn't appear to be having a major influence. We also note that the school duration distribution has no bearing on traffic assignment at all. Have added some additional discussion in Section 7.1 (Limitations)	Text amended.	Closed
13	Table 12 One main reason that traffic volumes are not estimated as good as some of the demand measures in previous sections is that MATSIM has a simplistic traffic simulation model, calling for integration with a more sophisticated dynamic traffic assignment model.	Please further clarify in the report. Possible direction for future work.	Minor	Acknowledged and agreed as an area for future improvement. Have added some additional discussion in Section 7.1 (Limitations)	Text amended.	Closed
14	Figure 26 Can you show a scatter plot, x axis observed volume and y axis the ABM estimated volumes. That's a better approach for comparison.	Please further clarify in the report.	Minor	The way Figure 26 is presented is as per the format agreed with and signed off by Infrastructure Victoria. As such we have opted to retain the current format.	No action.	Closed
15	Table 14 Any reason why Clifton Hill is specifically very different than others?	Please further clarify in the report.	Minor	We have not been able to identify the driver of the anomalous result for Clifton Hill. Given that the validation criteria are met for cordon	No action.	Closed

				loads, we propose this as an avenue for future work.		
16	Section 5.6.2 The travel time validation is done only using 2400/12 million that is 0.02% of entire number of trips per day. It's too small. Better to increase the sample size. Make sure the sample of travel times cover the more congested areas and congested time intervals.	Please further clarify in the report.	Minor	We confirm that the random sample covers the congested time intervals (as demonstrated in the existing Figure). We have also verified that the travel times cover the congested areas and directions. While we acknowledge a larger sample would be desirable, we are constrained by API quotas which limit our ability to substantially increase the sample size. We propose this as an avenue for future work.	No action.	Closed
17	Above Figure 46: This is very usual in large-scale traffic modelling. The phenomenon is called "gridlock". One way of reducing the probability of gridlocks being formed is to introduce certain travellers who are willing to switch routes and seek alternative routes given the prevailing travel time information. This is called "adaptive drivers". You may introduce 10% to 40% adaptive drivers to help the gridlocks to recover.	Possible direction for future work.	Minor	Acknowledged and agreed – an avenue for future refinement.	No action.	Closed
18	Section 5.7.1 So here, you are actually using analogous measures to model road pricing. You did not specifically change	Please further clarify in the report.	Moderate	We have amended the text to further emphasise that analogous measures have been employed.	Text amended	Closed

	the ABM to account for road pricing.					
19	Section 5.7.1.1 Going back to my earlier comment on travel distance rate. One reason you may see small elasticity is that the distance rate used (17.6 c/km) might be too small compared to reality. If the elasticity behaves non-linearly, I would test even a much larger c/km value, a number closer to the total cost of driving and not just fuel price.	Possible direction for future work.	Moderate	Acknowledged as an avenue for future work.	No action.	Closed
20	Section 5.7.1.4 I believe the main reason that the estimated elasticities are a little off the guidelines is that the choice models in the ABM can be improved. There might also be a chance that the elasticities in the DEDJTR guidelines are not realistic enough for comparison with an ABM outcome, they might be more suitable for a 4-step model evaluation. You need to explore how those numbers are put together.	Possible direction for future work.	Moderate	Agreed, an area for future work. In particular, we think that destination choice and non-linearity of elasticities should be explored in more detail, as well as a more detailed look at the elasticities as per your suggestion.	No action.	Closed
21	Section 5.8 There are methods to tackle this issue, by looking at	Possible direction for future work.	Minor	Agreed, an area for future work.	No action.	Closed

	the OD matrix as a graph (a set of nodes and links). We then compare the properties of the VISTA OD graph versus the model OD graph. Future work.					
23	Attachment A Equations 1 and 2: How did you measure these parameters from VISTA?	Please further clarify in the report.	Minor	An explanation has been added.	Text amended.	Closed
24	Below Equation 9: Generally the VOTs are reasonable. However, the VOT for public transport seems a bit high. This may need further exploration, as estimation of realistic VOT is critical for assessment of transport network pricing.	Possible direction for future work.	Moderate	We have added some additional clarification in Attachment A. Acknowledged as an area for future work.	Text amended.	Closed
25	The MABM, at its current stage of development, is fit for purpose for higher-level strategic evaluation of travel patterns change in Melbourne. However, it may still require further improvement for a detailed and comprehensive assessment of transport policies for implementation purposes.	Please further clarify in the report. Possible direction for future work.	Moderate	The MABM as it stands meets the agreed validation criteria and is fit for purpose for the current, strategic level analysis of network demand management policies and infrastructure priorities. Further improvement and testing to the model will be undertaken prior to undertaking detailed, implementation level analysis of policy and infrastructure options.	No action.	Closed

I hope the provided feedback and comments help improving the model development and calibration process and eventually, lead to more accurate and reliable model outcomes suitable for detailed implementation-level assessment of a wide range of transport policies. I appreciate the efforts that have made so far in developing the MABM and fully support the continuation of its further development and calibration.

Please do not hesitate to contact me if you have any question or require further clarification.

Sincerely,

Meead Saberi K.

Dr. Meead Saberi



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