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TRESIS (Transport and Environmental Strategy Impact Simulator): Application to a Case Study in NE Sydney

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ABSTRACT: This paper presents an integrated microsimulation urban passenger transport model system (TRESIS) for evaluating the impact of a large number of interrelated policy instruments on urban travel behavior and the environment. The model system has four integrated modules defining household location and automobile choices, commuter workplace and commuting travel choices, non-commuting travel activity, and worker distributed work practices. The demand model system, estimated as a set of discrete and continuous choice models, is combined with a set of equilibrating criteria in each of the location, automobile and commuting markets to predict overall demand for passenger travel in various socio-economic segments, automobile classes and geographic locations. The current version has been developed to operate at a high level of aggregation for the Sydney region, comprising a 14-zone system, with a spider-web network, and is designed to explore the impacts of broad strategic directions. The model system is embedded within a decision support system to make it an attractive suite of tools for practitioners. We illustrate the usefulness of TRESIS to a major investment option in Northeast Sydney, to replace a bottleneck opening bridge with either bridge improvements together with improvements to a number of intersections on the roads serving the region, or several possible tunnel options, including different levels of tolls for the tunnels. The application of TRESIS to this case was considered a success, with the model providing useful outputs on the revenue implications of various alternative tolls, the impacts of the proposals on regional travel, and the likely effects on public transport ridership.

KEY WORDS: ***Integrated Transport Systems, Passenger Transport, Environmental Impact, Modelling, Policy.***

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1. Introduction

This paper presents an integrated microsimulation urban passenger transport model system (TRESIS) for evaluating the impact of a large number of interrelated policy instruments on urban travel behavior and the environment. The model system has four integrated modules defining household location and automobile choices, commuter workplace and commuting travel choices, non-commuting travel activity, and worker distributed work practices. The demand model system, estimated as a set of discrete and continuous choice models, is combined with a set of equilibrating criteria in each of the location, automobile and commuting markets to predict overall demand for passenger travel in various socio-economic segments, automobile classes and geographic locations. The current version has been developed to operate at a high level of aggregation for the Sydney region, comprising a 14-zone system, with a spider-web network, and is designed to explore the impacts of broad strategic directions. The model system is embedded within a decision support system to make it an attractive suite of tools for practitioners. We illustrate the usefulness of TRESIS to a major investment option in Northeast Sydney, to replace a bottleneck opening bridge with either bridge improvements together with improvements to a number of intersections on the roads serving the region, or several possible tunnel options, including different levels of tolls for the tunnels. The application of TRESIS to this case was considered a success, with the model providing useful outputs on the revenue implications of various alternative tolls, the impacts of the proposals on regional travel, and the likely effects on public transport ridership. As an application of a strategic model, allowing rapid turn-around of results without detailed and extensive network coding, but with the impacts on home location and workplace being reflected in the model, TRESIS provided a comprehensive regional view of the likely outcomes of the alternatives.

2. Detailed Background to TRESIS

The Transport and Environmental Strategic Impact Simulator (TRESIS) is a microsimulation package, developed at the Institute of Transport Studies (ITS). It is designed as a policy advisory tool to evaluate, at a strategic level, the impact of transport and non-transport policy instruments on urban passenger travel behavior and the environment, with a wide range of performance indicators. As an integrated model *[1], [2], [3], [4]*, TRESIS offers users the ability to analyze and evaluate a variety of land use, transport, and environmental policy strategies or scenarios for urban areas. The behavioral engine of TRESIS encompasses key household, individual, and vehicle-related decisions; in particular where a household chooses to locate (and the type of dwelling to live in), where the workers from that household will work, the household's number and type of vehicles and level of use by trip purpose, and the means of travel that will be used for household member trips by departure time. Also, within the package, the total levels of trip making and an origin-destination (O-D) matrix are estimated for each trip purpose, and the resulting trips are assigned to a strategic network. From this a range of economic and environmental impacts are estimated. In the following discussion, whenever TRESIS is referenced, the reference is to version 1.4 of the software, which is the one used in this application.

TRESIS replicates the behavior of the different decision makers such as households and travel makers. The model allows testing of various scenarios associated with land use, transport, environmental policies, and projects. The results of a base case scenario are used as references to compare with those of the policies and projects to be tested. The system generates a number of performance indicators to evaluate these effects in terms of economic, social, environmental and energy impacts. Earlier versions of TRESIS (with a 1993 base year) have been developed and applied to six Australian cities, namely Canberra, Sydney, Melbourne, Brisbane, Adelaide, and Perth *[5]*. The latest version of TRESIS modified and enhanced (with a 1998 base year) examines strategic level policy options for the Sydney Metropolitan Area *[6]*.

TRESIS has a high temporal resolution with an annual step-up to a 28-year forecasting horizon. It has full integration of land use and transport interaction in each simulation period. The highly synthetic nature of the model provides a detailed description of the base year of 1998 to be estimated within the model. TRESIS is structured around seven key systems (see Figure 1). Each component is discussed in turn below.

2.1 Simulation specification system:

This system provides a means for users of TRESIS to control (i) the types, sources, and locations of input and output from TRESIS, (ii) the heuristic rule for accommodating the temporal adjustment process, (iii) the number of future years to be simulated from the present year, and (iv) the specification to control the calibration and iteration process of TRESIS run. While all control factors are self explanatory, the heuristic rule for accommodating the temporal adjustment process needs to be clarified. The model system in TRESIS is static and hence produces an instantaneous fully adjusted response to a policy application. In reality, choice responses take time to fully adjust, with the amount of time varying by specific decision. We expect that it would take longer for the full effect of the change in residential location to occur and much less time for departure time and even choice of transport mode. TRESIS allows users to impose a discount factor that establishes the amount of a change in choice probability that is likely to be taken up in the first year of a policy. It removes the rest of the change and uses the new one-year adjustment as the starting position for the next year. Intuitively, TRESIS is assuming that, if we had a fully dynamic choice model system, we would only observe the discounted impact after each year. Different discount factors would be specified to control the temporal process of change for different choice models in TRESIS.

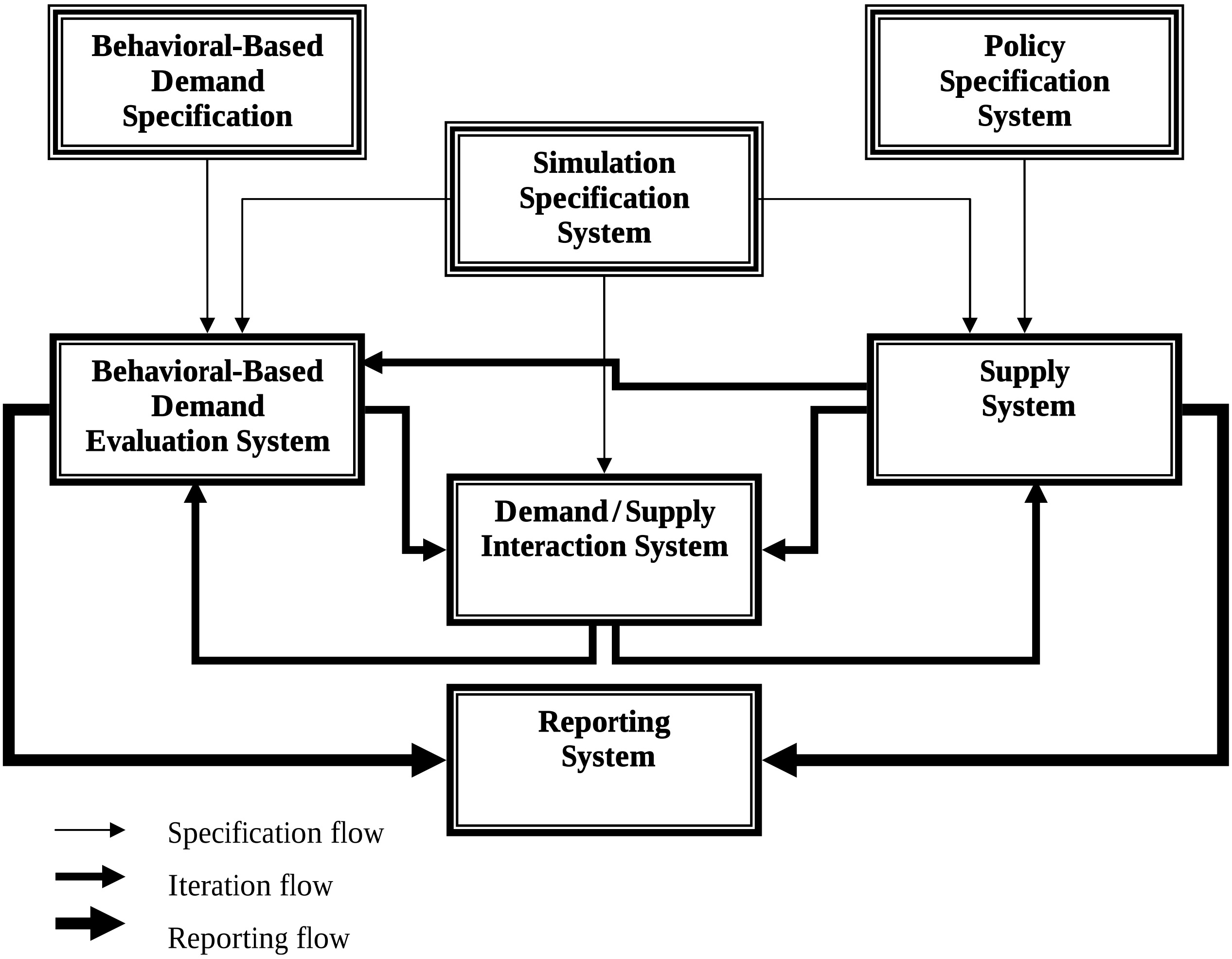

Figure 1. TRESIS Structure

2.2 Behavioral demand specification system:

This system provides the household characteristics data and model formulation for the *behavioral demand evaluation* system of TRESIS. It contains a module for constructing a synthetic household database as well as a suite of utility expressions representing the behavioral system of choice models for individuals and households. These models are based on mixtures of revealed and stated preference data *{7], [8], [9], [10], [11], [12]*: residential location choice, dwelling type choice, mode choice, trip timing, work place location, vehicle choice type, fleet size, and automobile use by location (for more details see Hensher *[13]*, Hensher *[14]*, McCarthy *[15],* McCarthy and Hensher *[16]*, *inter alia*). Each synthetic household carries a weight that represents its contribution to the total population of households. Through time TRESIS carries forward the base year weights or, alternatively, modifies the weights to represent the changing composition of households in the population. More detailed information on the specification and procedure for the generation of synthetic households to represent population data is in Ton and Hensher*[9]*.

Households adjust their residential location in response to changes in the transport system and for other reasons. Consequently any one of a number of strategies can influence the probability of a household both living in a particular location and the type of dwelling they choose to occupy. At any point in time there will be a total demand for dwelling types in each residential location. Excess demand will result in an increase in location rents and dwelling prices; excess supply will result in a reduction in the respective rents and prices. In TRESIS, dwelling prices are used to clear both the market for dwelling types and location, in the absence of data on location rents. The market clearing mechanism is linked into a set of impact indices which 'allocate' heuristically the impact of a strategy on the choice of residential location and dwelling type across time so that, in the absence of a dynamically specified adjustment process within the behavioural model set, the temporal response profile is 'realistic'. Equilibration is secured for both the dwelling type market and the residential location market. Disequilibrium is allowed for when an injection of new dwellings creates excess supply given the number of households. Under this strategy the simulator needs only to ensure that the demand for dwellings by type in a residential zone does not exceed supply for the zone. Any additional dwellings will be left vacant in the particular year as an indication that property developers may have created too much stock at that time. In future years as households grow the take up rate increases without creating increases in dwelling prices until the market is cleared.

The utilities for individuals for the different choices come from the same model and, as such, the scaling parameter is unity. In the current version of TRESIS we treat each worker as an independent chooser of a workplace location However when relating this worker model to a household residential location we added up the log sums for each worker.

2.3 Supply system:

This system contains four key databases. They are (i) the transport network database (with different levels of service for each time of day for each of six main modes of transport including drive alone, ride share, train, bus, light rail and busway), (ii) the land-use zone database (with attributes such as number of different dwelling types and associated prices, number of jobs, etc.), (iii) Automobile technology or vehicle database (number of different vehicle types and associated performance and energy indicators), and (iv) the policy and environment parameters database (carbon contents in petrol, diesel, CNG and electric vehicles and others). Key attributes (such as travel times for different times of the day, demand level and associated prices of housing) of transport network and zone databases are updated dynamically at run time during the calibration process to reflect the impact of the demand system on the supply system. In return, the newly updated attributes of the *supply* system will have an impact on the *behavioral demand evaluation* system. The iterative control process is handled by the *demand/supply interaction* system.

2.4 Policy specification system:

This is a key focus in the design of TRESIS. The richness of policy instruments is supported in TRESIS, such as new public transport, new toll roads, congestion pricing, gas guzzler or greenhouse gas taxes, changing residential densities, introducing designated bus lanes, implementing fare changes, altering parking policy, introducing more flexible work practices, and the introduction of more fuel efficient vehicles. The policy specification system employs a graphical and map-based (Map Objects) user interface to translate a single or mixture of policy instruments into changes in the supply system.

2.5 Behavioral demand evaluation system:

Given the input from the *behavioral demand specification* system and the *supply* system, the characteristics of each synthetic household are used to derive the full set of behavioral choice probabilities for the set of travel, location and vehicle choices and predictions of vehicle use.

2.6 Demand/Supply interaction system:

This system contains three key procedures to control or equilibrate the three different types of interactions between demand and supply. The key mechanism for driving these three procedures is the level of interaction between demand and supply. More detailed discussion of the underlying of these procedures is in *[6]*. The three procedures are briefly described as follows: (i) The equilibration in the residential location and dwelling type market involves establishing total demand for different dwelling types in each residential location calculated at any point in time. Excess demand will result in an increase in location rents and dwelling prices. In TRESIS, prices for different dwelling types are used to clear the markets for dwelling types and locations, in the absence of data on location rents. (ii) For equilibration in the automobile market: a vehicle price relative model is used to determine the demand for new vehicles each year. This model controls the relativities of vehicle prices by vintage via given exogenous new vehicle prices. A vehicle scrappage model is used only to identify the loss of used vehicles consequent on vintage and used vehicle prices, where the latter are fixed by new vehicle prices in a given year. The supply of new vehicles is determined as the difference between the total household demand for vehicles and the supply of used vehicles after application of the scrappage model based on used vehicle prices. (iii) For equilibration in the travel market: households might adjust their route choices between origin and destination, or trip timing and/or mode choice in response to changes in the transport system, particularly the travel time and cost values between different origins and destinations. In other words, different households can have different choices in responding to changes in different levels of service at different times of day.

TRESIS provides a comprehensive set of outputs (see Appendix A) representing performance indicators such as impacts on greenhouse gas emissions, accessibility, equity, air quality and household consumer surplus. The output is in the format of summary tables cross-tabulated by household types, household incomes and residential zones and in more detailed format by origin and destination (OD), by different times of day and by different simulation years. Table 1 summarizes the richness of policies that can be evaluated including the attributes that can be assessed in a what-if scenario setting.

Table 1: Classification of Policy Instruments via Key Input Data in TRESIS

Specific Policy	Attributes	Specific Location Application	Times of Day (TOD)
New/Existing Public Transport	Frequency; Travel Time; Fare; Access; Egress	Origin-Destination	6
New/Exiting Roadway	Distance; Capacity; Auto Travel Time; Congestion Pricing; Toll Cost	Origin-Destination	6
Parking Charges	Dollars/hour	Destination	6
Urban Density	3 categories: Houses; Semi-detached; Apartment/Flat and Associated Prices	Origin	None
Carbon Tax	Carbon Tax (cents/kg)	Not Location Specific	None
GST on New Vehicles	On New Vehicle (from 2000)	Not Location Specific	None
Automobile Technology	Mass (kg); Whole Sale Price ($); Acceleration (secs to 100 km/h); Fuel Efficiency: City (L/100 km); Highway (L/100 km)	Not Location Specific	None
Fuel Excise by Fuel Type	Wholesale Price of Petrol (cents/liter); Excise Component of Price of Petrol (cents/liter); Wholesale Price of Diesel (cents/liter); Excise Component of Price of Diesel (cents/liter)	Not Location Specific	None
Maximum Ages of Vehicles for Scrapping High Emitters	Maximum Vintage to Remove the High Emitters from Specific Classes of Vehicles (e.g. 16 years)	Not Location Specific	None
Vehicle Registration Charges	Dollars/Year for Different Vehicle Classes and Types	Not Location Specific	None
Fuel Efficiency of Current Fleet	Percentage of Fuel Efficiency of Current Fleet	Not Location Specific	None
Alternative Fuels-CNG Vehicles	6 Classes (from class 11 to class 16)	Not Location Specific	None
Price Rebate/Discounts on Vehicles	Rebate on New Vehicles	Not Location Specific	None

3. Application Issues

The behavioral choice and vehicle use models, together with the conditions for equilibration, define one part of an integrated model system. The application of the model system to evaluate a wide range of strategies and to derive useful empirical outputs requires a specification of a number of contextual dimensions. The following data inputs are required:

- The population of households
- The population of automobiles (number by type)
- The population of dwelling stock by location
- The population of employment opportunities (i.e., jobs) by location
- The attributes of automobiles
- The socioeconomic characteristics of individuals and households
- The network characteristics of each form of transport
- The future time profile of exogenous variables in a status quo scenario (e.g., fuel prices, income, population growth, dwelling prices, public transport fares and service levels, new vehicle releases, automobile prices, and attributes of new vehicles).

The sample of travelers and households used in model estimation is not used in model application. *Synthetic households* define the application units. There is a predefined number of such households in each city defined by core socioeconomic variables, e.g., the number of vehicles and lifecycle stage. A weight is attached to each synthetic household to indicate its incidence in the population. The set of socioeconomic characteristics that exist in the set of travel, vehicle, and location models is broader than the core socioeconomic variables.

To ensure that the richness of the fuller set of socioeconomic variables contributing to the explanation of each choice are captured in the definition of synthetic households, so that the diversity of household responses is captured throughout the model system, one draws additional samples from each 'core' synthetic household. The approach involves taking a random sample of households from a global source, such as the one percent unit record sample of households, conditional on each core synthetic household. Because each of these households is a random sample from a 1% random sample, we would capture the distribution of household types within each core synthetic household type. The data associated with each of these sampled households must be sufficiently rich in socioeconomic characteristics of the household and its members. For example, the variables available from the 1% sample of the Census in Australia are: at the household level, household income, dwelling type, number of vehicles; at the person level, age, industry sector, hours worked, industry, occupation, labor force status, relationship in the household, income, sex, education qualifications and mode for the journey to work. Ton and Hensher *[17]* provide full details on the derivation of particular synthetic households. We have evaluated the sensitivity of output indicators to differing numbers of synthetic households and found that a good number is in the 500 to 800 range. TRESIS can use any number of synthetic households up to 2000, chosen by the user at the calibration stage.

In application, each synthetic household is "introduced" into an urban area, carrying only a bundle of socioeconomic descriptors for each household member and the household as a whole. Through the application of the behavioral model system and given the specification of the transport network, location attributes, and automobile stock and attributes, the simulator calculates a full set of choice probabilities and vehicle use predictions associated with each of the alternatives in each of the travel, location, and vehicle demand models. The probabilities and predictions of use are expanded for each synthetic household to represent the demand by all households in the population represented by a synthetic household. The calculations are repeated for each synthetic household and then equilibration in the three markets (travel, location and vehicle) is undertaken to arrive at a final set of *demand estimates.* The set of outputs are also accumulated throughout the simulator calculations so that a comparison can be made for each application year of each output before and after the simulation of one or more policy instruments that define a strategy.

Complementing the synthetic households are data specifications for new and used automobiles by class and fuel type, the transport network for existing and new modes, spatial and dwelling attributes for residential locations, and employment attributes for workplace locations. Forecasting the set of exogenous factors through time relies on external benchmarks for population growth, household size growth, price changes for dwellings, fuel, vehicles, fares etc., and the release of new vehicles by type.

A base year for model development and implementation has to be selected (in the case study, we use 1998, with December the actual time point at which to measure all activities and external data such as vehicle registrations and population). The system has to be calibrated for the base year population profiles and then applied annually with summaries of outputs for each year over the range of specified years. Each of the behavioral models has to be calibrated to reproduce the base year shares and total on each alternative. Once the models are calibrated, the parameter set remains unchanged in all applications. New calibration is required when base input data are changed. The data items selected for calibration in the case study are shown in Table 2.

Table 2: Base Year Calibration Criteria

Decision Block	**Data Criterion**
Location (per location)	▪ dwelling type share ▪ total number of households ▪ total number of workers ▪ household fleet size distribution (0,1,2,3+)
Vehicle (per vehicle class)	▪ vehicle class shares ▪ total registered passenger vehicles ▪ total passenger vehicle kilometers ▪ household fleet size composition
Travel	▪ commuter mode share ▪ travel time (origin-destination) ▪ commuter departure time profile ▪ sample spatial and temporal work practice composition

4. The Warringah Case Study

In response to on-going traffic problems in the Warringah area, the Federal Bureau of Transport and Regional Economics (BTRE) commissioned ITS to assess the feasibility of a number of strategies for improving transport in the area. Two different tunnel options were considered, each with and without tolls, plus a do-nothing option. In the first stage of the project, ITS collected detailed travel time data on major traffic routes used to access Ku-ring-gai, Lower North Sydney and Inner Sydney from the Warringah area, using Global Positioning System (GPS) technology *[18]*. The travel time information gained was then used in TRESIS to evaluate the impact that each strategy would have on patterns of travel demand.

This section of the paper documents the second stage activities of the project, centered around the implementation of TRESIS version 1.4, in which we established baseline and options forecasts of travel demand for car and public transport modes over the period 2004 to 2025. It is assumed that the options are implemented by 2005, so 2004 represents the last year before the options are introduced. Values for 2002 are provided as a reference point to the present. Option A is two 2-lane tunnels from the Spit Bridge to the Warringah Freeway, and involves the addition of a new bridge at the Spit, and a total tunnel length of 5.1 km. Option A1 is the same, but introduces a toll of $3.50 for the tunnels in each direction. Option B extends the tunnels to 7.6 km in length, and includes a tunnel underneath where Spit Bridge currently sits, with exits into the main arterial roadways about 2 kms further northeast. Option B1 also introduces a $3.50 toll. The do nothing alternative assumes that no major works are undertaken in the area. The main results are summarized in Table 3.

From Table 3, it can be seen that the impacts of the alternatives are very small in overall terms. In general, differences in numbers of trips, VKM, bus trips, and total user money costs are quite small. Exceptions to this are found in total trips, where the tolled options (A1 and B1) decrease total trip making by around 8,000 trips per day, which stays fairly constant over the following years; the total travel time, which falls by around 100 million hours per year (600 million minutes), or about 8 percent of the total; total annual travel time cost, which falls by around $150 million dollars per year, or about 8 percent; and toll revenues, which increase by about $35 million per year for the tolled tunnels.

Table 3: Summary of Major Results for Each Option for the Warringah Region Using 2020 as a Reference Point

Statistic	Do Nothing	Option A	Option A1	Option B	Option B1
Total Trips	923,500	924,800	916,200	926,500	915,200
Commuting Trips	176,500	176,700	176,600	176,700	176,600
Total Travel Time	9,074,000,000	8,481,000,000	8,448,000,000	8,432,000,000	8,382,000,000
Total Annual Travel Time Cost	$2,242,000,000	$2,111,000,000	$2,093,000,000	$2,099,000,000	$2,077,000,000
Total Passenger VKM	2,481,000,000	2,494,000,000	2,490,000,000	2,495,000,000	2,491,000,000
Total Toll Revenues	$45,511,000	$50,484,000	$85,291,000	$51,038,000	$86,951,000
Daily Bus Trips	73,900	62,600	71,100	61,400	69,500
Total User Money Costs	$532,700,000	$537,600,000	$576,800,000	$538,300,000	$578,200,000

4.1 Detailed Results

While the overall statistics for Warringah show relatively little change with the options, these overall statistics mask somewhat more interesting shifts that take place within the more detailed sub-regions of the Sydney region. It is important to understand that overall population, jobs, and workers do not change across the options for the entire region, it being assumed that the effects of the project in Warringah will be to redistribute jobs, workers, residents, and trips. As a result, there will be generally small shifts in numbers throughout the region as the result of the implementation of any project. The main issues of interest, however, are the effects on trips that originate anywhere in the region and find a destination in Warringah, and those that originate in Warringah and find a destination anywhere in the region. Table 4 shows that there are relatively small differences in total trip making as a result of the options. The untolled options start with a lower figure for total trips in 2005 and 2010, but then climb past the do nothing case, ending, however, only at an increase of about 1,000 trips per day. The tolled tunnels result in decreased total trips, probably as a result of the tolls. The decrease is about 10,000 trips by 2025, or about 1 percent of total trip-making.

Table 4: Total Trips with an Origin or Destination in Warringah for Each Option

Option	2002	2004	2005	2010	2015	2020	2025
Do Nothing	777,800	800,300	807,000	845,000	883,700	923,500	967,000
A	777,800	800,300	805,400	843,800	886,600	924,800	968,800
A1	777,800	800,300	798,900	834,700	876,100	916,200	957,900
B	777,800	800,300	805,500	844,100	887,000	926,500	968,700
B1	777,800	800,300	799,200	835,200	877,900	915,200	958,900

Tables 5 and 6 show the numbers of households and jobs in Warringah, and show an expected relationship to Table 4. The effects of the option on households in Warringah are almost negligible. Differences are on the order of 200 to 400 households, or less than one half percent. There is a slightly greater impact on jobs in the region, with the tunnels apparently making it more attractive for employers to locate in Warringah. The overall increase in jobs under all tunnel options is about 2,000, and there is little difference between the tolled and untolled tunnels.

Table 5: Number of Households in Warringah for Each Option

Option	2002	2004	2005	2010	2015	2020	2025
Do Nothing	92,500	94,300	95,300	100,100	105,200	110,600	116,200
A	92,500	94,300	95,600	100,500	105,600	111,000	116,600
A1	92,500	94,300	95,500	100,400	105,500	110,900	116,500
B	92,500	94,300	95,600	100,500	105,600	111,000	116,600
B1	92,500	94,300	95,500	100,400	105,500	110,900	116,500

Table 7 shows the comparison of the 5 alternatives for the total trips with an origin in Warringah (zone 13) and a destination anywhere in the region for the years 2005 and 2025. (The trips with an origin anywhere in the region and a destination in Warringah is the transpose of each of these rows to a column, given the 24-hour symmetry of the trip table.)

Table 6: Number of Jobs in Warringah for Each Option

Option	2002	2004	2005	2010	2015	2020	2025
Do Nothing	74,600	76,000	76,800	80,600	84,500	88,700	93,000
A	74,600	76,000	78,200	82,400	86,500	90,900	95,400
A1	74,600	76,000	77,800	82,000	86,100	90,400	95,000
B	74,600	76,000	78,400	82,700	86,800	91,100	95,700
B1	74,600	76,000	78,000	82,200	86,300	90,600	95,200

Table 7: Comparison of Total Trips with an Origin in Zone 13 and a Destination in Zones 1-14

Option	Year	Destination Zone													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Do-Nothing	2005	39,800	8,100	8,800	7,800	6,300	4,400	6,100	12,200	6,800	11,600	65,500	30,800	590,100	8,800
	2025	48,700	9,800	10,900	9,600	7,800	5,400	7,500	15,100	8,500	14,600	79,600	38,600	700,000	11,000
A (no toll)	2005	40,900	8,500	9,200	8,000	6,500	4,500	6,700	12,500	6,800	11,600	68,600	30,600	582,300	8,800
	2025	50,900	10,700	11,400	10,000	8,200	5,600	8,400	15,600	8,400	14,400	85,900	38,300	690,000	10,900
A1	2005	41,300	8,600	9,200	8,100	6,600	4,500	6,800	12,500	6,800	11,600	58,600	30,700	584,800	8,800
	2025	51,500	10,800	11,600	10,200	8,300	5,600	8,500	15,700	8,500	14,500	70,500	38,400	692,700	11,000
B (no toll)	2005	41,100	8,600	9,200	8,100	6,500	4,500	6,700	12,500	6,800	11,600	69,300	30,500	581,400	8,800
	2025	51,100	10,800	11,500	10,100	8,200	5,600	8,400	15,600	8,500	14,500	86,900	38,300	688,500	10,900
B1	2005	41,500	8,700	9,300	8,100	6,600	4,500	6,800	12,600	6,800	11,700	59,300	30,600	584,000	8,800
	2025	51,800	10,900	11,600	10,200	8,300	5,700	8,600	15,800	8,500	14,600	71,700	38,400	691,900	11,000

As can be seen from the table, all of the options favor travel to and from the CBD (zone 1), compared to the do-nothing case. Within the options, there are only small differences in the trip numbers. All of the tunnel options reduce the number of trips that start and end within Warringah (zone 13). Travel to and from zones 5 (Fairfield-Liverpool), 6 (Outer South Western Sydney), 9 (Outer Western Sydney), 10 (Blacktown-Baulkham

Hills) and 14 (Gosford-Wyong) is essentially unaffected by the options, while travel to and from zone 11 (Lower Northern Sydney) increases even more than to and from the CBD for the untolled tunnels, but decreases significantly for the tolled tunnels. These shifts are about what one would expect. It is important to note, however, that the total number of trips within the Northern Beaches area represent about 75 percent of the total trip making. Therefore, the trips moving into and out of the region are a small percentage of total trip making.

Table 8 shows the impact of the alternatives on total travel time for residents of Warringah. It can be seen that the tunnel options save significant amounts of travel time, especially alternative B1. The time savings result partly from a reduction in total trips and partly from increased speeds in the tunnels and on the competing surface roads.

Table 8: Comparison of Total Travel Time for Warringah Residents (Millions of Minutes)

Option	2002	2004	2005	2010	2015	2020	2025
Do Nothing	7,192	7,461	7,555	8,032	8,535	9,074	9,654
A	7,192	7,461	7,038	7,500	8,006	8,481	9,039
A1	7,192	7,461	7,022	7,465	7,957	8,448	8,975
B	7,192	7,461	6,984	7,441	7,943	8,432	8,960
B1	7,192	7,461	6,975	7,419	7,919	8,382	8,924

Table 9 shows the expected annual total toll revenues for residents in Warringah. The Do Nothing case covers the tolls on all the other toll roads in the region. The increments under the tunnel options show both additional tolls paid on such facilities as the Harbour Bridge and Tunnel, and the M2, M4, etc., and A1 and B1 show the additional amounts that would be obtained from the new tolled tunnels across the Middle Harbour. From this Table, one can see that toll revenues will increase by about $3 million per year to about $5 million per year on the other toll facilities of the region under option A, and from about $3.5 million per year to about $5.5 million per year under option B. However, the toll tunnels across Middle Harbour bring in a total toll revenue increase on the order of $35 million in 2005 to $42 million in 2025, although it is not possible to determine how much of those increases are paid on other toll facilities in the region.

Table 9: Comparison of Total Annual Toll Revenues Paid by Warringah Residents ('000 dollars)

Option	2002	2004	2005	2010	2015	2020	2025
Do Nothing	$38,111	$39,205	$39,521	$41,371	$43,378	$45,511	$47,818
A	$38,111	$39,205	$42,648	$45,555	$48,092	$50,484	$53,181
A1	$38,111	$39,205	$74,114	$76,918	$81,104	$85,291	$89,643
B	$38,111	$39,205	$42,983	$46,007	$48,576	$51,038	$53,657
B1	$38,111	$39,205	$75,315	$78,498	$82,904	$86,951	$91,612

Overall, the tunnel options do not improve the bus share of the market, because they represent additional roadway capacity in and out of the Northern Beaches area, and consequently result in an increase in car use. Even the imposition of an all-day toll of $3.50 in 2002 constant dollars does not result in an increase in public transport use. Rather, it has the effect of reducing the decline in the public transport market share in the region, but does not reverse it. Total trip making on a daily basis increases with the untolled tunnels, and decreases with the tolled tunnels. Both changes are on the order of one percent of trips. The tunnels leave the population of the Northern Beaches almost unchanged, but increase the number of jobs by about two percent, and the number of workers in the region by less than one percent.

While total travel is barely affected, there are shifts in travel, with more travel being made to the CBD. With the untolled tunnels, travel increases even more significantly to the Lower Northern Sydney area, while travel to this area decreases sharply under the toll options. However, total travel into and out of the Northern Beaches area comprises only about 25 percent of all travel made in the region.

As might be expected, total commuting time and travel-time costs are reduced by the tunnel alternatives. These reductions are on the order of seven to eight percent. However, passenger vehicle kilometers of travel increase by less than one half of a percent. Toll revenues under the two tunnel toll options appear to be quite significant, and increase even with the untolled tunnels, because of the increased use of other tolled facilities around Sydney.

Bus patronage is lower under all options than without the tunnels. The reductions in bus use are significantly greater for the untolled tunnels than tolled. The decline under the untolled options puts bus patronage from Warringah residents back to a level that would probably have been reached about 12 years earlier without the tunnels. With tolls imposed on the tunnels, the decrease in public transport patronage is about 2,000 bus riders per day.

5. Conclusions

Is an ongoing development with a number of new initiatives in progress. The major new developments include the replacement of the expansion of commuter trips to all trips with a suite of non-commuting mode, timing, destination, and frequency models; the generalization to an urban area’s maximum number of traffic zones (e.g.,904 in Sydney) but with a capability to choose the number of zones in conjunction with the number of synthetic households (mindful of the exponential increase in memory and computational time in processing the baseline calibration as well as applications); a restructure of the TRESIS architecture to facilitate portability to different urban areas anywhere in the world; and new methods to aggregate or disaggregate networks as the number of traffic zones are changed. The gaps that are noted for future research in particular are a property market model for land and housing, a new vehicle release predictive model for automobiles, and a choice model system to predict the demand for alternative distributive work practices (e.g., telecommuting, compressed work week). Like all integrated model systems there are weaknesses, however we believe that TRESIS offers the potential to be the most flexible of all currently available integrated land use, transport and environment packages with user-friendly input and output interfaces.

The application of TRESIS to the Warringah study was considered to be a success. The study required a strategic level tool, where individual facility impacts were not of interest. It was rather intended to assess the overall feasibility of a tunnel to replace the bridge, and to assess the likely revenue generation of different levels of toll for the tunnel. The application satisfied these needs, without entailing a major set of runs of a conventional four-step modeling procedure. Most of the weaknesses of the model are also, in a sense, its strengths. In this current version, the model is highly aggregate, and therefore relies on rather broad specifications of the capacity and level of service of links between the 14 zones. This means that it requires exogenous input of the speeds and capacities of these links, and is not a model that will estimate the link-by-link changes in speeds and levels of service. However, it does well at the strategic level in estimating the changes in overall travel times for the region, based on these aggregate connections. The model is also unable to provide information on what happens within a zone. With very large zones, this could be a problem for some types of local policies, which would not be appropriate to test with this version of TRESIS. However, the ongoing change to a 904-zone version for Sydney will permit more local policies to be tested.

The fact that TRESIS showed rather small overall impacts in transport performance and other indicators seems to the authors to be very realistic. There is a tendency for many more detailed models to over-predict the amount of change that will take place in a region as a result of a single relatively localized investment.

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TRESIS 1.4 outputs

Note: A trip = A Person Trip (e.g., 2 persons ride sharing = 2 person trips)

Output	Description	Units	Comments
TCO2(kg)	Total annual carbon dioxide	Kilograms (kg)	Car (includes all passenger automobiles – sedan, wagons, utes, panel vans, 4WD).
NOx (kg)	Total annual nitrogen oxides	Kilograms (kg)	Car, based on 1.03 grams/vkm
CO (kg)	Total annual carbon monoxide	Kilograms (kg)	Car, based on 1.08 grams/vkm
NMVOC (kg)	Total annual ……	Kilograms (kg)	Car, based on 0.53 grams/vkm
N2O (kg)	Total annual nitrogen dioxide	Kilograms (kg)	Car, based on 0.01 grams/vkm
CH4 (kg)	Total annual chlorofluorocarbons	Kilograms (kg)	Car, based on 0.01 grams/vkm
TEUC.MC ($98)	Total annual end-use money cost	Dollars ($)	All person trips, includes for car: op cost, regn charges, annualised vehicle cost, parking, toll, congestion charge; for PT=fares
TEUCPV.MC ($98)	Total annual end-use money cost in present value terms	Dollars 98 ($98)	All person trips, 8% discount rate
TEUC.OC ($98)	Total annual end-use operating costs	Dollars 98 ($98)	All person trips, car operating cost plus public transport fares
TEUCPV.OC ($)	Total annual end-use operating costs in present value terms	Dollars 98 ($98)	All person trips, car operating cost plus public transport fares
TEUC.TTC ($98)	Total annual end-use travel time cost	Dollars ($)	All person trips; with travel time for ride-share for each person in car (converted to $s). Tu: check for PT it includes all components of time.
TEUCPV.TTC ($)	Total end-use travel time cost in present value terms	Dollars 98 ($98)	All person trips; with travel time for ride-share for each person in car (converted to $s). Tu: check for PT it includes all components of time.
TEUC.Time (min)	Total annual end-use travel time	Minutes (min)	All person trips; with travel time for ride-share for each person in car. Tu: check for PT it includes all components of time.
TEMUDTMC ($98)	Total annual expected maximum utility from each model system for each of the model components defined - by the mode choice (CMC) links.	Dollars ($)	Replace TEMUCMC with this and Tu to recalculate using full set of 36 exp*V functions etc
TEMURLC ($98)	Total annual expected maximum utility from each model system for each of the model components defined - by the linkage: residential location choice (RLC) links	Dollars ($)	

Output	Description	Units	Comments
ACCDTMC(Utility units)	Accessibility Indicators - by departure time and mode choice (DTMC) links.	Utility units	
ACCRLC(Utility units)	Accessibility Indicators - by the linkage: residential location choice (RLC) links	Utility units	
TVKM(km)	Total annual passenger vehicle kilometers	Kilometers (km)	Car
TVKMTwAw(km)	Total annual passenger vehicle kilometers: to/from work and as part of work	Kilometers (km)	Car
TVKMOU(km)	Total annual passenger vehicle kilometers: other urban	Kilometers (km)	Car
TVKMNonU(km)	Total annual passenger vehicle kilometers: non urban	Kilometers (km)	Car
AvOpCost(c/km)	Average operating cost of autos	C/km	Car
VehAnnCost($98)	Annualised automobile capital cost	Dollars ($)	Car, 15 yrs at 8% real rate of interest, 11.68% amortisation factor pa, on 85.5% of value (15% residual value)
VehOpCost($98)	Total annual auto operating cost	Dollars ($)	Car. Fuel prices assumed to increase by 0.05% pa
Tvehicles(number)	Total passenger vehicles	Number	Cars
Tenergy(liters)	Total energy consumed by passenger vehicles	Liters	Car (petrol and diesel)
TGovtVehReg($98)	Total government revenue from auto ownership	Dollars ($)	Car
TGovtExcise($98)	Total government revenue from fuel excise	Dollars ($)	Car (petrol and diesel)
TGovtCarbT($98)	Total government revenue from carbon tax	Dollars ($)	Car (petrol and diesel)
TGovtSalesT($98)	Total government revenue from sales tax (GST post 2000)	Dollars ($)	Car (petrol and diesel
TTollRev($98)	Total revenue from toll roads	Dollars ($)	Car
TPark($98)	Total revenue from parking strategy	Dollars ($)	Tpark ($) Car
TRCong($98)	Total revenue from congestion pricing	Dollars ($)	Car
TPT($98)	Total revenue from public transport use	Dollars ($)	All PT (all modes, private and public). Fares assumed to remain at $98 levels over 1999-2017
TGVehPurCost($98)	Total government revenue from vehicle purchase cost	Dollars ($)	Car
TVehMaxAgeValue($98)	Total cost of vehicle maximum age buyout	Dollars ($)	Car
TGVehRebCost($98)	Total government vehicle rebate cost	Dollars ($)	Car
THhld(number)	Total number of households	Number	Growing at 1% per annum
Tpop(number)	Total number of people resident in each city	Number	Growing at 1% per annum
TWrkrRes(number)	Total number of workers (p/t and f/t) in each residential location	Number	Growing at 1% per annum

Output	Description	Units	Comments
TWrkrWork(number)	Total number of workers (p/t and f/t) in each workplace	Number	Growing at 1% per annum
TDA(proportion)	Modal share for car drive alone mode share	Proportion	All person trips
TRS(proportion)	Modal share for ride share	Proportion	All person trips
Ttrain(proportion)	Modal share for train travel	Proportion	All person trips
Tbus(proportion)	Modal share for bus travel	Proportion	All person trips
TLrl(proportion)	Modal share for light rail travel	Proportion	All person trips
Tbwy(proportion)	Modal share for busway use	Proportion	All person trips
TDA(PA)(number)	Total number of annual car drive alone trips	Number	All person trips
TRS(PA)(number)	Total number of annual car ride share trips	Number	All person trips
TTrain(PA)(number)	Total number of annual train trips	Number	All person trips
TBus(PA)(number)	Total number of annual bus trips	Number	All person trips
TLrl(PA)(number)	Total number of annual light rail trips	Number	All person trips
TBwy(PA)(number)	Total number of annual busway trips	Number	All person trips
Class01micro	Vehicle Class Proportion Class 1	Proportion	Cars
Class02small	Vehicle Class Proportion Class 2	Proportion	Cars
Class03med	Vehicle Class Proportion Class 3	Proportion	Cars
Class04upmed1	Vehicle Class Proportion Class 4	Proportion	Cars
Class05upmed2	Vehicle Class Proportion Class 5	Proportion	Cars
Class06large	Vehicle Class Proportion Class 6	Proportion	Cars
Class07lux	Vehicle Class Proportion Class 7	Proportion	Cars
Class08lcom	Vehicle Class Proportion Class 8	Proportion	Cars
Class094WD	Vehicle Class Proportion Class 9	Proportion	Cars
Class10ltruck	Vehicle Class Proportion Class 10	Proportion	Cars
Class11EVsm	Vehicle Class Proportion Class 11	Proportion	Cars
Class12EVmed	Vehicle Class Proportion Class 12	Proportion	Cars
Class13EVlge	Vehicle Class Proportion Class 13	Proportion	Cars
Class14AFsm	Vehicle Class Proportion Class 14	Proportion	Cars

Output	Description	Units	Comments
Class15AFmed	Vehicle Class Proportion Class 15	Proportion	Cars
Class16AFlge	Vehicle Class Proportion Class 16	Proportion	Cars
RVKMPCar	Vehicle kilometers per vehicle	Vkm/Car	Cars
RVKMPVehicle	Vehicle kilometers per vehicle	Vkm/veh	DELETE
RVehiclePHhld	Vehicle per household	Veh/hld	Cars
RC02PVKM	CO2 per Vehicle kilometer	CO2/vkm	Cars
REnergyP100VKM	Energy per 100 Vehicle kilometers	Litres/100km	Cars
RVehPCapita	Vehicle per capita	Veh/capita	Cars
RGCPersT ($98)	Generalised cost per person trip for car	$/car person trip	Cars, includes travel time (converted to $s) and all money costs
RGCOPers ($98)	Generalised cost per person trip for car	$/car person trip	Cars, includes travel time (converted to $s) and only car op cost
RGCPubT ($98)	Generalised cost per person trip for PT	$/PT person trip	All modes of public transport, fares plus travel time (converted to $'s)
RTEUGCPersT ($98)	Total end use generalized cost per person trip	$/person trip	Sum of TEUC.OC plus TEUC.TC ($98)
REMUDTMCPersT ($98)	Departure Time and Mode Choice Consumer surplus per person trip	$/person trip	
REMURLCPersT ($98)	Residential Location (total) Consumer surplus per person trip	$/person trip	
CmcAll (all trip matrices)	Number of all trips by mode	Number	
CmcCom (commuting to and from work trip matrices)	Number of commuting trips by mode	Number	