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MetroScan: A Quick Scan Appraisal Capability to Identify Value Adding Sustainable Transport Initiatives

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Abstract: One of the most important features of comprehensive land use and transport planning is an ability to identify candidate projects and policies that are adding value to the sustainable performance of transport networks and to the economy as a whole. Standard methods of identifying a shortlist of projects to assess are often qualitative in nature and/or influenced by prejudices of elected officials or their advisers without a systematic way of narrowing the many potential options to evaluate, in sufficient detail, a truly value-adding set. There is a case to be made for having a capability to undertake, in a timely manner, a scan of a large number of potentially worthy projects and policies that can offer forecasts of passenger and freight demand, benefit–costs ratios and economy-wide outcomes. Such a framework would then be meaningful in the sense of offering outputs that are similar to those that are the focus of assessments that are typically spread over many months, if not years, on very few projects, which may exclude those which have the greatest merit. This paper introduces MetroScan, a strategic-level transport and land use planning application system that allows for mapping of passenger and freight activity, as well as an endogenous treatment of the location of households and firms. We summarise the analytical framework of MetroScan and show its capability (including the many useful outputs) with a case study for a 25 percent reduction in public transport fares across the entire network.

Keywords: MetroScan; integrated transport and land use tools; freight and passenger sector; demand applications; benefit–cost analysis; economic impact analysis; case study

1. Introduction

A very early phase in the development of strategic transport plans is the identification of a list of potentially relevant initiatives, be they projects, network enhancements, policies, or mixed programs. In one sense, this is a relatively subjective process, often tinged with the 'pet project' motive or the political promise (if we are elected). In some jurisdictions, 'experts' are asked to express a view on a long list of possible initiatives, sometimes using a subjective ranking or rating scale. Whatever procedures are used in this exercise, the call for more formal methods, such as demand forecasting, benefit–cost analysis, and economy-wide economic impact assessment, is typically limited to a significantly reduced number of possible initiatives (often a single project with small variants), and in the case of major infrastructure, such as a motorway, a rail corridor, or bus rapid transit, often requires significant resources in the evaluation process and a timeline that can stretch for many months, if not years.

It has been recognised for many years that there is a need for a technically robust way of assessing a long list of initiatives in a quick manner that is informative about real prospects of patronage and/or freight demand costs and benefits, in addition to economy-wide impacts in terms of jobs, GDP, and income. There is, however, a gap in the transport planner's toolkit that supports a very transparent and quick scan capability that can refine the appeal of specific initiatives in a context in which it is possible to claim (within reasonable practical bounds) that these are indeed the best, in a value adding sense, prospective initiatives that may be worthy of a more detailed investigation or that have shown sufficient merit through a quick scan to proceed with.

To meet these needs, we have designed a complete, all-in-one forecasting and scanning system enabling us to conduct quick forecasting on the demand characteristics for cars, public transport, freight activities, and many other travel demand characteristics. The system can also provide related costs and benefits for different transport modes and passengers and freight activities, as well as the economic impact for any related changes. We named the system MetroScan Transport Infrastructure, or MetroScan for short. The overview of this system is depicted in Figure 1. In terms of the policy cycle, MetroScan is a tool to assist the process of need identification, as well as being useful for appraisal at a strategic level. Analysts have to define the overarching setting in terms of societal goals, such as improved accessibility, reduced emissions, reduced congestion, improved productivity, and so forth. MetroScan provides numerous outputs that are aligned with these societal goals (see Appendix A).

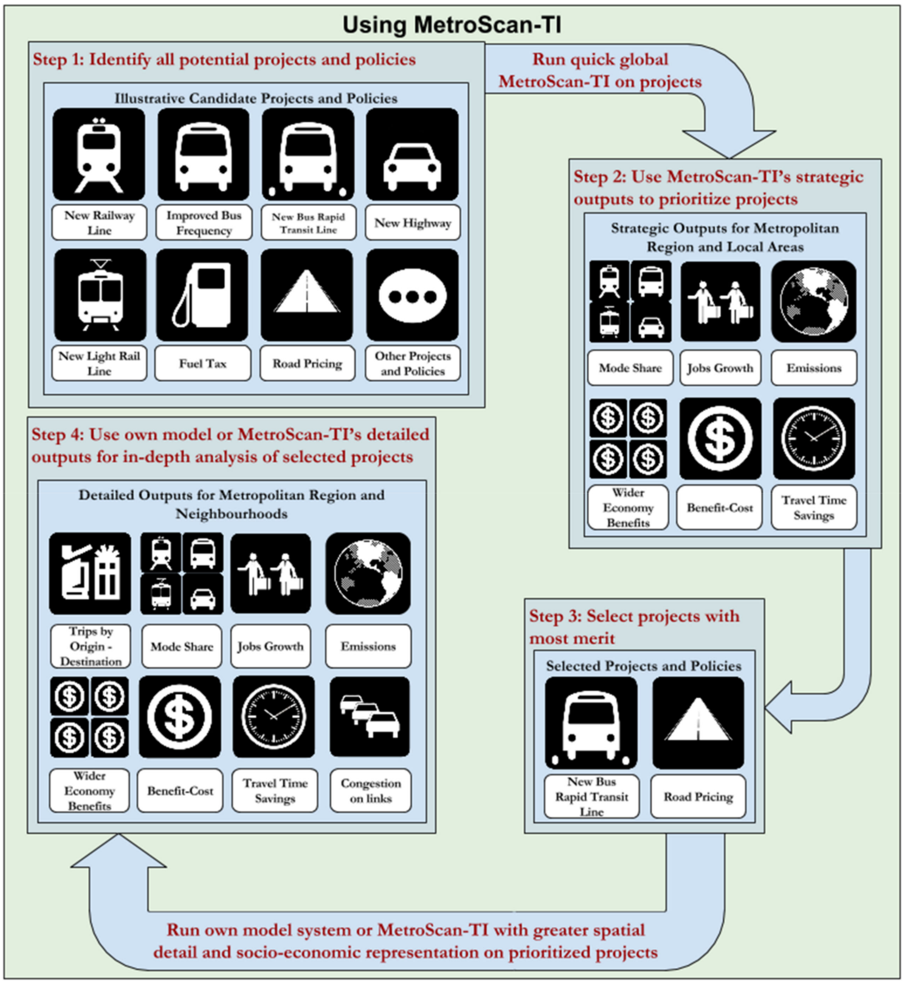

Figure 1. An overview of the practical appeal of MetroScan.

Pre-existing models on both the demand and supply sides of transport developed by researchers and governments are important components for such a system. Such models include models on mode shares in relation to road and transit; models on socio-demographics, such as residential and work choices; models for mode choice for any origins and destinations and trip purposes; models for job and firm location choices; models for freight demand and more. These models were developed based on data from either primary or secondary research and calibrated for the entire Metroscan system for the Greater Sydney Metropolitan area. The models work coherently within the MetroScan system to ensure consistency in forecasting results covering different applications for any chosen spatial or aspatial scenarios.

The purpose of the paper is to illustrate how different demand and supply models associated with transport and location decisions are used to obtain forecasts of outputs of interest associated with the performance on the transport system, with a specific emphasis on indicators related to sustainability, and what a transport change means for the benefit–cost ratio of specific initiatives, and beyond that to the broader economic impacts such as jobs and regional GDP. The MetroScan framework consists of a user front end, a backend engine executing models on a high-performance computer (HPC), and a large number of forecasting outcomes presented on web pages in both spatial or aspatial forms using tables or graphs and stored in database servers for use. Key elements of the system include model parameters; synthetic data representing people, households, and firms; as well as calibration, rules, and assumptions applied in the forecasting process. These elements work jointly to process any scenarios of interest chosen by users. The resulting outcomes differ from the default setting ("base scenario") with scenario analysis used to identify changes in the performance of the transport system and its impact on the wider economy.

A new transport and related economic planning system with models and analytical tools should stay relevant to the overall purpose of identifying and adding core values to potential new transport planning initiatives and goals. The new initiatives, like any major infrastructure ones, would often require federal or state investments and have long-term social and economic benefits or costs to implement. Integrated systems like MetroScan aim to provide informed evidence on the costs and benefits associated with specific transport initiatives, recognizing that a rich model system must have the capability to accommodate the many behavioural responses that the passenger and freight sectors are likely to use in responding to change circumstances. The great majority of transport planning tools have a passenger focus and a limited number of behavioural choices stemming from the four-step modelling framework that has existed since the 1960s, with the major improvements in strategic metropolitan models being the addition of a time of day choice model and some refinements in the sophistication of the modal choice model to accommodate additional influences such as travel time reliability and crowding. The freight sector has been totally ignored with rare exception [1], the spatial resolution of which is so detailed that it typically takes hours if not days to undertake a single scenario analysis where such spatial detail is unnecessary, as well as limiting the number of scenarios to assess.

In developing a setting for MetroScan, we wanted to avoid using the word 'project' since it has become a very narrow imposition on opportunities to provide network wide opportunities that are more value-adding through a structured program than simply seeing projects as the drivers of best performance outcomes (in some jurisdictions, project packaging is used to attract private sector participation (PPPs), which tends in many cases to reduce the risk to the private partner but increase the loss of social value to society by neglecting alternatives that might be network focussed). We found the word 'initiatives' appealing since it removes the focus on projects, and especially large infrastructure projects, giving smaller but potentially very effective improvements a chance to show their metal. This opens up recognition of many spatial and aspatial initiatives that can add value within the context of demand outcomes (both passenger and goods (including services)), benefit–cost outcomes, and in economy-wide impacts.

If a planning tool is to be of value to many users, it must also recognise the heterogeneity of outputs (and presentational formats) that are likely to be requested. It will always be a challenge to try and prescribe a set of popular performance metrics; however it is necessary to do so but with sufficient flexibility in choosing the sets that are of interest and to be able to add in measures that may not be in the available set. We summarise an extensive array of main outputs in Appendices A and B.

In addition to the breadth of outputs, we needed to offer sufficient flexibility in choosing amongst candidate initiatives, be they spatial or aspatial, infrastructure (transport—passenger and freight, and land use (housing and businesses))-related, or changes in service levels, including pricing reforms or changes. Examples of non-spatial policies are fuel excise, congestion charging (cordon and/or distance-based), public transport fare changes, changing work patterns, controlling emission levels by introducing fuel efficient vehicles, autonomous vehicles, etc. Spatial policies include changes in travel times by specific modes, increases in the frequency of public transport between certain areas, local parking policies, changing residential and/or business densities, including the mix of dwelling types and tenures status, etc. In addition to such policies, MetroScan is capable of analysing specific initiatives, such as expansion of certain road infrastructure; introduction of specific new public transport lines, walkways, and cycle ways; the introduction of toll roads; and extensions to rail and bus networks.

This article fills an important gap in the broader literature on integrated transport and land use model systems in metropolitan areas in at least four important ways. First, in integrating passenger and freight movement models into one system so that the influence of each sector on the other can be accounted for. Second, our model allows for an endogenous treatment of the location of both residences and firms, with the latter having an important influence on the number of jobs in various locations, which has feedback implications on travel-related decisions. Third we seamlessly integrated the outputs of the demand forecasting module (Tresis) into the benefit–cost and economic impact analysis modules (Tredis), ensuring full consistency between the evidence from all modules. Fourth, we offer a much expanded set of behavioural and policy relevant outputs (listed in Appendices A and B), which are typically limited in all other integrated transport and land use model systems. The theoretical underpinnings of the integrated system are presented in other papers listed in the references by the MetroScan team.

To illustrate the importance of the first point, using Metroscan and introducing a distance-based road usage charge (DBC) of 20 cents per kilometre for trucks and 5 cents per kilometre for passenger vehicles, we assessed the impact on travel time, defined as the total end-use travel time in present value terms [1]. For a DBC on only cars, there is a 4.38% improvement in travel time, which when combined with a DBC for trucks, improves further to 5.23%, given a gain of 3.42% for trucks. This is an expected result given the dominance of cars in the road network. If only trucks were subject to a DBC, the travel time benefit for cars improves by only 0.39%; however, trucks obtain a 4.19% increase in benefit. This highlights the importance of accounting for both cars and trucks, since the impact is profound on the other sector regardless of whether it is also subject to a DBC.

In summary, the MetroScan framework is the product of extensive development over many years of advanced travel and location choice models that have been fully embedded in one integrated system so that the relationships including feedback can be accommodated as it the case in real markets. Key papers that provide relevant details are [2–10]. The current papers focusses on synthesising how the behavioural components are structured in a single integrated framework and an application to illustrate the rich outputs associated with travel demand, benefit–cost, and economic impact, with the application run talking no more than 1 h using advanced high speed computing.

2. Methodology

There are two platforms within MetroScan that were extensively enhanced from previously developed forecasting and planning tools covering assessment of transport initiatives on two levels: (1) transport demand and related components, and (2) economic impact including costs and benefits. The tool for transport demand is the Transportation and Environment Strategy Impact Simulator or "TRESIS", specialising in simulating and forecasting the impact of any changes to the transport environment, including mode choice, passenger, road, transit, land use, environment, and other considerations in the transport field [2,3]. The tool for assessing aspects of economic impact is called "TREDIS", the Transportation Economic Development Impact System. This is a system developed by the Economic Development Research Group (EDRG) in the USA. The purpose of the system is to evaluate economic impacts to inform the differences between two alternatives: the "build" alternative (e.g., introducing new policies or building new infrastructure) and the "no-build" (e.g., remaining as status quo) [11–14]. The system provides economic forecasting results that can be aggregated or disaggregated by spatial, temporal, and categorical elements, including increasing returns to scale at the industry level.

In MetroScan, these two separate tools become two modules that can be used independently or jointly. If a researcher is only interested in a travel demand forecast, then the TRESIS module can provide the assessment results. If the researcher is also interested to know the potential economic impact, then travel demand outputs can be directly inputted to the TREDIS module for estimation and forecasting. The TREDIS module can also be used as a standalone tool to provide economic impact assessment for any travel demand inputs not generated from the TRESIS module. A schematic overview of the MetroScan modules is shown in Figure 2.

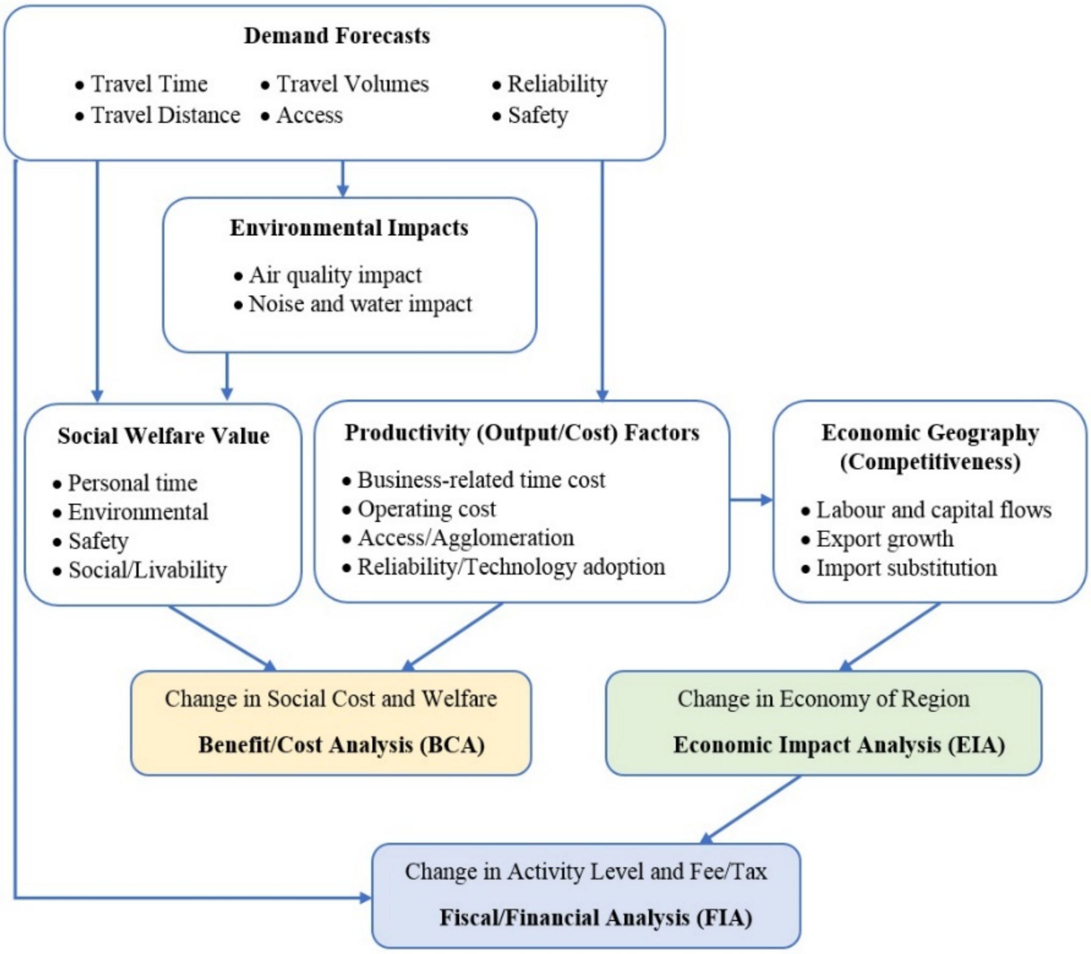

Figure 2. A schematic overview of MetroScan.

Figure 2 summarises the connections between the three main components of travel demand, benefit–cost, and economic impact. Benefit–cost analysis (BCA) compares the discounted net present value of social benefit streams and cost streams, providing a measure of the efficiency of investments in terms of their relative payback value. Economic impact analysis (EIA) depicts the expected change in the economy of a particular region, state, or nation at future points in time and recognises impacts on labour markets, capital flows, exports, and imports.

MetroScan integrates, in a seamless and transparent way, all of the features in Figure 2, enabling the analyst to select a scenario of interest (e.g., reduce public transport fares) and perform a quick scanning task to obtain demand forecasts, benefit–cost outputs, and economic analysis outputs. The front-end interface allows users to make many different kinds of policy changes on spatial or nonspatial instruments, such as changes to public transport fares, introduction of a carbon tax, and new infrastructure, be it roads or public transport. The behavioural models underlying the user-friendly interface integrates the macro generator and the two modules of TRESIS and TREDIS. Figure 3 shows how spatial and non-spatial aspects are integrated to perform assessments and forecasts and Figure 4 shows the many demand-side behavioural models, such as those for passengers, vehicles, public transport, and freight, that act simultaneously or in sequential order to generate travel demand forecasts for follow-up analysis (e.g., environmental impact, BCA, and EIA). Details of various components of the behavioural demand modelling system are given in Hensher et al. [1–5], Ho et al. [6,7], Ho and Hensher [8], and Ellison et al. [9]. In those papers, we also provided a review of other model developments that are embedded to varying degrees in integrated transport and land use model systems. Metroscan differs from any other known model frameworks in that it seamlessly integrates advanced travel demand models for passengers and freight movement and location models for residential and business location decisions, together with benefit–cost analysis and economic impact analysis.

While MetroScan can evaluate a large number of initiatives, it is not designed to identify needs; however, once these needs are identified, MetroScan is a powerful framework within which to evaluate initiatives that align with an interpretation of needs.

Figure 3 shows how the macro generator works by taking inputs from existing transport models, such as the road and public transport network, and any OD matrices for the starting year to be used as a base, then uses the network travel times and distances by time of day. Characteristics of households, such as dwelling, household types, or car ownership, in synthetic data carry sociodemographic and behavioural elements into the system. The scheme also uses some defaults for values and distributions to fill in gaps when input data or models do not support such information (e.g., population growth rate or inflation rate). One of the central features of the macro generator is the adoption of macrozones. These macrozones can be predefined using the standard zone definition (e.g., from the Australian Bureau of Statistics), but can also be manually defined in the system. The macro generator can aggregate any OD skims to the macrozone layer. If executed outside the system, this would be a difficult task that can require months to correct. MetroScan has this process automated so changes to any OD skim matrices can be contemplated on the macrozone level when a proposed initiative is being processed. To provide further background, the macro generator applies a data manager to manage imported networks from different origins, such as TRANSCAD, VISUM, EMME, CUBE, and other systems. While preserving the accuracy for fast scanning, the macro generator largely reduces many detailed zones to a manageable number of macrozones, including the ones made by users. By doing so, initiatives under investigation can be assessed very fast in order to generate forecasting results from travel demand and economic impact. A trade-off exists between computation time and accuracy due to the detailed level of the macrozone. For example, in Sydney, there are over 3000 detailed zones in the transport network. In practice, we would apply 60 macrozones, which could satisfy both accuracies of forecasting and efficiency of the computation process. In reality, the forecasting results for major macro zones would also provide more meaningful and actionable insights for policymakers. Many strategic initiatives also start with higher levels of macrozones and request scanning results at the same level from travel demand to economic impact factors.

The TRESIS module was designed to apply synthetic households as units to gain numerous responses to alterations in the system driven by both broad and in-depth policy measures as presented in Figure 4. TRESIS applies a large number of choice models on both the macro and micro level, including behavioural aspects, providing more behavioural realistic market responses robust in contrast to traditional model systems. TRESIS processes and delivers forecasts for different modes, travel purposes, and time-of-day choices for medium to long-term decisions up to 20 to 30 years (i.e., currently forecasting up to 2056). It also suggests long-term decisions or choices on vehicle types, fleet size, vehicle technology, residential and work locations, job and firm growth areas, dwelling types, and many others. Besides forecasting commuting, non-commuting trips, such as personal business and social purposes, and business trips, light commercial vehicle, and freight commodity models support business activity responses by location, volumes, and trips at macrozone levels.

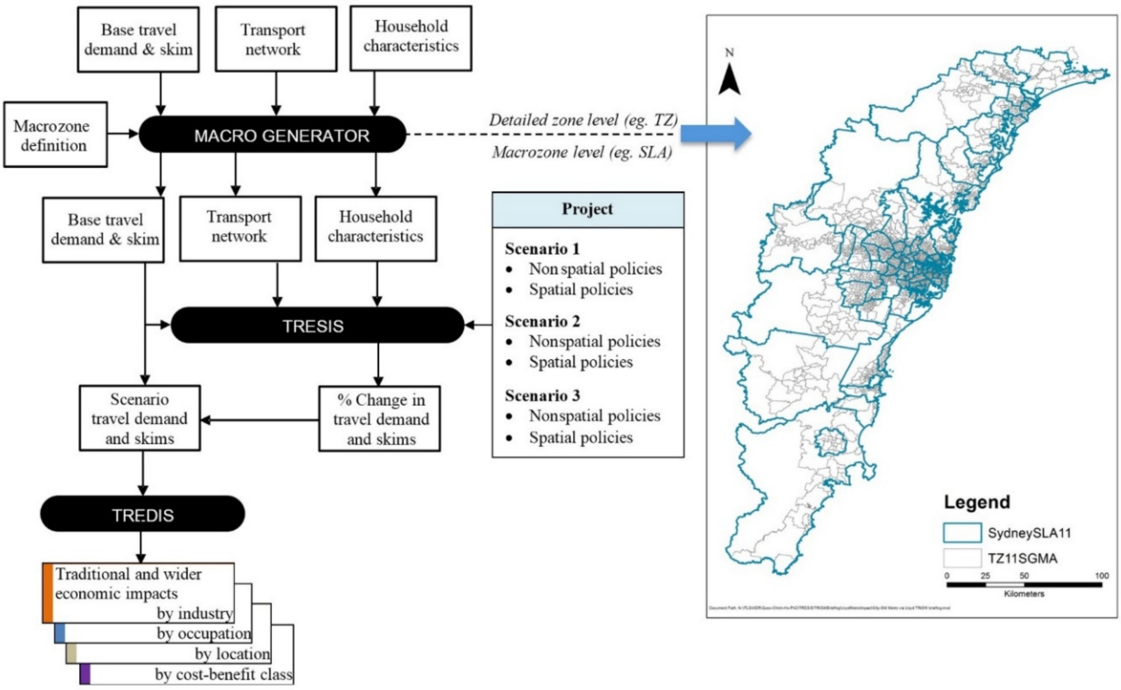

Figure 3. MetroScan framework.

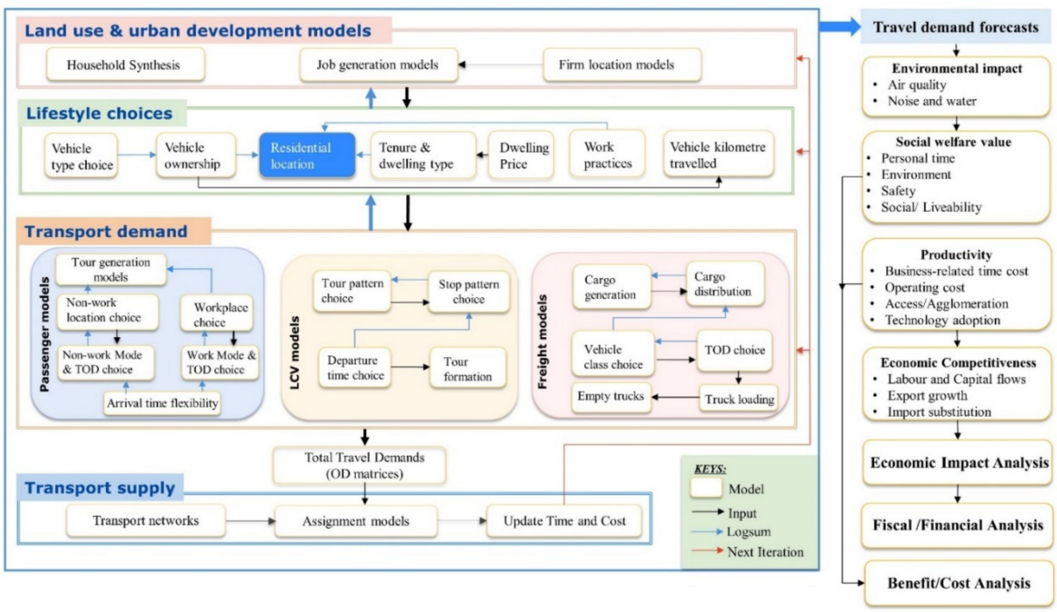

Figure 4. The demand-side behavioural model system for passenger, light commercial, and freight travel activity and the benefit-cost analysis (BCA) and economic impact modules.

Models implemented in TRESIS were originally developed using data from primary household travel surveys. All behavioural travel and location choice models were estimated as either discrete choice models of the multinomial nested logit form (if the dependent variable was discrete) or a regression model for continuous variables such as house prices and vehicle kilometres. The behavioural parameter estimates are typically location specific, but can be adapted by the user to other locations with appropriate model calibration. TRESIS makes forecasts for the base year, and for any variant that is specified, and instead of using these absolute forecasts, a relative change (percentage) between the base and the variants is calculated, which is then applied to the base year obtained from the original model. The pivot point method ensures consistency with the original model while avoiding the need for re-calibration. TRESIS uses synthetic household samples to simulate all household choices over the years [10]. It also uses its own internal traffic assignment routines. The assignment module in MetroScan utilises the open-source traffic assignment platform PLANit (https://github.sydney.edu.au/PLANit), developed at ITLS (University of Sydney). The assignment configuration is hard-coded and conducts a traditional static traffic assignment with the following properties: route choice and network loading is done by deterministic user equilibrium (DUE), following Beckman et al. [15]; the shortest path algorithm is Dijkstra one-to-all; smoothing uses the method of successive averages (MSA); the number of iterations is user configurable; when set to 1 (default), DUE collapses to an all-or-nothing (AON) assignment; the duality gap threshold is user configurable; and the approach overall is based on [16].

The TREDIS module was built on a widely accepted system worldwide specialising in benefits and costs and economic impact analysis for transport initiatives. The economic impact analysis (EIA) quantifies the impacts of the short-term construction activity, ongoing maintenance, changes in household expenditures due to fees, and efficiency improvements to local business from improved access, faster travel times, and reduced delay. The EIA captures the multiplier effects of spending in terms of direct, indirect (supplier effect), and induced (income effects).

Direct impacts represent the change in household expenditures from user fees and transit fares. These direct impacts, in turn, stimulate shifts in demand for local goods and services resulting in changes to indirect and induced effects—sometimes called "multiplier" or "spinoff" effects.

Indirect impacts represent the additional economic activity associated with business-to-business purchase of goods and services, or supplier impacts. In this case, changes in vehicle operating expenditures. Each supplier has a portion of its revenue change and will also use that revenue to pay workers as well as their own supply chain.

Induced impacts are the additional household spending from worker income on items such housing, retail purchases, and services. Those expenditures support jobs in associated industries, whose workers then spend their salaries in the three regions of the model.

From a user's perspective, the online front-end enables users to design scenarios consisting of one or more initiatives, such as reducing travel time on roads and increasing public transport fares at the same time, either in all areas or particular OD locations. The scenario then triggers the macro generator and the two modules of TRESIS and TREDIS to run in the background, with both formatted reports and data sets generated. Some of the most popular outputs requested are summarised in Table 1. In the following sections, we illustrate the application of MetroScan through an assessment of the impact of a 25 percent reduction in public transport fares across the entire network.

Table 1. Indicative outputs from MetroScan.

Initiatives/Policies	Outputs
Spatial policies	Residential, employment location
Change in PT service frequency	Industry and occupation patterns
Introduction of new PT lines	Economic activity patterns
Expansion of roads, motorways	Mode and ToD travel patterns
Introduction of toll roads	Demographics and commuting
Change in parking policies	Freight shipment patterns
Change in residential densities	Environmental impacts
And many more	Tax revenue impacts
Nonspatial policies	Business outputs
Change in PT fare	Total jobs created
More flexible work practices	Total value added
Emission/congestion charges	Operating, maintenance costs
Introduction of greener vehicles	Net benefits
And many more	Cost-Benefit Ratio

3. Case Study: A Reduction in Public Transport Fare Levels

To illustrate the various outputs that Metroscan can provide, we set out in some detail the results associated with a 25 percent reduction in public transport fares for all services in the Greater Sydney Metropolitan Area, which includes the Sydney Metropolitan area, Newcastle (including lower Hunter) to the north and Wollongong to the south), and report the results for 2025, although MetroScan produces results for every year up to 2056. MetroScan can also be applied to assess many other policy initiatives such as infrastructure improvements (for example, a new road, new public transport, extra capacity on an existing road), as well as broad-based policy changes, such as a carbon tax, road pricing reform, and density of housing and firms in specific locations.

A 25% reduction in transit fares would be captured using the "charge per passenger trip" variable that is most commonly used for transit fares. The following sections describe how we validated the data that we input so that it was logically consistent with the narrative around the scenario that we expected, describe how cost–benefit information can be interpreted for this scenario, and describe how economic impact information can be interpreted for this scenario. The reduction in PT fares case study does not include any capital costs and hence the cost–benefit analysis and economic impact analysis show the results of the lower fare and reduction in transit revenue, as well as the increase in travel time and lost trips.

In interpreting changes in travel, the differences presented in tracing validation represent the change in conditions as the base case minus the policy or alternative case. Therefore, negative values in the tracing validation screen correspond to higher values in the travel metric in the alternative case. Positive values represent reductions in travel metrics. The reduction in transit fares by 25 percent would result in savings of 1.7 billion total vehicle kilometres travelled and 38.2 million fewer vehicle hours (as shown in Table 2) for the Greater Sydney Metropolitan region. For meaningful analysis in terms of both cost–benefit analysis and economic impact analysis, these vehicle hours needed to be converted to passenger hours. Over 47.1 million hours of in-vehicle user time were eliminated from car modes, with over 100 million passenger trips no longer made by car. Compared to personal travel, car travel changes for business purposes would result in almost a net zero change in passenger trips made by car, about 30 million fewer vehicle kilometres travelled, but an addition of passenger time considering vehicle occupancy. There would be a shift from driving alone to shared rides for business travellers, but no real decrease in car utilisation. We allowed for out of vehicle time only for public transport transit travel, which was quite small, and reliability savings (gross buffer time), with the latter decreasing by 7 million hours for on-road users.

Table 2. Car-only extract from the "change in travel characteristics" report for trips originating in the Greater Sydney Metropolitan region in 2025.

Reduction/Savings in:	Car DA Business	Car RS Business	Car DA Personal	Car RS Personal	Car Totals
Gross Vehicle Trips	1,492,736	(599,599)	79,949,592	8,274,158	89,116,887
Gross VKT	60,143,520	(27,613,698)	1,438,592,768	235,373,184	1,706,495,774
Gross VHT	1,287,220	(685,509)	32,766,562	4,804,496	38,172,769
Gross Out of Vehicle Hours	0	0	0	0	0
Gross Buffer Time (hours)	130,316	(157,470)	6,979,600	97,155	7,049,601
Passenger Trips	1,492,736	(1,552,961)	79,949,592	25,567,148	105,456,515
Passenger Kilometres	60,143,520	(71,519,478)	1,438,592,768	727,303,139	2,154,519,949
Passenger Hours	1,287,220	(1,775,469)	32,766,562	14,845,893	47,124,206

The 25 percent fare reduction would have the expected effect of shifting car travel to transit (see Table 3). Note that this policy-level analysis does not provide any additional transit service, which is represented by the zeros for the vehicle trip, distance, and time variables. Overall transit passenger trips would grow by 111.9 million in 2025 and result in 81.9 million net new passenger hours on transit. It appears some business travellers would reduce their bus use, shifting to train and the car rideshare mode (as was shown in Table 2).

Table 3. Transit-only extract from the "change in travel characteristics" report for trips originating in the Greater Sydney Metropolitan region in 2025.

Reduction/Savings in:	Bus Business	Train Business	Bus Personal	Train Personal	Transit Totals
Gross Vehicle Trips	0	0	0	0	0
Gross VKT	0	0	0	0	0
Gross VHT	0	0	0	0	0
Gross Out of Veh Hours	19	(1)	(11,803)	(16,850)	(28,635)
Gross Buffer Time (h)	0	0	0	0	0
Passenger Trips	51,252	(9337)	(45,694,004)	(66,208,241)	(111,860,330)
Passenger Kilometres	1,870,589	(73,597)	(689,842,433)	(1,842,711,278)	(2,530,756,719)
Passenger Hours	54,777	(2781)	(33,757,660)	(48,189,707)	(81,895,371)

When comparing transit and car modes, Table 4 confirms that the transit trips would make up for and exceed the lost car trips, demonstrating the mode shift from car to transit because of the lower fare. In total this would generate 6.4 million net new trips, 6% more added to transit than removed from cars. Additionally, the number of passenger kilometres added would be 376 million in 2025, which represents 17.5% more kilometres travelled on transit than had been in cars, indicating some circuity. Finally, 74% more hours would be spent on transit in the fare reduction alternative than that removed from cars, reflecting slower trip speeds.

Table 4. Passenger mode totals (cars and transit) for trips originating in the Greater Sydney Metropolitan region in 2025.

Reduction/Savings in:	Car Totals	Transit Totals	Pass. Totals
Passenger Trips	105,456,515	(111,860,330)	(6,403,815)
Passenger Kilometres	2,154,519,949	(2,530,756,719)	(376,236,770)
Passenger Hours	47,124,206	(81,895,371)	(34,771,165)

Turning from passenger travel to freight movement, Table 5 summarises the two types of freight trucks included in the MetroScan model. The imposition of the 25% fare reductions that removes car trips would result in creating 900,290 net new truck trips due to mode shifts from car to transit alleviating congestion, improving travel times, and increasing speeds. The increased truck trips add another 154 million truck kilometres and 2.1 million truck hours in 2025. Tonne-hours would also increase by 32 million in 2025 for the Greater Sydney Metropolitan region.

Table 5. Freight truck extract from the "change in travel characteristics" report for trips originating in the Greater Sydney Metropolitan region in 2025.

Reduction/Savings in:	Truck Rigid Freight	Truck Articulated Freight	Truck Totals
Gross Vehicle Trips	(441,034)	(459,254)	(900,288)
Gross VKT	(60,961,856)	(93,152,704)	(154,114,560)
Gross VHT	(949,328)	(1,136,148)	(2,085,476)
Freight Tonne Trips	(2,593,283)	(10,769,518)	(13,362,801)
Freight Tonne Kilometres	(358,455,713)	(2,184,430,909)	(2,542,886,622)
Freight Tonne Hours	(5,582,049)	(26,642,671)	(32,224,720)

We now consider how these changes in travel can be valued as cost savings (or dis-savings) to households and businesses. After summarising the changes provided by the travel inputs we need to convert transportation performance metrics to monetary values. The results of these changes are summarized in Table 6 for trips originating in the Sydney Metropolitan Region in 2025.

Overall, passengers would save about $264 million in travel costs (in Table 6, Year 2025 row (totals of all rows below), all columns except Truck Rigid Freight and Truck Articulated Freight) with positive and negative savings in several categories and with differences across modes and purposes. The analysis also shows overall passenger time cost in cars declining as passengers shift to transit. The majority of the decline in passenger car trips are for personal trips and suggest that business trips are less able to change modes. This analysis shows a passenger cost savings of $815 million from the primary value of travel time savings (VTTS) for cars, (Table 6. Passenger Cost (In Vehicle) row, Car DA Business + Car RS Business + Car DA Personal + Car RS Personal columns) but $1449 million in negative passenger time cost savings (Table 6. Passenger Cost (In Vehicle) row, Bus Business + Train Business + Bus Personal + Train Personal column) (plus a further $760,500 cost increase from out of vehicle time (Table 6. Passenger Cost (Out of Vehicle) row, Total column)) for transit, resulting in an overall increase in traveller time costs of over $634 million per year (Table 6. Passenger Cost (In Vehicle) + Passenger Cost (Out of Vehicle) rows, Total column). This is moderately balanced by the $123.8 million in reliability cost savings (Table 6. Reliability Cost row, Total column). The costs associated with travel distance are fuel costs and taxes (calculated based on litres of fuel per kilometre), and maintenance and wear and tear costs, the two primary costs for operating a car (other than charges and fees). By eliminating significant vehicle kilometres travelled (VKT) for passenger cars, cost savings from fuel and maintenance would exceed $849.2 million (Table 6. Fuel Cost w/Taxes + Veh O&M Cost rows, Car DA Business + Car RS Business + Car DA Personal + Car RS Personal columns).

There would be a $2.75 million reduction in fees paid from per vehicle kilometre charges due to elimination of VKT, and therefore lower toll contributions (Table 6. Fee per Vehicle Kilometre row, Total column). Fees per passenger trip on transit would increase by $79.9 million (Table 6. Fee per Passenger Trip row, Total column) (negative cost savings) in 2025 for the Greater Sydney Metropolitan region (despite a 25% per trip decrease) due to the additional ridership, which would predominantly come from shifts in personal travel.

For freight travel, there are costs associated with travel time. While the VTTS for passengers is reported as "Passenger Cost", freight trucks have both negative crew cost and freight cost savings associated with fewer additional trips and travel time as observed Table 5. For the transit fare policy scenario, nearly $114 million of new time costs were estimated for freight (Table 6. Crew Cost + Freight Cost rows, Truck Rigid Freight + Truck Articulated Freight columns). Unlike passenger cars, freight vehicles see an increase in fuel and operating and maintenance costs due to the increase in VKT. Fuel cost would increase by $82 million in the Greater Sydney Metropolitan region in 2025 (Table 6. Fuel Cost w/Taxes row, Truck Rigid Freight + Truck Articulated Freight columns), with another $273 million in vehicle operating costs (Table 6. Veh O&M Cost row, Truck Rigid Freight + Truck Articulated Freight columns), resulting in a total increase of $355 million in distance-based freight costs under this scenario (Table 6. Fuel Cost w/Taxes + Veh O&M Cost rows, Truck Rigid Freight + Truck Articulated Freight columns). Under the transit fare reduction scenario, there would be no changes in fee costs for freight.

Table 6. Screenshot of the "cost savings by type" report for Case 2 considering trips originating in the Greater Sydney metropolitan region in 2025 ($1000s).

Reduction/Savings in:	Car DA Business	Car RS Business	Bus Business	Train Business	Car DA Personal	Car RS Personal	Bus Personal	Train Personal	Truck Rigid Freight	Truck Articulated Freight	Total
Passenger Cost (In Vehicle)	73,989	−102,054	3149	−160	580,623	263,069	−598,186	−853,922	0	0	−633,490
Passenger Cost (Out of Vehicle)	0	0	1	0	0	0	−314	−448	0	0	−761
Crew Cost	0	0	0	0	0	0	0	0	−32,132	−37,805	−69,937
Freight Cost	0	0	0	0	0	0	0	0	−8317	−35,701	−44,018
Reliability Cost	7491	−9,051	0	0	123,679	1722	0	0	0	0	123,839
Fuel Cost w/Taxes	8789	−4167	0	1395	210,235	33,556	0	0	−21,398	−60,642	167,768
Veh O&M Cost	21,303	−10,278	0	488	509,550	80,192	0	0	−107,902	−164,880	328,472
Fee per Vehicle Trip	0	0	0	0	0	0	0	0	0	0	0
Fee per Passenger Trip	0	0	18,242	17	0	0	−52,712	−45,525	0	0	−79,978
Fee per Passenger Kilometer	0	0	0	0	0	0	0	0	0	0	0
Fee per Vehicle Kilometer	−2116	−267	0	0	4089	1046	0	0	0	0	2752
Safety Cost	0	0	0	0	0	0	0	0	0	0	0
Environmental Cost	0	0	0	0	0	0	0	0	0	0	0
Induced Benefit	0	0	0	0	0	0	0	0	0	0	0

We also captured travel costs and changes over time; however, in this case the changes between the base and transit fare scenario are fairly consistent over time and slightly increase over time. These annual estimates are important for the proceeding cost–benefit and economic impact analysis sections, which look at the cumulative effects to the regions over time.

3.1. The Cost–Benefit Perspective

The summary table for cost–benefit analysis is shown in Table 7 (all monetary concepts are in millions of AUD). The key categories for this policy scenario have been expanded so that the component discounted streams can be seen. The transit fare reduction scenario would result in overall disbenefits of $5.3 billion AUD, discounted at 7%, as mode shifts to transit result in longer travel times and added freight cost. The results for a discount rate of 3% are also displayed.

Table 7. Screenshot of the summary table for cost–benefit analysis for a 25% fare reduction.

	7% Discount Rate	3% Discount Rate
Present Value of Benefit Stream	−5319.91	−9452.11
Travel Benefits	−3696.50	−6258.53
Value of Consumer Surplus From Induced New Activity	0	0
Value of Improved Travel Time Reliability	1674.07	2942.42
Value of In-Vehicle Travel Time (IVTT)	−9720.74	−17,026.87
Value of Out-of-Vehicle Travel Time (OVTT)	−10.023	−17.597
Value of Safety Improvement	0	0
Value of Vehicle Operating Cost (VOC)	4360.19	7843.52
Environmental and Social Benefits	0	0
Logistics & Supply Chain Cost Savings	−945.294	−1644.78
Transfer Benefit Effects (net benefit adjustment)	−678.114	−1548.80
Revenue Collected by Government	−678.114	−1548.80
Present Value of Cost Stream	−678.114	−1548.80
Project Costs	0	0
Cost Adjustments	−678.114	−1548.80
Revenue Collected by Government	−678.114	−1548.80
Residual Value of Capital Spending	0	0
Net Benefit (Benefits—Costs)	−4641.80	−7903.31
Benefit Cost Ratio (Benefits/Costs)	7.845	6.103

Although on-road users would see an increase in travel time reliability (1.8 billion AUD), the reliability benefits would be dwarfed by the increase of in-vehicle travel time (−9.7 billion AUD from both passengers and truck drivers). Vehicle operating costs and fuel savings would be a direct result, shown in overall fewer VKT being driven (substantial decreases in personal car VKT, with modest increases in freight VKT, resulting in a total discounted benefit over 35 years of 4.4 billion AUD), but again would be less than the loss of $9.7 billion from additional in-vehicle travel time. Reported under "wider economic (productivity) benefits", shippers (or receivers) would experience over 0.9 billion AUD of disbenefits from increased freight costs distinct from driver time and VKT-associated costs.

In the MetroScan, increases in fees are represented as disbenefits and reductions in government cost. Following this logic the present value of the benefit stream is negative due to $687 million in new transit revenue collections. This reflects the discounted payment stream described earlier with transit revenues increased by $80 million in 2025, due to additional ridership despite the 25% fare reduction. Due to the fact that there is no spending associated with this policy scenario, total costs are negative (reflecting positive government revenues from the policy/scenario). This means that the net benefit of the scenario would be a loss of 4.6 billion AUD (the first two rows under net benefits do not consider freight logistics costs). Although benefit–cost ratios are provided, they do not have a meaningful interpretation given that the discounted benefit stream and cost stream are both negative values.

This case study did not account for how higher ridership will impact the transit agency's ability to operate, or if there will be additional costs despite no changes in service, routes, or headways. Although not reported here, the value of benefits and cost and net benefits reports provide annual details on undiscounted and discounted benefit flows and can be matched to the cost savings by type report.

3.2. Economic Impacts

We now turn to the economic impact results. The transit fare reduction policy does not include any construction outlays, changes in transit service levels, or significant accessibility changes. All effects are driven by behavioural impacts in MetroScan of less expensive forms of travel for passengers. This would result in system users transferring payments from their budgets for car travel partially to transit fares. Household net savings can be spent on other goods and services, while the portion going to transit fares are held by the government or service provider. For this transit fare reduction, the freight and truck travel responses drive a significant portion of the changes in economic activity as trucks would accrue $354 million in additional vehicle operating costs and fuel, along with an additional $70 million in crew costs and $44 million in freight costs in 2025 due to additional VKT and VHT. These shifts in monetary flows for freight and households are the drivers of changes in economic activity. Changes in business travellers' time and monetary costs are relatively negligible in this case study, although they are tracked by the model.

Flows previously spent on transportation (car travel in this case), would be removed from the industries they would have flowed to in order to be reallocated to the household's general basket of goods or transit fares. This can be seen primarily in industries automotive repair and maintenance, and motor vehicle and parts—other transportation equipment manufacturing. The other primary flow is related to higher costs for trucks. Costs increases for truck travel are passed on to the industries that make and use the commodities carried by the trucks. If the additional transit fare collections were modelled as expansions in transit operations or transit investments, the economic impact estimates below would likely be larger in the supported sectors or if travel was further improved in a way that affected monetary flows.

The following sections review each of the four key economic impact metrics. The following sections only present results for the year 2025 as an example.

3.3. Business Output (Sales)

The reduced transit fare would result in an overall decline in economic activity. Without initial capital outlays to improve transit service, the shifts in household expenditures from car expenses to PT fares would result in some net loss of economic activity. An even larger drag on the economy would result from the added truck costs produced by the new travel estimated by Metroscan. Regionally, the result would be an average annual net loss of $892 million in business output per year for the Sydney metropolitan region, a net loss of $176 million for the Newcastle and Hunter region, and a net loss of $160 million for the Wollongong region.

For the Sydney Metropolitan region, automotive repair and maintenance and motor vehicle parts and equipment manufacturers would be the top two industries impacted as a direct result of reduced VKT, which reduces the demand for vehicle maintenance, parts, and insurance as there is less wear and tear on vehicles. Additionally, industries like professional technical services and finance would see large declines in major consumers of the commodities carried by trucks in the urban area. The decline is almost entirely attributed to added truck cost, as business traveller cost changes are very small compared to truck costs, and these sectors are not heavily tied to household consumption.

For the Sydney Metropolitan region, industries would show positive growth, benefitting from household out-of-pocket cost savings. These gains are shown along with the industry declines in Table 8. The largest change would come to ownership of dwellings and the accommodations sector. The Sydney Metropolitan region is the only region with significant growth in industries outside of ownership of dwellings. Many of the other industries showing positive growth are a direct result of additional disposable household income for goods and services, like healthcare, education, and sports and recreation.

Table 8. Top 10 positive and negative changes in output for 2025 – Sydney Metropolitan region in millions of AUD.

Industry	Decrease	Industry	Increase
Automotive Repair & Maint.	−$383.6	Ownership of Dwellings	$157.3
Motor Vehicles & Parts; Equip. Mfg	−$372.6	Accommodation	$27.7
Prof., Sci, and Tech. Services	−$69.2	Finance	$24.6
Non-Res Property Operators & Real Estate	−$40.9	Residential Care & Social Assist.	$23.7
Wholesale Trade	−$33.7	Health Care Services	$22.4
ISP, Internet Pub., Websearch & Data	−$28.4	Food & Beverage Services	$21.1
Employment, Travel, and Other Admin.	−$24.0	Primary & Secondary Education Services	$18.0
Postal, Courier, & Delivery Service	−$19.7	Personal Services	$8.7
Rental and Hiring Services (ex. Real Estate)	−$18.0	Higher Education Services	$7.8
Aux. Finance & Insurance Services	−$17.2	Other Services	$7.0

Similarly, in Newcastle and Lower Hunter (Table 9), the top two industries impacted by the fare policy change would be automotive repair and motor vehicles and parts. Longer travel times for freight and additional truck VKT will increase overall costs and reduce competitiveness, resulting in declines in sales for power generation, fuel sources, professional, scientific, and technical services, and accommodation. Compared to Sydney, a much greater share of trucking in this region supports coal exports and electricity generation and is directly impacted by these changes in freight costs.

Table 9. Top 10 changes in output for 2025—Newcastle and Lower Hunter in millions of AUD.

Industry	Change in Output
Automotive Repair & Maint.	−$42.4
Motor Vehicles & Parts; Equip. Mfg	−$40.8
Prof., Sci and Tech. Services	−$9.4
Other Agriculture	−$5.6
Non-Res Property Operators & Real Estate	−$5.5
Nonmetallic Mineral Mining	−$5.2
Coal mining	−$4.7
Cement Lime and Concrete Mfg	−$4.4
Meat and Meat Product Mfg	−$4.3
Employment, Travel, and Other Admin Services	−$4.2

On the growth side, ownership of dwellings would grow by $13 million, followed by residential care and social assistance by $1.8 million. Compared to Sydney, where household expenditures support the accommodations sector, in Newcastle and Lower Hunter added costs for supplies due to trucking impacts balance and additional demand, leading to almost no change in the sector rather than being the second-most positively impacted. This can be traced in the cost savings by industry report.

The impacts for the top five industries in Wollongong (Table 10) would be similar to those in Newcastle and Lower Hunter, with iron and steel manufacturing replacing electricity generation as the key consumer of coal. The increase in freight travel time and cost would result in large declines in energy and energy-related industries. The balance between added cost for sectors and added household demand would be similar but slightly different. As for positive economic growth, ownership of dwellings would grow by $14 million and residential care and social assistance would grow by $2 million in 2025. As with all regions, decreased demand for car-related industries would not be completely reallocated to other household goods and services, as some payments would shift towards being held by PT providers.

Table 10. Top 10 changes in output for 2025—Wollongong in millions of AUD.

Industry	Change in Output
Automotive Repair & Maint.	−$41.1
Motor Vehicles & Parts; Equip. Mfg	−$39.0
Iron & Steel Mfg	−$20.2
Prof., Sci, and Tech. Services	−$9.9
Other Agriculture	−$8.8
Nonmetallic Mineral Mining	−$5.5
Wholesale Trade	−$5.0
Non-Res Property Operators & Real Estate	−$4.5
Construction Services	−$4.2
Electricity Trans., Dist., and Market Operation	−$3.3

3.4. Value Added or Gross Regional Product (GRP)

The change in GRP due to the transit fare reduction policy would be an average annual decline of $282 million in the Sydney Metropolitan region, which would result in a cumulative loss of $10 billion over the period from 2020 through 2056. For Newcastle and the Lower Hunter, the average annual loss of economic activity would be $64 million. For Wollongong, the annual losses of economic activity would be $56 million per year. The patterns for value added changes would be similar to those for business output. The biggest difference in relative changes between industries is due to differences in how much different sectors depend on intermediate inputs purchased from other sectors.

3.5. Jobs

For the Sydney Metropolitan region, it will see (Table 11) an average decline of around 2000 jobs over the 35-year analysis period. The annual job loss would peak at 2301 in 2026 and decline to 1750 in 2056. The corresponding business output associated with these two years is a decline of $902 million and $928 million—a much more stable (and increasing) amount. This reflects the industry-specific productivity forecast in the model. In 2025, approximately 1250 of the jobs lost will be in motor vehicle repair and maintenance sector, nearly twice the number of jobs lost in the more capital-intensive manufacturing sector, despite nearly identical changes in output. Retail trade would also have much higher job losses relative to other industries compared to its decline in value added and output due to its labour-intensive nature. All ten most negative sectors are shown in Table 11, along with growing sectors. Social assistance and healthcare show positive growth, creating 283 new jobs. Another 136 new jobs in primary and secondary education are also estimated in 2025. Despite these positive job growths from shift in spending, overall job growth would be negative for the region.

The Newcastle and Lower Hunter region (Table 12) will see a decline of 443 jobs in 2025, falling to 310 jobs lost in 2056. In 2025, an estimated 214 jobs will be lost in motor vehicle repair or manufacturing due to less passenger travel by cars, a direct result of less VKT. Similar to the Sydney Metropolitan region, a shift in disposable household expenditures from auto travel to other household expenditures and transit would slightly reduce the losses from increased freight costs. The primary sectors losing jobs are shown in Table 12 There would be 45 new jobs in Newcastle and Lower Hunter. Job growth would be concentrated in residential care and social assistance, healthcare, personal services, and primary and secondary education industry sectors.

For the Wollongong region (Table 13), we would see a decline of 370 jobs in 2025, falling to 261 jobs lost in 2056. In 2025, an estimated 207 jobs lost will be in motor vehicle repair, sales, or manufacturing due to less car driving, a direct result of less VKT. Similar to the other regions, increased freight costs would also result in job losses in agriculture, mining, and manufacturing, as well as retail and wholesale trade as shown in Table 13. Positive job growth would occur in the poultry and other livestock industry, with 33 new jobs, followed by another 31 jobs in residential care and social assistance and primary and secondary education.

Table 11. Top 10 changes in jobs for 2025—Sydney Metropolitan region.

Industry	Decrease		Increase
Automotive Repair & Maint.	−1251	Health Care Services	143
Motor Vehicles & Parts; Equip. Mfg	−699	Residential Care and Social Assistance	140
Prof., Sci, and Tech. Services	−175	Primary and Secondary Education	136
Retail Trade	−139	Food and Beverage Services	115
Other Manufactured Products	−103	Personal Services	74
Wholesale Trade	−68	Other Services	38
Furniture Manufacturing	−60	Accommodation	32
Employment, Travel & Other Admin.	−44	Finance	30
Non-Res Property & Real Estate	−41	Arts, Sports, Adult, and Other Education	19
Public Order & Safety	−37	Higher Education Services	19

Table 12. Top 10 changes in jobs for 2025—Newcastle and Lower Hunter.

Industry	Change in Jobs
Automotive Repair & Maint.	−138
Motor Vehicles & Parts; Equip. Mfg	−76
Other Agriculture	−31
Prof., Sci, and Tech. Services	−25
Nonmetallic Mineral Mining	−24
Other Manufactured Products	−20
Food and Beverage Services	−16
Retail Trade	−15
Specialized Machinery and Equipment Mfg	−8
Construction Services	−8

Table 13. Top 10 changes in jobs for 2025—Wollongong.

Industry	Change in Jobs
Automotive Repair & Maint.	−134
Motor Vehicles & Parts; Equip. Mfg	−73
Other Agriculture	−55
Nonmetallic Mineral Mining	−26
Prof., Scientific, & Tech. Services	−25
Iron and Steel Mfg	−19
Retail Trade	−14
Construction Services	−14
Wholesale Trade	−10
Specialized Machinery and Equipment Mfg	−7

4. Labour Income

The income impacts would follow the same trends as job growth and business sales. Total income losses during the reduced transit fare scenario period would be $11.6 billion for the Sydney Metropolitan region, $2.0 billion in the Newcastle and Lower Hunter region, and $1.9 billion for the Wollongong region. Figure 5 shows the share of income losses by region. Income losses would actually surpass the value added losses, since the top sector providing positive value added would be ownership of dwellings, which does not have any associated labour income (or employment) in the economic model. Income patterns, like the other economic impact metrics, may shift if additional transit operating expenditures and investment follow from the higher passenger volumes and revenues suggested from the scenario. However, the significant increases in truck costs are likely to dominate as long as the model suggests such a costly response to less car traffic.

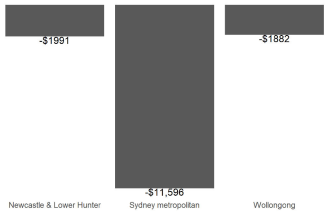

Figure 5. Income losses by region from 2020 through 2056 in Millions of $AUD.

5. Conclusions

The paper has presented the overall framework of a new integrated transport and land use planning tool, MetroScan, Unlike many such modelling systems, MetroScan incorporates both passenger and freight demand models, as well as land use models associated with residential locations and firm locations, with additional model for jobs linked to firms and three dwelling-related models on prices, tenure (rent, own), and type (detached, town houses, and apartments) (Figure 4). There is endogenous feedback amongst the location and transport decisions. In addition, we had a seamless integration of the outputs of the demand model system as forecasts of passenger and freight vehicle movements with a benefit–cost module and an economic impact analysis.

We have shown the practical value of MetroScan through an application associated with a 25% reduction in public transport fares across the entire network. The case study offers an example of how travel demand forecasts are exported into a benefit–cost setting to assess the impact of a transport initiative on some key elements of economic sustainability, such as agglomeration impacts that increase productivity. The extension to consider the wider economic impacts, such as jobs and regional output associated with the value of business production, is defined by the revenue from product sales minus the cost of nonlabour inputs. Unlike almost all other integrated transport and land use modelling systems, there is no framework that embeds the appraisal process within it, which we have done with MetroScan, as well as showing the types of useful policy outputs through the case study application.

As with any modelling system there will be limitations [17]; however, what we have developed in MetroScan is a comprehensive way of accommodating both passenger and freight activity (including light commercial vehicles), as well as an endogenous treatment of residential and firm location choices. Areas worthy of further research to embed inn this rich behaviour system are mobility as a service (Maas), autonomous cars and trucks and buses, and a real estate agent property advisory choice model for both private dwellings and business accommodation. What we now have is a framework that facilitates incremental revisions to the suite of behaviourally relevant models.

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Appendix A

Table A1. List of Key MetroScan Outputs.

General Outputs			
Output	**Description**	**Units**	**Comments**
TCO2(kg)	Total annual carbon dioxide	Kilograms (kg)	Car (includes all passenger automobiles—sedan, wagons, utes, panel vans, 4WD), light commercial service vehicles, freight vehicles
NOx (kg)	Total annual nitrogen oxides	Kilograms (kg)	
CO (kg)	Total annual carbon monoxide	Kilograms (kg)	
NMVOC (kg)	Total annual volatile organic compounds	Kilograms (kg)	
N2O (kg)	Total annual nitrogen dioxide	Kilograms (kg)	
CH4 (kg)	Total annual chlorofluorocarbons	Kilograms (kg)	
TEUC.MC ($)	Total annual end-use money cost	Dollars ($)	All person trips, includes for car, LCV, and freight: op cost, regn charges, annualised vehicle cost, parking, toll, congestion charge; for PT = fares
TEUCPV.MC ($)	Total annual end-use money cost in present value terms	Dollars ($)	All person trips
TEUC.OC ($)	Total annual end-use operating costs	Dollars ($)	All person trips, car operating cost plus public transport fares
TEUCPV.OC ($)	Total annual end-use operating costs in present value terms	Dollars ($)	All person trips, car operating cost plus public transport fares
TEUC.TTC ($)	Total annual end-use travel time cost	Dollars ($)	All person trips; with travel time for ride-share for each person in car (converted to $).
TEUCPV.TTC ($)	Total end-use travel time cost in present value terms	Dollars ($)	All person trips; with travel time for ride-share for each person in car (converted to $).
TEUC.Time (min)	Total annual end-use travel time	Minutes (min)	All person trips; with travel time for ride-share for each person in car.
TEMUDTMC ($)	Total annual expected maximum utility from each model system for each of the model components defined—by the mode choice (CMC) links.	Dollars ($)	

Table A1. *Cont.*

General Outputs			
Output	**Description**	**Units**	**Comments**
TEMURLC ($)	Total annual expected maximum utility from each model system for each of the model components defined—by the linkage: residential location choice (RLC) links	Dollars ($)	
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 kilometres	Kilometres (km)	
TVKMTwAw(km)	Total annual passenger vehicle kilometres: to/from work and as part of work	Kilometres (km)	
TVKMOU(km)	Total annual passenger vehicle kilometres: other urban	Kilometres (km)	
TVKMNonU(km)	Total annual passenger vehicle kilometres: nonurban	Kilometres (km)	
AvOpCost(c/km)	Average operating cost of autos	C/km	
VehAnnCost($)	Annualised automobile capital cost	Dollars ($)	
VehOpCost($)	Total annual auto operating cost	Dollars ($)	
Tvehicles(number)	Total passenger vehicles	Number	Cars
Tenergy(litres)	Total energy consumed by passenger vehicles	Litres	Car (petrol and diesel)
TGovtVehReg($)	Total government revenue from auto ownership	Dollars ($)	Car
TGovtExcise($)	Total government revenue from fuel excise	Dollars ($)	Car (petrol and diesel)
TGovtCarbT($)	Total government revenue from carbon tax	Dollars ($)	Car (petrol and diesel)
TGovtSalesT($)	Total government revenue from sales tax (GST post 2000)	Dollars ($)	Car (petrol and diesel)
TTollRev($)	Total revenue from toll roads	Dollars ($)	Car

Table A1. *Cont.*

General Outputs			
Output	**Description**	**Units**	**Comments**
TPark($)	Total revenue from parking strategy	Dollars ($)	Tpark ($) Car
TRCong($)	Total revenue from congestion pricing	Dollars ($)	Car
TPT($)	Total revenue from public transport use	Dollars ($)	All PT (all modes, private and public).
TGVehPurCost($)	Total government revenue from vehicle purchase cost	Dollars ($)	Car
TVehMaxAgeValue($)	Total cost of vehicle maximum age buyout	Dollars ($)	Car
TGVehRebCost($)	Total government vehicle rebate cost	Dollars ($)	Car
THhld(number)	Total number of households	Number	
Tpop(number)	Total number of people resident in each city	Number	
TWrkrRes(number)	Total number of workers (p/t and f/t) in each residential location	Number	
TWrkrWork(number)	Total number of workers (p/t and f/t) in each workplace	Number	
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

Table A1. *Cont.*

General Outputs			
Output	**Description**	**Units**	**Comments**
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
Class15AFmed	Vehicle Class Proportion Class 15	Proportion	Cars
Class16AFlge	Vehicle Class Proportion Class 16	Proportion	Cars
RVKMPCar	Vehicle kilometres per vehicle	Vkm/Car	Cars
RVehiclePHhld	Vehicle per household	Veh/hld	Cars
RC02PVKM	CO2 per Vehicle kilometre	CO2/vkm	Cars
REnergyP100VKM	Energy per 100 Vehicle kilometres	Litres/100km	Cars
RVehPCapita	Vehicle per capita	Veh/capita	Cars
RGCPersT ($)	Generalised cost per person trip for car	$/car person trip	Cars, includes travel time (converted to $) and all money costs
RGCOPers ($)	Generalised cost per person trip for car	$/car person trip	Cars, includes travel time (converted to $) and only car op cost

Table A1. *Cont.*

General Outputs			
Output	**Description**	**Units**	**Comments**
RGCPubT ($)	Generalised cost per person trip for PT	$/PT person trip	All modes of public transport, fares plus travel time (converted to $)
RTEUGCPersT ($)	Total end use generalized cost per person trip	$/person trip	Sum of TEUC.OC plus TEUC.TC ($)
REMUDTMCPersT ($)	Departure time and mode choice consumer surplus per person trip	$/person trip	
REMURLCPersT ($)	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	
Crowding	Likelihood of getting a seat	Proportion	PT modes
Reliability	Likelihood of arriving on time/being late	Proportion	All modes
Reliability costs		$/person trip	All modes
Value of personal time and reliability		$/person trip	All modes
Safety cost		$	All modes
Additional consumer surplus		$	All modes
Additional Light Commercial Service Vehicle Outputs			
Output	**Description**	**Units**	**Comments**
Number of trips	Number of trips by origin and destination	Number	By industry/occupation
Number of tours	Number of tours by origin and destination(s)	Number	By industry/occupation
Tour patterns	Types of tours by number of stops	Number	By industry/occupation
Trip time reliability	Reliability of trip times for service trips	Proportion	
Vehicle costs		$	
Labour costs	Labour costs associated with travel for service trips	$	

Table A1. *Cont.*

General Outputs			
Output	**Description**	**Units**	**Comments**
Expected savings	Expected savings from improvements in travel time or reliability	$	
Time lost due to congestion	Minutes lost due to congestion (relative to free flow)	Min	
Additional Freight Outputs			
Output	**Description**	**Units**	**Comments**
Number of trips	Number of trips by origin and destination	Number	By vehicle and commodity class
Number of tours	Number of tours by origin and destination(s)	Number	By vehicle and commodity class
Total VKT	Total distance travelled	Km	By vehicle and commodity class
Tonnes	Total tonnes carried	Tonnes	By vehicle and commodity class
Tonne/km		Tonne/km	By vehicle and commodity class
Tour patterns	Types of tours by number of stops	Number	By vehicle and commodity class
Trip time reliability	Reliability of trip times for freight trips	Proportion	By vehicle class
% Empty running	Proportion of VKT with empty vehicles	Proportion	By vehicle class
Vehicle costs		$	
Labour costs	Labour costs associated with travel	$	
Parking costs	Parking costs including time	$	
Expected savings	Expected savings from improvements in travel time or reliability	$	
Freight value	Value of freight carried	$	By vehicle and commodity class
Time lost due to congestion	Minutes lost due to congestion (relative to free-flow)	Min	By vehicle and commodity class
Economic impact and cost-benefit outputs			
Output	**Description**	**Units**	**Comments**
Total employment (jobs)		Jobs	By industry or occupation
Business productivity		$	Total
Social/environmental benefits		$	Total

Table A1. *Cont.*

General Outputs			
Output	**Description**	**Units**	**Comments**
Additional gross regional product		$	Total
GRP plus traveler non-$ benefits		$	Total
GRP plus total non-$ benefits		$	Total
Impact/Cost ratio			By impact measure
Total annual wages		$	By industry or occupation
Total annual value added	Gross value added (for metropolitan area)	$	By industry or occupation
Total annual business output	Region equivalent to GDP (for metropolitan area)	$	By industry or occupation
Value of imports		$	
Value of exports		$	
Value of internal flows		$	
Intermodal connectivity benefits	Benefits from access to multiple modes	$	
Labour productivity benefits		$	
Business productivity benefits	Measures of agglomeration economies	$	
Government revenue impacts	Changes in business sales, worker and business income, consumer spending, travel-related tolls and fees, and government revenues	$	
Total benefits	Undiscounted nominal benefits	$	
Total benefits (discounted)	Discounted real total benefits	$	
Start-up costs	Project(s) start-up costs	$	
Operating and maintenance costs		$	
Residual value		$	
Total costs	Undiscounted nominal costs	$	

Table A1. *Cont.*

General Outputs			
Output	**Description**	**Units**	**Comments**
Total costs (discounted)	Discounted real total costs	$	
Net benefits		$	
Cost benefit ratio		$	
Firm location outputs (Planned)			
Output	**Description**	**Units**	**Comments**
Location of firms	Location of firms by industry/occupation	Firms	By industry, occupation
Firms by size	Number of firms by size	Firms	By industry and occupation
Location of business units	Location of business units (e.g., individual shop or office)	Business units	By industry and occupation
Location of jobs	Location of jobs	Jobs	By industry and occupation
Location of unfilled positions	Location of unfilled jobs (difference between jobs and employment)	Number	By industry and occupation
Productivity outputs	Productivity outputs by location	$	By industry
Goods output	Goods outputs of firms by location	$	By industry
Freight input (by value)	Materials/freight inputs for business use	$	By industry
Freight input (by tonnes)	Materials/freight inputs for business use	Tonnes	By industry
Freight output (by value)	Freight outputs from business value-added	$	By industry
Freight output (by tonnes)	Freight outputs from business value-added	Tonnes	By industry

Note: A trip = a person trip (e.g., 2 person's ride sharing = 2 person trips).

Appendix B. Benefit—Cost and Economic Impact Analyses

In addition to the traditional user benefits, MetroScan's economic analysis incorporates business pattern impacts (employment concentration and export portion) into its economic impact analysis (EIA) calculations, and the productivity impacts into its benefit–cost analysis (BCA) modules. We summarise the main outputs from the BCA and EIA components of MetroScan in Tables A1 and A2, respectively. Readers can refer to these tables when interpreting the results presented in subsequent figures and tables.

Table A2. Explanation of benefit–cost analysis key results.

Category	Source of Benefit and Cost	Explanation	Other Comments
Present Value of Benefit Stream		The dollar value of net welfare gain to transport system users (user benefits) and non-users (external benefits). It is possible that a transportation project may serve to reduce driver frustration about expected or unexpected delays, reduce air pollution levels, and enhance or otherwise affect the visual beauty of an area. All of these impacts are seen as having a value to society, which shows up in either willingness to pay studies (representing stated preferences) or in observed property value changes (reflecting revealed preferences). Such "societal" (or social) benefits can be counted in a benefit–cost analysis. However, not all types of benefits change the flow of income in the economy.	
Travel Benefits		The traditionally used measure of user benefits, and are defined to include benefits accruing to drivers and passengers and vehicle costs as a result of improvements in travel times, travel expenses, and travel safety. Additional benefits, associated with switching modes of travel, origin–destination patterns, and "induced" generation of additional travel are also counted (through the concept of "consumer surplus").	They also can include logistics benefits. These are the time and shipping cost savings to industries producing or consuming the commodities on board freight modes. Benefits arise because as shipping costs go down, businesses can increase productivity through inventory management, production scheduling, or distributional efficiencies.
	Value of Vehicle Operating Cost (VOC)	Fuel and oil consumption, tyre wear, maintenance, and depreciation, as well as fares and tolls (note—latter two costs are transfer payments if related to government)	Accounts for free flow ($/km) and congested conditions ($/km or $/hr depending on mode)
	Value of In-Vehicle Travel Time (IVTT)		Note—when we move from car to PT, we save the car time totally and incur a PT time, the difference reflecting the net INVT time benefit.
	Value of Out-of-Vehicle Travel Time (OVTT)	This includes all ways of accessing or egressing a mode	Note that when we move from car to PT, we actually incur OVT losses
	Value of Improved Travel Time Reliability	This is linked to buffer time. TREDIS will compute the CHANGE in entered value of buffer time cost (difference between the project and base case) and then multiply that difference by the entered buffer time cost value.	
	Value of Safety Improvement	Based on average crash rates (per 100 million *VKT*) for all modes, and average costs incurred for each crash type ($/accident).	We allow for personal fatalities personal injuries and property damage.
Environmental and Safety Benefits			
	Value of Emission Reduction for Mobile Source Pollutants	Accounts for free flow ($/km) and congested conditions ($/km or $/h depending on mode)	Local air pollution
	Value of Emission Reduction for Carbon Dioxide	Accounts for free flow ($/km) and congested conditions ($/km or $/h depending on mode)	Climate change, enhanced greenhouse gas emissions

Table A2. *Cont.*

Category	Source of Benefit and Cost	Explanation	Other Comments
Wider Economic (Productivity) Benefits		Wider social benefits can also include "agglomeration" benefits, when a transport project facilitates greater accessibility and connectivity of productive factors in an economy. These "market access" effects are the result of knowledge spillovers, better matching of worker skills (and other inputs) to business needs, and sharing of commonly needed inputs to production. Increased worker productivity. Accessibility feeds agglomeration economies by means of input sharing, input matching, and knowledge spillovers. These mechanisms can create value in a region that is additional to user benefits. As such, productivity benefits are included in benefit/cost analysis.	
Transfer Benefit Effects (net benefit adjustment)		Increase in public transport fares and car tolls collected from users (which are used to reduce net public investment cost)	
Present Value of Cost Stream			
Project Costs			
	Capital Investment Costs		
	Operation and Maintenance Costs		
Cost Adjustments			
	Residual Value of Capital Costs	The residual value adjustment attempts to represent the value of the capital investment remaining after the analysis period. In CBA, the capital investment is spread over the built facility life. For example, if the project life is 40 years and analysis only goes for 20 years, then the nondepreciated value of the capital investment is credited as residual value. The user can choose the Useful Life in the inputs spreadsheet. Residual value applies only to capital investments that are associated with physical assets, i.e., construction categories "right-of-way", "structures", "terminals", and "vehicles". Residual value has the opposite sign of the project-minus-based capital investment costs.	In EIA, the capital investment is counted in the year in which it is actually spent. This residual credit is calculated based on linear depreciation of the construction cost, which is an excepted proxy for future benefits outside the project analysis period.
	Reduction in Effective Capital Cost Due to Value-Added Fees Collected by Government	This relates to fares and tolls (although we can decide how much of toll revenue accrues to Government or the private sector). The UK's CBA guidance (WebTAG) is followed in Australia, which counts government toll collection as a reduction in the BCR denominator. (In the USA, practice counts it as an addition to the numerator offsetting user cost of tolls.)	You can see a matching value reflected under "Transfer Benefit Effects (net benefit adjustment)" "Change in Tax Revenues Collected By Government". In the USA's case, the two values would appear under the net benefit adjustment in the lines called "added fees."
Net Benefit (Benefits–Costs)			
	Transportation System Efficiency—Traveller Benefits Only		
	Traditional BCA—Traveller Benefits + Environmental Benefits		
	Full Societal BCA—All Benefit Categories		
Benefit–Cost Ratio (Benefits/Costs)			
	Transportation System Efficiency—Traveller Benefits Only		

Table A2. *Cont.*

Category	Source of Benefit and Cost	Explanation	Other Comments
	Traditional BCA—Traveller Benefits + Environmental Benefits		
	Full Societal BCA—All Benefit Categories		
Economic Impacts	Impacts on the flow of money in the economy, and are typically measured in terms of increased Jobs or Income.		It is possible that a transportation project will reduce business operating costs, which can increase profits (a component of value added). That may also improve competitiveness for locating a business in the affected area, resulting in further business sales and income growth there. Such impacts directly affect the flow of corporate income and lead directly to increases in worker income. As such, they represent an economic impact on the affected area.
Productivity	The ratio of economic output/cost of inputs		The denominator is the total cost of all input factors, including labour, materials, utilities, transportation, and other services. Factors that affect the flow of income are productivity factors, whilst factors that have a social value (counted in CBA) do not directly affect income flows. Agglomeration and other productivity factors in the middle group are the core drivers of job and income growth in the economy.
Market Access	Refers to the ability of transportation facilities and services to provide households and businesses with access to opportunities that they desire. Market access is often measured through the concept of "effective density", which refers to the magnitude of surrounding market opportunities (e.g., workers to be utilised or customers to be served) from a specific location. An improvement in the performance of transportation facilities and services can enhance productivity in two ways: (1) By reducing time and/or expense costs incurred in the continuing operation of businesses. That effectively raises productivity by decreasing the denominator of the ratio. (2) By enlarging market access or connectivity, which grows the numerator while the denominator either remains constant or grows proportionally less than the numerator. This can occur as long as there are scale economies or other business operating efficiencies enabled by access to a larger market.		Transportation investments can potentially expand any of these forms of market access below: Businesses desire access to three basic kinds of markets: 1. Labour market: the workforce with required skills that a business can draw from to obtain its employees; 2. Input material market: the sources of specialised materials that a business can acquire (or specialised services that it can use) to produce its output; 3. Customer market: the buyers whose specific needs can be reasonably and competitively served by a business (this can include shoppers, tourists, or freight delivery recipients). For households, transportation can be viewed as providing worker access to employment and shopping opportunities that match to their skills and needs.
Economic Geography (Competitiveness)	Labour and capital flows; export growth, import substitution; workforce and population migration.		Factors that cause shifts in the spatial pattern of economic growth. They are additional economic impacts that are a consequence of productivity changes. They count in EIA as they can affect the level of economic activity occurring in a defined study area, but in CBA they are considered spatial shifts which cancel out.
Connectivity	This represents a form of "access" that is between two systems.		However, in practice it is useful to distinguish market access and connectivity. Whereas "market access" refers to a surrounding area or region comprising the market, connectivity commonly refers to characteristics of the link to terminals or interchanges.
Output	The value of business production. For productivity analysis, it is measured as net value added. (For other analyses, it may be measured as gross business revenue.)		
Value Added	A measure of business output (revenue from product sales) minus the cost of nonlabour inputs used to produce that product.		
Gross Domestic Product	The amount of business value that is generated in a given nation, state, or region; this is almost the same as gross value added but it adds further adjustments for taxes paid (+) and subsidies received (-) by business units.		
Gross Regional Product	GDP value for a state or region within a nation.		

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