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An Agent Based Model for the Simulation of Road Traffic and Transport Demand in A Sydney Metropolitan Area

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ABSTRACT

Agent based modelling has emerged as a promising tool to provide planners with sophisticated insights on social behaviour and the interdependencies characterising urban system, particularly with respect to traffic and transport planning. This paper presents an agent based model for the simulation of road traffic and transport demand of an urban area in south east Sydney, Australia. In this model, each agent represents an individual in the population of the study area. Each individual in the model has a travel diary which comprises a sequence of trips the person makes in a representative day as well as trip attributes such as travel mode, trip purpose, and departure time. Individuals in the model are associated with each other by their household relationship, which helps define the interdependencies of their travel diary and constrains their mode choice. This feature allows the model to not only realistically reproduce how the current population uses existing transport infrastructure but more importantly provide comprehensive insight into future transport demands of an urban area. The router of the traffic micro-simulation package TRANSIMS is incorporated in the agent based model to inform the actual travel time of each trip (which agents use in considering new travel modes) and changes of traffic density on the road network. Simulation results show very good agreement with survey data in terms of the distribution of trips done by the population by transport modes and by trip purposes, as well as the traffic density along the main road in the study area.

Keywords

Agent based model, TRANSIMS, road traffic, transport demand, urban planning

1. INTRODUCTION

The ability to realistically predict the demand of transport and traffic on the road network is of critical importance to efficient urban transport planning. Agent based models of urban planning have been increasingly introduced over the last decades. Miller et al. [9] developed model ILUTE (Integrated Land Use, Transportation, Environment) to simulate the evolution of the whole Toronto region in Canada with approximately 2 million households and 5 million people over an extended period of time. Besides giving useful information to analyse a wide range of transport and other urban policies, ILUTE also explicitly models travel demand as an outcome of the integration between individual and household decisions

based on activities that they commence during a day. Raney et al. [13] presented a multi-agent traffic simulation for all of Switzerland with a population of around 7 million people. Balmer et al. [1] demonstrated the flexibility of agent based modelling by successfully developing an agent based model that satisfactorily simulate the traffic demands of two scenarios: (i) Zurich city in Switzerland with 170 municipalities and 12 districts and (ii) Brandenburg city in Germany with 1008 traffic analysis zones. Many other agent based models for transport and urban planning can be found in the literature with different geographical scales and at various levels of complexity of agent's behaviours and autonomy [2, 4, 5, 8, 14-19]. They proved that with a large real world scenario, agent based modelling, while being able to reproduce the complexity of an urban area and predict emergent behaviours in the area, has no issue with the performance [17]. They also show that for traffic and transport simulation purposes, agent based modelling has been considered as a reliable and well worth developing tool that planners can employ to build and evaluate alternative scenarios of an urban area.

Many models that have been reported in the literature however are unable to explicitly simulate the dynamic interactions between the population growth, the transport/traffic demands, urban mobility (i.e. residential relocation of households), and the resulting changes in how the population perceive the liveability of an urban area. The agent based model presented in this paper aims at addressing this gap in the literature. The heterogeneity of the population is represented in the model in terms of demographic characteristics, environmental perception, and decision making behaviour. Inherently, the simulated population will evolve over time facilitating the interactions between dynamics of residential relocation of households, transportation behaviours and population growth. Thanks to this feature, the model can be used for exploring long-term (e.g. 20 year time horizon) consequences of various transport and land use planning scenarios.

Individuals are represented in this model as autonomous decision makers that make decisions that affect their environment (i.e. travel mode choice and relocation choice) as well as are required to make decisions in reaction to changes in their environment (e.g. family situation, employment). With respect to transportation, each individual has a travel diary which comprises a sequence of trips the person makes in a representative day as well as trip attributes such as travel mode, trip purpose, and departure time. Individuals in the model are associated with each other by their household relationship,

which helps define the interdependencies of their travel diary and constrains their mode choice. This feature, together with the interactions between urban mobility, transportation behaviours, and population growth, allows the model to not only realistically reproduce how the current population uses existing transport infrastructure but more importantly provide comprehensive insight into its future transport demands. The router of the traffic micro-simulation package TRANSIMS is incorporated in the agent based model to inform the actual travel time of each trip (which agents use in considering new travel modes) and changes of traffic density on the road network.

Major components that constitute the agent based model in this study are (i) synthetic population, (ii) residential relocation choice, (iii) perceived liveability, (iv) travel diaries, (v) traffic micro-simulation, and (vi) transport mode choice. These components equip the model with unique features that allows it to be used as a comprehensive tool for assisting integrated travel – land use planning. These components are briefly described in Section 2 in order to provide a full picture of the model features and capabilities. The focus of this paper however will be in reporting the simulation results in regards to road traffic and transport demands (Section 3). The paper closes with discussions on further developments of the model.

2. MODEL COMPONENTS

This section provides an overview of the six main components that constitute the agent based model in this study. Details on the model architecture and integration of these components are given in [3].

2.1 Synthetic Population

The purpose of the synthetic population is to create a valid computational representation of the population in the study area that matches the distribution of individuals and household as per the demographics from census data. The construction of the synthetic population involves the creation of a proto-population calibrated on socio-demographic information provided by the Australian census data (full enumeration). Different to the majority of existing algorithms for constructing a synthetic population, the algorithm used in this study uses only aggregated data of demographic distributions as inputs, i.e. no disaggregated records of individuals or households (e.g. a survey) are required. The resulting synthetic population is made of individuals belonging to specific households and associated with each other by household relationship.

This initial population is evolved according to annual increments during the simulation period. Each individual and household is susceptible to various demographic (e.g. aging, coupling, divorcing, reproducing of individuals) and economic changes controlled by conditional probabilities. The consequent changes in the structure of households as a result of these processes are also captured. Further details of the algorithms for the construction and evolution of the synthetic population used in this study can be found in [6]. An immigrant population may be added to the existent population of the study area at the end of each simulation step.

2.2 Residential Location Choice

Household relocation modelling is an integral part of both the residential and transport planning processes as household locations determine demand for community facilities and services, including transport network demands. The approach used to model residential location choice includes two distinct

processes: the decision to relocate, and the process of finding a new dwelling. A multinomial logit model was used to represent the process by which households make decision to relocate. The attributes of this model are change in household income, change of household configuration (e.g. having a newborn, divorced couples, newly wed couples), and the tenure of the household. The HILDA data was used to regress the coefficients associated to each of these attributes needed in the binomial logit model. Further details on the development of the model for triggering household relocation can be found in [12].

Once a household is selected for relocation, the second decision determines where the household will relocate and whether they will be renting or buying a dwelling in the target location, if a suitable a dwelling is found. This process of finding a new dwelling is modelled as a constraint satisfaction process, whereby each household will attempt to find a suitable dwelling based on three factors, affordability, availability, and satisfaction.

2.3 Perceived liveability

A significant departure of the current model to other existing approaches is the assumption that residential location choice is based not only on availability and affordability principles but also on the perception that individuals have of the quality of their living environment. The perceived liveability component uses a semi-empirical model to estimate individual levels of attraction to and satisfaction with specific locations. The semi-empirical model is a statistical weighted linear model calibrated on a computer assisted telephone interviewing (CATI) survey data collected in the study area. Further details of this semi-empirical model can be found in [10, 11].

2.4 Travel Diaries

Each individual in the synthetic population is assigned with a travel diary which comprises a sequence of trips the person makes in a representative day as well as trip attributes such as travel mode, trip purpose, departure time, origin and destination. Because these details of travel behaviours of the population are not completely available in any single source of data (for confidentiality reasons), the process of assigning travel diaries to individuals comprises two steps. The first step assigns a trip sequence each individual makes in a representative day using the Household Travel Survey data. Details of each trip in this trip sequence include trip purpose, travel mode, and departure time. The second step assigns locations to the origin and destination of each trip in the trip sequence.

2.4.1 Assigning Trip Sequences To Synthetic Population

The Household Travel Survey (HTS) data was used to assign trip sequences to individuals in the synthetic population. This data is the largest and most comprehensive source of information on individual patterns for the Sydney Greater Metropolitan Area. The data is collected through face to face interviews with approximately 3000-3500 households each year. Details recorded include information of each trip (e.g. departure time, travel time, travel mode, purpose) as well as socio demographic attributes of the interviewed household.

The assignment of trip sequences to the synthetic population comprises two steps. The first step deterministically searches in HTS data for households that best match the household type, the number of children under 15 years old, and the number of adults of a synthetic population household. This deterministic search gradually relaxes the constraints on exact matching

conditions so that the search always returns at least one HTS household. The second step randomly selects a HTS household from the list of households identified in stage 1 and assigns travel diary of individuals in the HTS household to those in the synthetic population household. The random selection follows a uniform distribution.

Further details of the algorithms for the assignment of trip sequences to the synthetic population can be found in [7].

2.4.2 Assigning Locations To Trips In Trip Sequences

Once the trip sequences for all the households in the synthetic population are assigned then the following procedure is carried out to assign activity locations to each trip in a sequence. This procedure had to be followed because the HTS data used for this study did not contain activity locations to ensure the confidentiality of the data and so alternative arrangements needed to be made to ensure that each agent was assigned a location of where to go for a particular activity type either inside or outside the study area. In the case of activity locations outside of the study area, main entry and exit points which acted as the origin/destination of trips coming into or going out of the study area. These main entry/exit points are located near where main entry/exit roads pass the boundary of the study area.

Attributes of activity locations in the study area that are available to this study include the geolocations (i.e. coordinates) and the type of the locations. In order to assign specific coordinates to origin and/or destination of a trip, an activity type must first be determined based on the trip purpose. Based on location type and trip mode, a set of coordinates associated with this location type is assigned to the destination. Details of these two processes are given below.

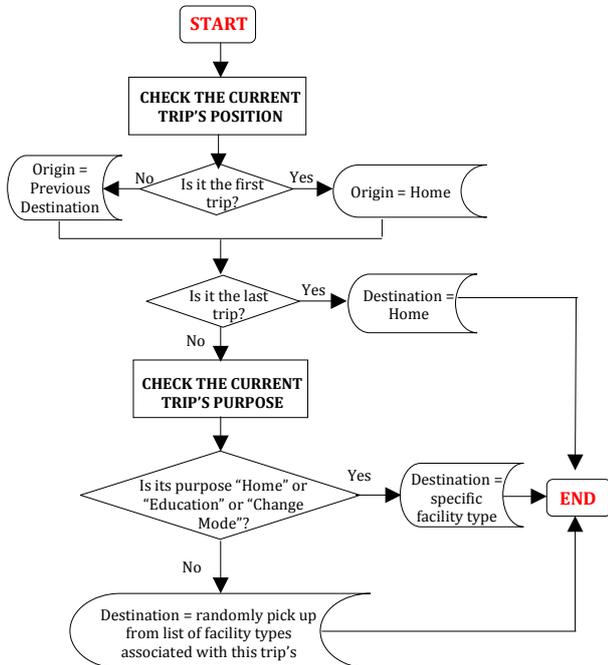


Figure 1. Flow chart of the assignment of activity types to origin and destination of a trip.

A flow chart of the assignment of activity types to origin and destination of a trip is shown in Figure 1. The algorithm described in this flow chart applies to all trips of everybody in the population. Depending on the trip purpose, further constraints are applied to correct the assigned activity type. For

example, activity types associated with trip purpose "Education" are "Child_care_centre", "Kindergarten", "Education_primary", "Education_school", "Education_university". Choosing which type for the trip destination depends on the age of the individual making that trip.

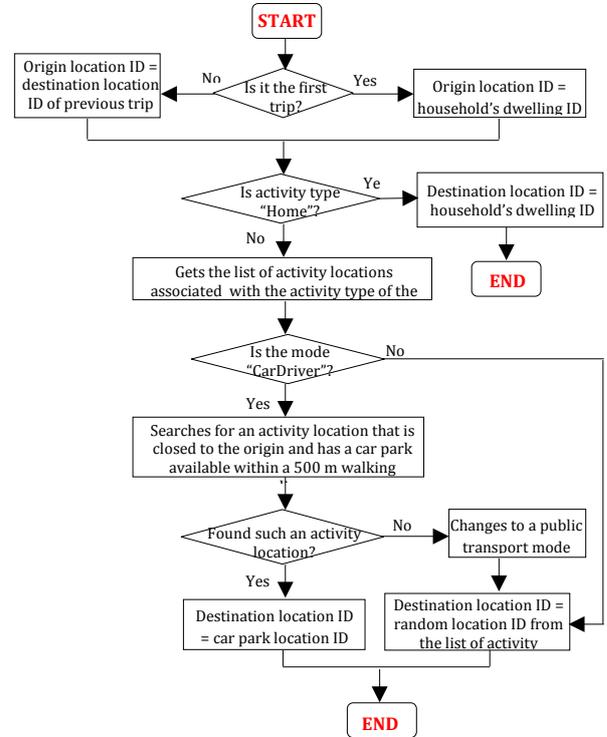


Figure 2. Flow chart of the assignment of activity locations to origin and destination of a trip.

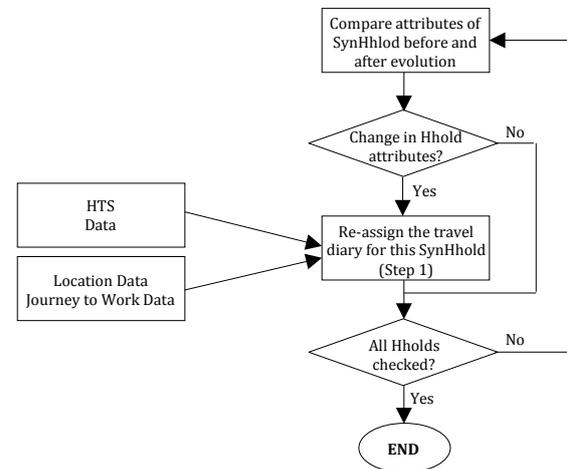


Figure 3. Travel diaries assignment for successive simulated years.

flow chart for the assignment of coordinates to trip origin and destination is shown in Figure 2. The algorithm described in this flow chart applies to all trips of everybody in the population. Travel destinations are assigned to account for the constraints of people in the same household travelling together, e.g. destination of a trip of an adult who takes a child to school is similar to the destination of a child. The Journey To Work data is used to assign work locations to work trips. This dataset provides the distribution of trip counts to/from a travel zone from/to another travel zone by each travel mode. For non-work

trips (e.g. social and recreational trips), the location of trip destinations is assigned on a random basis.

After each individual has been assigned with a travel diary and specific locations for their trips, corrections to their travel diary may be required to ensure that (i) any children under 15 years old always travel (i.e. have the same modes) with an adult in the household, and (ii) any two individuals who depart and arrive at the same time for the same trip purpose will have the same travel mode and destination. Corrections may also be required to the trip modes of an individual who drives in some trips of his/her travel diary to ensure that a car is used throughout these trips. These corrections are particularly needed after individuals make their travel mode choice (see Section 2.6) during the simulation. This is because the travel mode choice model in itself does not have the visibility of the constraints of co-travelling of individuals in a household nor the connection of trips in an individual's travel diary.

2.4.3 Updating Travel Diary Of Individuals During The Simulation

Sections 2.4.1 and 2.4.2 describe the assigning of initial travel diaries to the synthetic population. Due to changes in the synthetic household attributes (e.g. household type, number of children under 15, etc) as the population evolves, travel diaries may need to be reassigned in subsequent simulation steps to these households in the model. Figure 3 shows the process that is used to reassign/update travel diaries in households whose attributes are different the previous simulation step.

2.5 Traffic Micro Simulation

TRANSIMS was chosen as the traffic micro-simulator as, in its current iteration, it is a clean, efficient, C++-based (including good use of STL) platform that supports an individual (person and vehicle) level of modelling, and supports detailed micro-simulation of traffic to support the requirements of our software, including but not limited to:

- road-by-road and minute-by-minute analysis of traffic patterns; and
- details of what individuals are going where on public transport, and analysis of usage (raw, and percentage utilisation).

Normally one would use a process analogous to simulated annealing to arrive at the solution; running the router to establish initial routes, then finding when vehicles jam, and either redirecting them off the street temporarily into a park (if the numbers are sufficiently low) or by then re-routing them using the router and then running the simulation until numbers jammed are sufficiently low. Given the typical travel volumes (around 100,000 commuters), and our desire to simulate a 20-year period, we are forced to run only one typical weekday and weekend in simulation per year, and run only one iteration of the router. We have compared this with test runs of multiple iterations of router and the core micro-simulator of vehicle movements, and found that travel times are within 5%; this we consider sufficient for our purposes.

2.6 Transport Mode Choice

The purpose of the travel mode choice algorithm was to accurately describe the decision-making processes of individuals travelling on the transport network in the study area, thus enabling the prediction of the choice of travel modes of individuals in the population. Travel modes considered in this

study are car driver, car passenger, public transport, taxi, bicycle, walk, and other.

A multinomial logit (MNL) model was developed for this purpose. At the heart of the MNL formulation is a linear part-worth utility function that calculates the utility of each alternative travel mode choice. Independent variables for this function include the difference of fixed cost and difference of variable cost of the selected travel mode with the cheapest mode. The variable cost is dependent on the estimated travel time, which is the output of the traffic micro-simulation. Another independent variable is the individual's income, acting as a proxy for the individual's perception of value of time. Multinomial logit regression was used on the HTS data to estimate the utility coefficients vector for the possible travel modes.

3. SIMULATION RESULTS WITH REGARDS TO TRANSPORT DEMANDS AND ROAD TRAFFIC

The agent based model described in Section 2 is applied to simulate the dynamic interactions between population growth, urban relocation choice and transport demands for Randwick - Green Square, a metropolitan area in south east of Sydney, Australia. This area has a population of approximately 110000 individuals in around 52000 households that live in private dwellings.

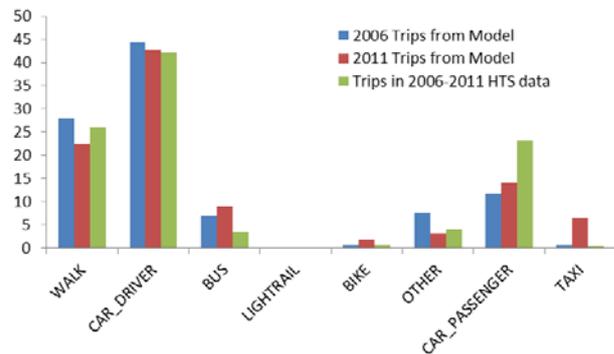


Figure 4. Percentage of trips by modes from simulation years 2006 and 2011 versus 2006-2011 HTS data.

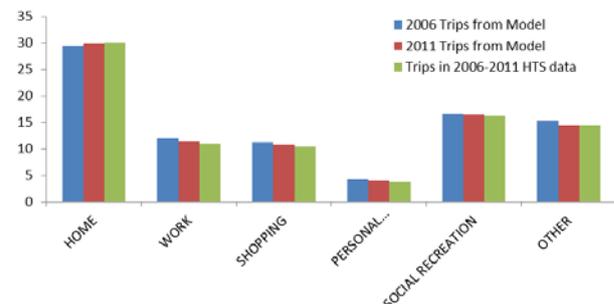


Figure 5. Percentage of trips by purposes from simulation years 2006 and 2011 versus 2006-2011 HTS data.

The simulation period is from 2006 to 2011. The initial synthetic population is constructed using the 2006 census data that is available from the Australian Bureau of Statistics. This initial synthetic population was validated that it matches the demographics of the real population at both individual level and household level, and thus is a realistic computational representation of the real population in the area [6]. It was also

shown that the synthetic population in year 2011 (i.e. after 5 simulation years) matches the demographics of the population in the study area as described in the 2011 census data. This affirmed that the algorithm to evolve the population while simulating the evolution at individual level can capture the dynamics of household structures in the population.

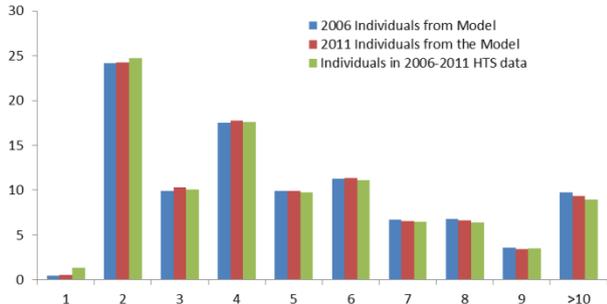


Figure 6. Percentage of population by number of daily trips for simulation years 2006 and 2011 versus 2006-2011 HTS data.

Figures 4 and 5 respectively show the percentage of trips by each mode and each purpose with respect to the total number of trips made by the whole population for year 2006 (initial year) and simulation year 2011. Figure 6 compares the percentage of individuals in the synthetic population against that in the HTS data by the number of trips made daily. The distributions in these graphs are in very good agreement with the HTS data for the whole Sydney Greater Metropolitan Area. Please note the HTS data used for comparisons in Figures 4 to 6 is the collective data of years from 2006 to 2011. This is to comply with the suggestion that three or more years of data are pooled to give reliable estimates of travel at a particular geographical level [21].

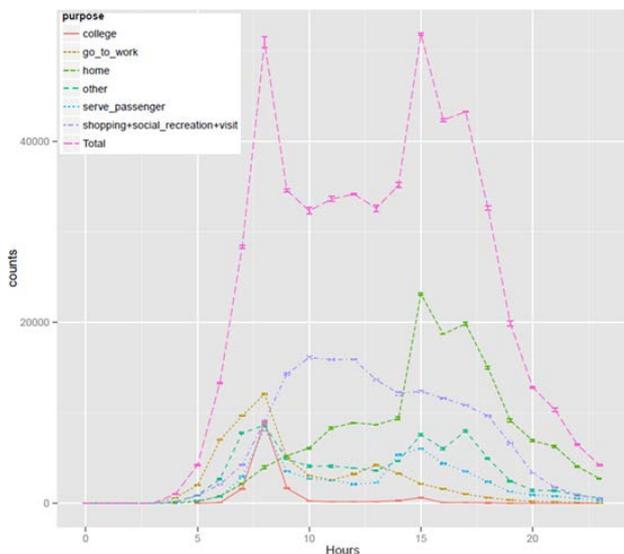
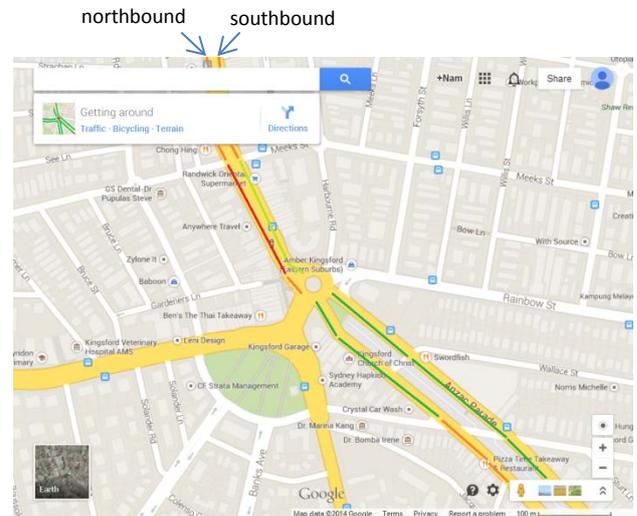


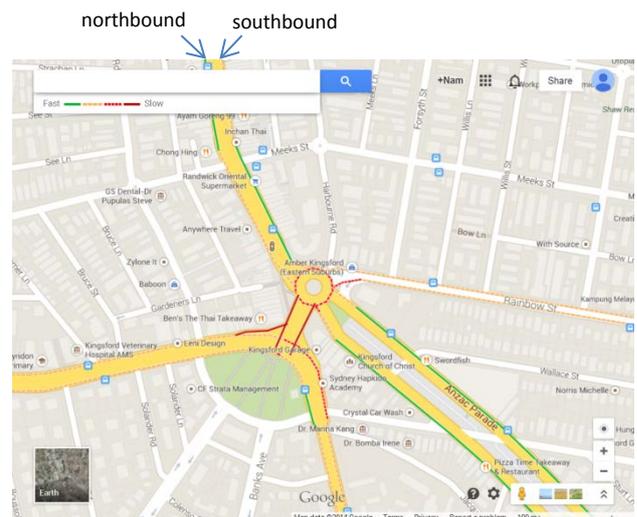
Figure 7. Trip counts by purposes over 24 hours of a representative day in year 2011.

Trip counts by purposes over 24 hours of a representative day in year 2011 are shown in Figure 7. In this figure, trips go to work and go to school both peak at 8.00am to 9.00am. Counts of trips go to work however are higher than trips to school at earlier hours (6.00am to 8.00am) which reflects early workers. Trips to work also have a smaller peak between 1.00pm and 2.00pm to reflect trips by people doing afternoon and/or night shifts. Trips for shopping, social activities, recreational and personal

services (i.e. 'visit') reach their peak at around 9.00am to 12.00pm and gradually drop in the afternoon. These observations affirm that the model can realistically reproduce the patterns of travel demand of the population in the study area as well as the change of these patterns as the population evolves.



(a) traffic density from simulation results

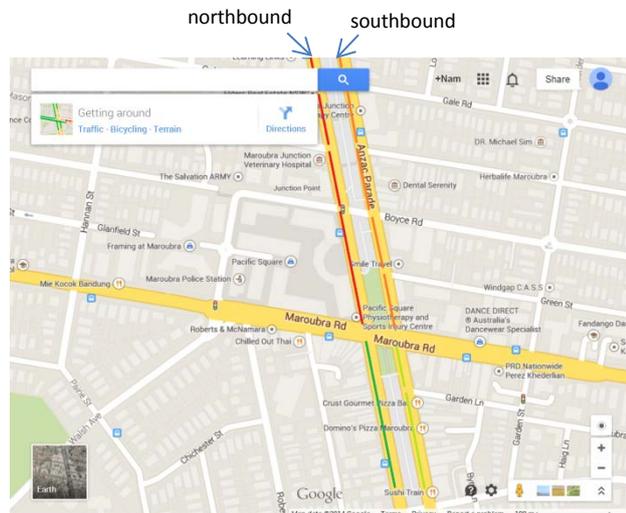


(b) congestion profile from Google Maps

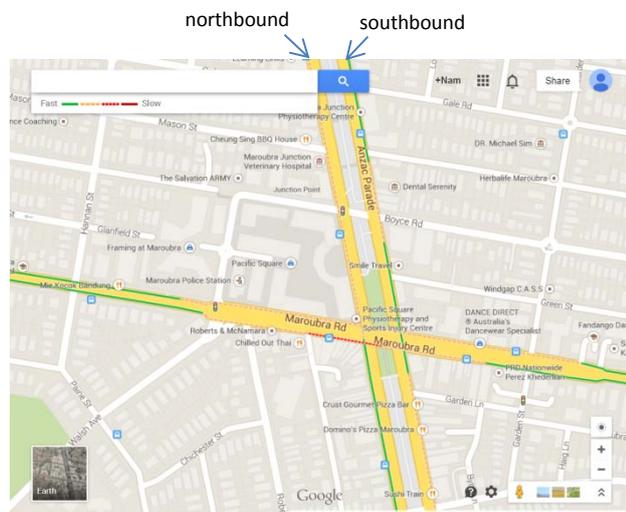
Figure 8. Traffic density on Anzac Parade near the intersection with Rainbow street in the morning peak hour.

Traffic density (that was outputted from TRANSIMS router) at two major intersections along Anzac Parade, the main road in the study area, in the morning peak hour (8.00am to 9.00am) compared against their congestion profiles from Google Maps [20] are shown in Figures 8 and 9. The model is able to reproduce the relatively higher northbound traffic density on the part of Anzac Parade north of the intersection with Rainbow street and the part of Anzac Parade north of the intersection with Maroubra Road. The southbound traffic on Anzac Parade at these two locations however is relatively less congested compared to the northbound. These results are in agreement with observations of traffic profiles from Google Maps. Qualitative trends of traffic counts at major cross sections from simulation results were also analysed and in good agreement with survey data in the study area.

Such agreement however does not occur on all parts of the road network. This could be attributed to the randomness in the assignment of activity locations to origin and destination of trips in the travel diaries of the population (see Figure 2). While the assignment of destination locations of trips related to work is constrained by the Journey To Work data, the randomness in assigning destination locations to trips of other purposes does not guarantee a realistic representation of traffic profiles in the model. Note that non-work trips have a significant proportion in the total number of trips made by the population in the study area (see Figures 5 and 7).



(a) traffic density from simulation results



(b) congestion profile from Google Maps

Figure 9. Traffic density on Anzac Parade near the intersection with Maroubra Road in the morning peak hour.

4. CONCLUSIONS

This paper has presented an agent based model for the simulation of transport demands and land use for an urban area in south east Sydney, Australia. Being comprised of six major components (synthetic population, residential location choice, perceived liveability, travel diary assignment, traffic micro-simulator, and transport mode choice) the model is able to capture the decision making of the population with respect to relocation and transport, and thus is able to explicitly simulate the dynamic interactions between population growth, transport

demands, and urban land use. This is a unique feature that has not been found in many other agent based models for urban transport and urban planning. Thanks to this feature, the model can be used for exploring long-term consequences of various transport and land use planning scenarios.

Various aspects of the simulation results on transport demands of the study area were presented, particularly the percentage of trips by each mode and each purpose with respect to the total number of trips made by the whole population, percentage of population by number of daily trips and the distribution of trips by each purpose over 24 hours of a typical day. Being in good agreement with the corresponding survey data, these results affirm that the model's capability to realistically reproduce travel demand of an urban area and any changes to this travel demand as the population evolves. This is because individuals in the model are associated with each other by their household relationship, which helps define the interdependencies of their travel diary and constrains their mode choice.

Traffic density (from TRANSIMS router) at various locations along the main road in the study area also matches with the observations of traffic congestion on the same road from Google Maps. Mismatches however occur on other (smaller) roads in the study area. This could be attributed to two factors. The first is the lack of a survey data on the origin and destination of non-work trips. The randomness in assigning a location to the destinations of these trips obviously cannot guarantee a realistic representation of traffic demands in the simulation model. The second factor is the limited ability of the TRANSIMS router to realistically reproduce the reasoning of a person in choosing a possible route for the trips the person makes, including dynamic routing to avoid heavy traffic in real time.

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