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How much is your daily commute? Developing a working model to estimate the total travel cost

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Abstract

When evaluating travel costs, most commuters only consider user or financial costs. For example, if passengers commute by public transport they usually only consider the fare or if travelling by car they usually only consider the fuel and road toll costs. However, there are additional costs that commuters typically ignore which have social and environmental impacts.

Policy makers want to know the whole spectrum of costs for assessing accessibility and planning public transport provision. To quantify all costs involved in a trip, we have developed a commuter cost model which estimates all trip costs including economic costs not normally considered by commuters such as travel time, maintenance and operating costs, infrastructure provision costs, health benefits and externalities (congestion, greenhouse gas emissions and accident costs). These costs are categorised as internal (user) costs, service provision (agency) resource costs and external (society) costs. The cost model detailed in this paper is based on a trip database which consists of a matrix of the 100 highest patronage stations in the Sydney Trains network for 5 modes: train, bus, car, cycle and walk. Trip data such as distance, travel time, fare and toll have been collected for each Origin-Destination pair. The user can select the origin, destination, time period and, for a car trip, whether a tolled or untolled road is used. The relevant trip cost components are then determined for each mode type to calculate the total cost of a journey.

The model can be used as a tool for policy makers in transport planning and provision. The model also compares trip cost components of different modes, allowing commuters and other users to make an informed decision when selecting the transport mode, in turn creating awareness of the broader impacts of their travel choices not only on themselves but also on society.

1. Introduction

When asked how much it costs to travel, the majority of people only consider user costs such as fare, petrol and tolls; most fail to consider other economic costs which also have an impact on society. However effective transport planning and policy making requires a greater understanding of the full spectrum of costs, many of which are generally not considered by the commuter and difficult to measure. Individuals also make decisions every day, such as whether to wait in car traffic, wait for public transport or walk to their destination. All these modes involve costs that should be considered in the choice of transport mode.

The purpose of this paper is to quantify the full economic trip cost for each mode of transport based on real world journey data. In addition to out-of-pocket costs, other costs associated with travel time, maintenance, infrastructure provision, environmental emissions, congestion and accident have also been quantified.

2. Literature review

2.1 The need to examine full transportation cost

The mode of transport chosen by the user is usually a function of the perceived cost paid by the user, whether in terms of money or time. However, there are costs that are often not considered by the user when selecting the transport mode. As a consequence, the selection of transport mode based solely on the evaluation of direct costs results in economically excessive use of vehicle travel (Astrid et al. 2006, Glazebrook 2008).

In recent years, there has been growing interest to look beyond the internal costs. Determining the full cost of transportation is an important input into infrastructure planning, pricing policies and investment evaluations. In turn, this enables Governments to formulate incentives for selection of transport modes that balance the social costs with the allocation of resources to obtain an economically efficient use of transport modes.

2.2 Previous studies on the cost of transportation

Studies on the cost of commuting have captured different costs in each study. Some have focused on the financial costs only, while others have attempted to also capture broader social / external costs to determine the ‘full’ value of transport. A common finding in the literature is that public and active transports are cheaper than driving.

Wang (2013) examined the potential savings converting from driving to public transport for commuters working in the CBD. For Sydney commuters, the average savings when an individual leaves their car at home and commutes via public transport is estimated to save an average of $8,232 per year, or an average saving of $11,946 per year if no car is owned at all. However, this study only focused on the private, ‘out-of-pocket’ costs, including vehicle fixed costs, variable running costs, parking costs, public transport costs and taxi fares (for non-car owners).

The Australian Railway Association (ARA, 2015) also compared the potential savings when switching from driving to different public transport modes. A commuter living in North Sydney and working in the Sydney CBD saved $898 to $1,401 per year if they decided to leave the car at home and commute using public transport only, incurring only the vehicle’s fixed cost and the train fare. If the same commuter chose to sell or not buy a car, the savings were estimated to increase to the range of $6,186 to $10,655 per year.

ARA’s (2015) estimate of the savings from owning a car but commuting via public transport is significantly lower than that derived by Wang (2013). This difference is largely due to the types of cost captured in driving costs: car parking costs in the CBD were not considered in ARA (2015) and both studies did not include toll costs.

The preceding two studies compared the savings that could be achieved if commuters switched from private car travel to public transport, highlighting the notion that public transport use generates real financial savings compared to driving. However, these studies focused solely on direct, ‘out-of-pocket’ financial costs. Non-financial costs related travel time, environmental impact and congestion were not considered.

An estimation of the full costs of different transport modes in Sydney was undertaken by Glazebrook (2009). This study differs from previous commute cost studies in Sydney in that both the private costs to the individual as well as the social/external cost have been quantified.

The report found that the ‘out-of-pocket’ costs paid by car users were only around one-sixth of the total cost, suggesting that selection of transport modes in most instances are without consideration of the full costs to both the user and society at the time of a trip. If motorists were faced with full costs, transport modes selected would be quite different.

Consistent with other studies, driving was found to be the most expensive transport mode, followed by bus and train, with or without inclusion of external costs. The study also found that despite the total cost of driving to be much higher than trains, the external costs of both modes are very similar. The large externality costs of cars is largely due to the high environmental, congestion and accident costs that are borne by society whereas public transport's cost is borne by society in the form of subsidies from the Government.

In Canada, an interactive cost of commute model was developed for road transport for bus routes in downtown Vancouver. The model estimated the full costs of different transport modes including car, bus, cycling and walking. Findings from the model reported that bus services were so efficient at transporting people that it actually saves society two cents every time a passenger travels one kilometre (Discourse Media 2015). The Canadian model, with its interactive feature to estimate the cost of commute for individual bus routes in downtown Vancouver, inspired the initiation of the model presented in Section 4 of this paper.

2.3 Accounting for the full costs of transport: internal and external costs

As discussed in the previous sections, the common approach in the literature categorises the total cost of transport into two broad categories: internal and external.

The internal cost is a private out-of-pocket cost that is borne by the user, which generally includes petrol, toll and fares. User fixed costs, such as insurance and vehicle registration fees are generally accounted for by proportioning these costs on the basis of distance.

An external cost is generated by the individual, but borne by either the agency (Government) or society. The external cost is the difference between total cost and private (internal) costs "reflecting all costs occurring due to the provision and use of transport infrastructure, such as wear and tear costs of infrastructure, capital costs, congestion costs, accident costs, environmental costs" (Move, 2014).

The literature varies in determining what costs are considered external costs. It is noted that there are other cost elements that may also be classified as external costs and the boundary is not always clear. For instance, studies in other countries have broadened the definition to include land opportunity costs and tourism impacts (Transport Canada 2008, COWI 2009). Litman (2006) provides two broad categories for external costs in Table 1.

Table 1: External cost categories

External cost category	Private Transport	Public Transport
Environmental and other externalities	Pollution, noise, congestion, accident costs above insurance, 'free' or subsidised parking.	Pollution, noise, accident costs, contribution to congestion, etc.
Government subsidies	Payments to road agencies from general revenue, Local government rates spent on road.	Government subsidies to operators.

Whether costs are classified as either internal or external is mostly subject to the author's perspective and the context of the study. The next sections of this paper, describes the data that has been collected and the definitions used to categorise the costs.

3. Data

The interactive model gives users the ability to generate journeys by selecting any two stations from the 100 highest patronage stations in the Sydney Trains network. The database for the model was compiled by querying Google Maps and TfNSW's transport information website[1]. For each Origin-Destination pair, the following trip data was extracted for each mode:

- Trip duration (peak and off-peak, toll and untolled)
- Trip distance (toll and untolled)
- Toll cost (peak and off-peak)
- Public transport fare (peak and off-peak)

Departure time at 8am and 10am was considered peak and off-peak period, respectively, in order to collect trip data. As the model examines the costs of each mode only, multi-modal journeys were excluded.

It is noted that the toll cost is dependent on the route chosen by the user, which will likely vary depending on traffic conditions and familiarity with the area. For consistency, the fastest route recommended by Google Maps was used to determine the toll cost.

The data extracted was compiled for use as inputs into the model. The next section describes the model and the derivation of commute costs.

4. Model

4.1 Classification of costs

The cost elements considered in this report are grouped into three categories:

- Internal (user) costs – the costs that are incurred by the users as a result of undertaking the transport activity. In this study, out-of-pocket costs as well as travel time costs have been captured as internal costs.
- Agency cost – the resource cost incurred by the Government for provision and maintenance of transport services and infrastructure.
- Society (external) cost – the cost generated by the user but borne by society, including environmental impact and other externalities such as congestion and accident costs.

Table 2 shows the various cost elements grouped into the three categories above. The summation of the cost elements for each mode is the total economic cost of the trip ($/trip).

Table 2: Classification of total economic costs

Cost elements	Train	Bus	Car	Bicycle	Walk
Access / Egress cost[a]	I	I			
Wait time cost[b]	I	I			
In-vehicle travel (IVT) / travel time cost[c]	I	I	I	I	I
Vehicle operating cost (VOC) - financial[d]			I	I	
Fare[e]	I	I			
Toll[f]			I		
Health benefit[g]				I	I
Rollingstock / fleet / bicycle capital cost[h]	A	A		I	

[1] This was undertaken through developing an Excel macro which automatically extracted the required data to complete the database.

Cost elements	Train	Bus	Car	Bicycle	Walk
Infrastructure provision cost[i]	A	A	A	A	A
Maintenance and operating cost[j]	A	A	A	A	A
Crowding cost[k]	S	S			
Congestion cost[l]		S	S		
Air pollution[m]	S	S	S		
Greenhouse gas emission[m]	S	S	S		
Noise[m]	S	S	S		
Water Pollution[m]	S	S	S		
Accident cost[n]	S	S	S	S	S

Legend:

I Internal (user) cost
A Agency cost
S Society (external) cost

a = access and egress time adjusted using the access/egress multiplier to convert it into equivalent in-vehicle time (hr). This is then multiplied by the value of travel time ($/hr) to arrive at the access and egress cost[2].

b = wait time adjusted using the wait multiplier to convert it into equivalent in-vehicle time (hr). This is then multiplied by the value of travel time ($/hr) to arrive at the wait cost[3].

c = in-vehicle travel time (hr) for the trip is then multiplied by the value of travel time ($/hr) to get the in-vehicle travel cost. The total travel cost is the sum of the above access, egress, wait and IVT costs[4].

d = vehicle operating cost for car (including capital cost of car) or bicycle ($/km).

e = actual fare cost for trip depending on whether peak or off peak period is selected ($/trip).

f = actual toll cost for peak and off peak depending on what is selected ($/trip).The Sydney Harbour Bridge and Tunnel operates on time of day tolling with a cheaper toll outside peak period.

g = health benefit of walking or cycling ($/passenger km). Forms of active transport such as walking and cycling leads to improve health and reduced mortality risk.

h = capital cost for rolling stock, bus fleet and bicycle ($/passenger km).

i = infrastructure provision cost. Track, road, cycleway and walkway/pavement provision cost to cover all modes ($/passenger km).

j = operating & maintenance cost for train and bus including labour and infrastructure maintenance costs ($/passenger km)[5].

[2] For trips to and from CBD stations and trips involving at least one CBD station, access and egress time was adjusted downward by 50% and 25%, respectively, as it reasonable to assume that access/egress is lower due to closer proximity of stations. CBD stations in this study include Central, Town Hall, Museum, Martin Place, St James, Circular Quay, Wynyard, North Sydney, Milsons Point.
[3] For trips departing from CBD stations, waiting cost was also adjusted downward by 25% to align with the reduced access/egress cost assumption.
[4] The total travel time cost includes access and egress time, wait time and in-vehicle time. Access and egress time is calculated from research conducted by TfNSW Economic Evaluations which reported average access and egress distance of 700m and 600m respectively and walk speed of 1.1m/s. Weighted value of travel time of $17.97 in 2014 values was used.
[5] VOC for car and bicycle is considered an internal/user cost rather than an agency cost as the user directly pays for it.

k = crowding cost ($/trip) only applied to trips in peak period and was calculated using the estimated crowding multiplier.

l = road congestion cost depending on whether peak or off peak period is selected ($/passenger km).

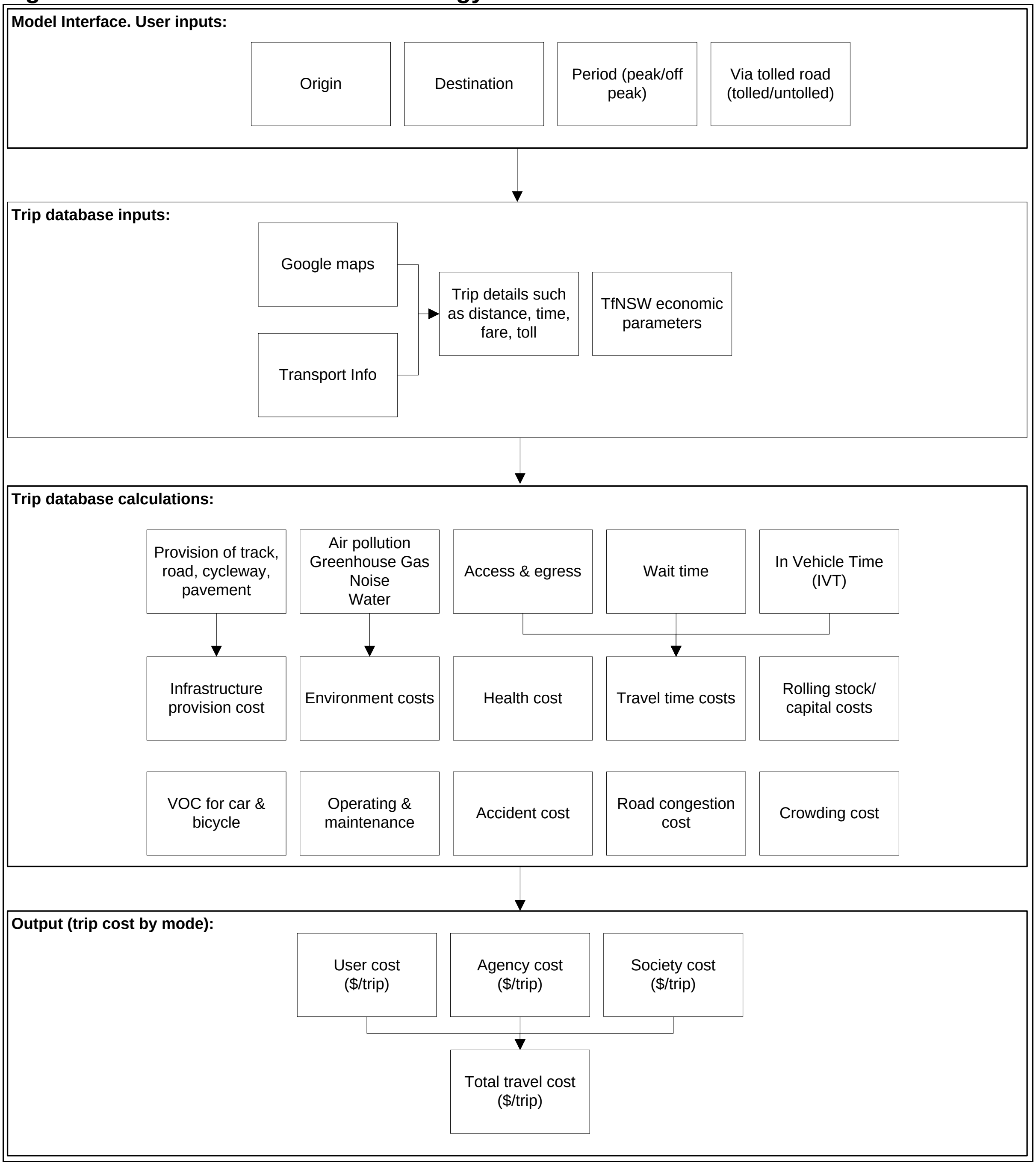
m = environment externality costs which is the total of air pollution, greenhouse gas emission, noise and water pollution costs (cents/passenger km).

n = accident/crash cost for each mode ($/passenger km).

4.2 Methodology

The methodology used to calculate the full economic trip cost is shown in Figure 1.

Figure 1: Cost of commute methodology



The user selects the origin, destination, whether travel is during the peak or off peak period and, for car trips, whether a tolled or untolled route is used. The model user interface is shown in Figure 2. Trip data obtained from Google Maps and Transport Info were used as inputs into the database for the top 100 Origin-Destination trip matrix. Economic parameters (TfNSW 2013) expressed on a per kilometre basis were applied to these inputs and used to calculate the various cost elements (seen in Table 2) in the trip database for each Origin-Destination pair. All trip costs are in 2014 values.

Whilst the majority of parameters used to calculate trip cost have already been estimated and are readily available (TfNSW 2013), parameters used for crowding cost and infrastructure service provision costs are calculated separately in this model on a per passenger kilometre basis. A weighted peak crowding multiplier was estimated in order to estimate the crowding cost. Train load data for each rail line in 2015 from the Bureau of Transport Statistics (BTS) was obtained and the train crowding factor per minute of on board travel time was estimated. This was based on the distribution of seating and standing passengers and crowding multipliers for each rail line based on the number of seated and standing passengers (Douglas 2006, Wang 2012). The factor for each rail line was then weighted by the number of passengers on each line to arrive at the weighted crowding factor per minute of travel time of 0.13[6].

Waiting time of 5 minutes was assumed for bus and train, which is generally equal to half the headway during peak period. During the off peak period, the wait time is capped at 10 minutes following research suggesting that using half the headway tends to overstate waiting time for non-frequent services (Douglas Economics 2016). For access and egress time, research conducted by TfNSW Economic Evaluations reported average access and egress distance of 800m and 600m, respectively, and walk speed of 1.1m/s (TPDC 2006). However it did not seem reasonable to apply a fixed access and egress cost for each Origin-Destination trip regardless of trip duration, as access and egress time usually increase with trip duration to a certain point (Krygsman 2004). As a result, access and egress cost was assumed to be the lower value of either the average access/egress distance[7] or 5% of the travel distance (Douglas Economics 2008, TPDC 2006).

A “bottom-up” approach was used to estimate agency (service provision) unit costs. This is in contrast to a “top-down” approach of using aggregate budget or total expenditure conventionally used to determine the agency’s unit costs. Parameters used to estimate service provision cost (i.e. capital cost to provide track, road, cycleway, footpath etc.) are calculated from annualised capital costs on an annuity basis over the asset’s economic life, which was then divided by annual passenger kilometres travelled to estimate the average unit cost. Train and bus operating and maintenance costs and road maintenance cost per km were divided by the number of passengers (i.e. capacity) to determine the unit cost per passenger kilometre. Maintenance cost for cycleway and pavement was assumed to be 10% of the capital cost.[8]

The trip cost for all Origin-Destination combinations are calculated in the database for all modes. However, it makes reasonable sense to exclude long distance trips for walking and cycling as they are not feasible. If a trip length is greater than 4km, then walking is not considered and if greater than 15km, then the cycle cost is not considered. Evidence from

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[6] The crowding factor is assumed to be the same for bus and train and there is no crowding in off peak period.

[7] The model assumes walk only as access and egress to take the train or bus. Based on evidence average access is 700m and egress is 600m (TPDC 2006) which represents about 5% of the average rail trip distance of 26km (Douglas Economics 2008).

[8] Majority of unit capital costs are from TfNSW (2013). Capital costs for rail track ($60M/km) and rolling stock ($30.4M/train) from NGTSM (2015). Bus capital cost is assumed to be $450,000 and bicycle capital cost and equipment of $1,320.

the BTS Household Travel Survey shows in 2014/15, the average commute by walking was 1.3km. In addition, TfNSW Transport Positive Provision Policy for Walking and Cycling recommends provisions for walking and cycling to be in a 2km and 5km catchment, respectively. Thus it was decided to include a larger but reasonable distance catchment for the calculation of walking and cycling trip cost.

Once the user selects the trip details, the model will present the total travel cost and the breakdown of user, agency and society cost per trip for all available modes as shown in Figure 2.

Figure 2: Model user interface and output

Cost of travel

Origin	Burwood
Destination	Ashfield
Period	Peak
via Tolled road (if applicable)	Untolled

Select from drop down list

Cost per trip ($/trip)

	Train	Bus	Car	Cycle	Walk
User cost	$6.89	$9.91	$3.51	$0.03	$5.24
Agency costs	$0.16	$0.13	$0.12	$0.06	$0.03
Society cost	$0.12	$0.74	$1.12	$0.62	$0.42
Total Cost	**$7.17**	**$10.78**	**$4.75**	**$0.70**	**$5.69**

Breakdown

	Train
User cost:	
Access/egress costs	$0.82
Waiting cost	$1.80
IVT cost	$0.90
Fare	$3.38
Agency costs:	
Infrastructure provision	$0.09
Operating & Maintenance cost	$0.05
Rollingstock capital cost	$0.02
Society cost:	
Crowding cost	$0.11
Air Pollution	$0.001
Greenhouse gas emission	$0.000
Noise	$0.000
Water pollution	$0.000
Accident cost	$0.000

	Bus
User cost:	
Access/egress costs	$0.92
Waiting cost	$1.80
IVT cost	$5.09
Fare	$2.10
Agency costs:	
Infrastructure provision	$0.00031
Operating & Maintenance cost (bus VOC + road maintenance)	$0.07
Bus capital cost	$0.06
Society cost:	
Crowding cost	$0.65
Air Pollution	$0.02
Greenhouse gas emission	$0.01
Noise	$0.00
Water pollution	$0.00
Accident cost	$0.00
Congestion cost	$0.06

	Car
User cost:	
IVT cost	$2.34
VOC	$1.18
Toll	$0.00
Agency costs:	
Infrastructure provision	$0.04
Operating & Maintenance cost (road maintenance)	$0.08
Society cost:	
Air Pollution	$0.06
Greenhouse gas emission	$0.05
Noise	$0.02
Water pollution	$0.01
Accident cost	$0.06
Congestion cost	$0.93

	Cycle
User cost:	
Travel time cost	$3.00
VOC	$0.11
Vehicle capital cost	$0.0004
Health cost (benefit)	-$3.08
Agency costs:	
Infrastructure provision	$0.02
Operating & Maintenance cost (cycleway maintenance)	$0.04
Society cost:	
Air Pollution	$0.00
Greenhouse gas emission	$0.00
Noise	$0.00
Water pollution	$0.00
Accident cost	$0.62

	Walk
User cost:	
Travel time cost	$9.58
Health cost (benefit)	-$4.34
Agency costs:	
Infrastructure provision	$0.01
Operating & Maintenance cost (pavement maintenance)	$0.02
Society cost:	
Air Pollution	$0.00
Greenhouse gas emission	$0.00
Noise	$0.00
Water pollution	$0.00
Accident cost	$0.42

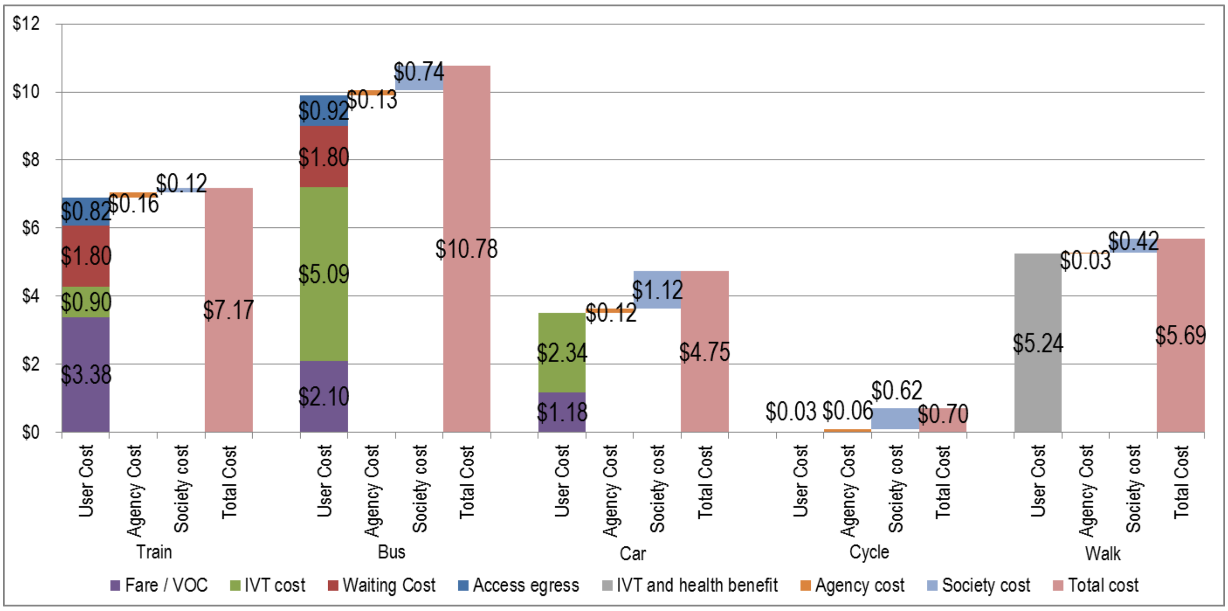
5. Results

The cost of commute model allows users to generate a journey by selecting any two stations. As each journey combination is unique, two illustrative scenarios have been selected to provide a comparison of the costs involved in each mode.

Burwood to Ashfield: comparing all modes

This 2.7 km journey represents a common trip between two populated suburbs in Sydney's inner west. The journey can be undertaken by all transport modes and the total costs are presented in Figure 3 below.

Figure 3: Burwood station to Ashfield station (untolled routes, peak period)



Note: User cost for cycling and walking comprise of travel time (positive cost) and health benefit (negative cost). Depending on the magnitude of each cost element, the net cost can be positive or negative.

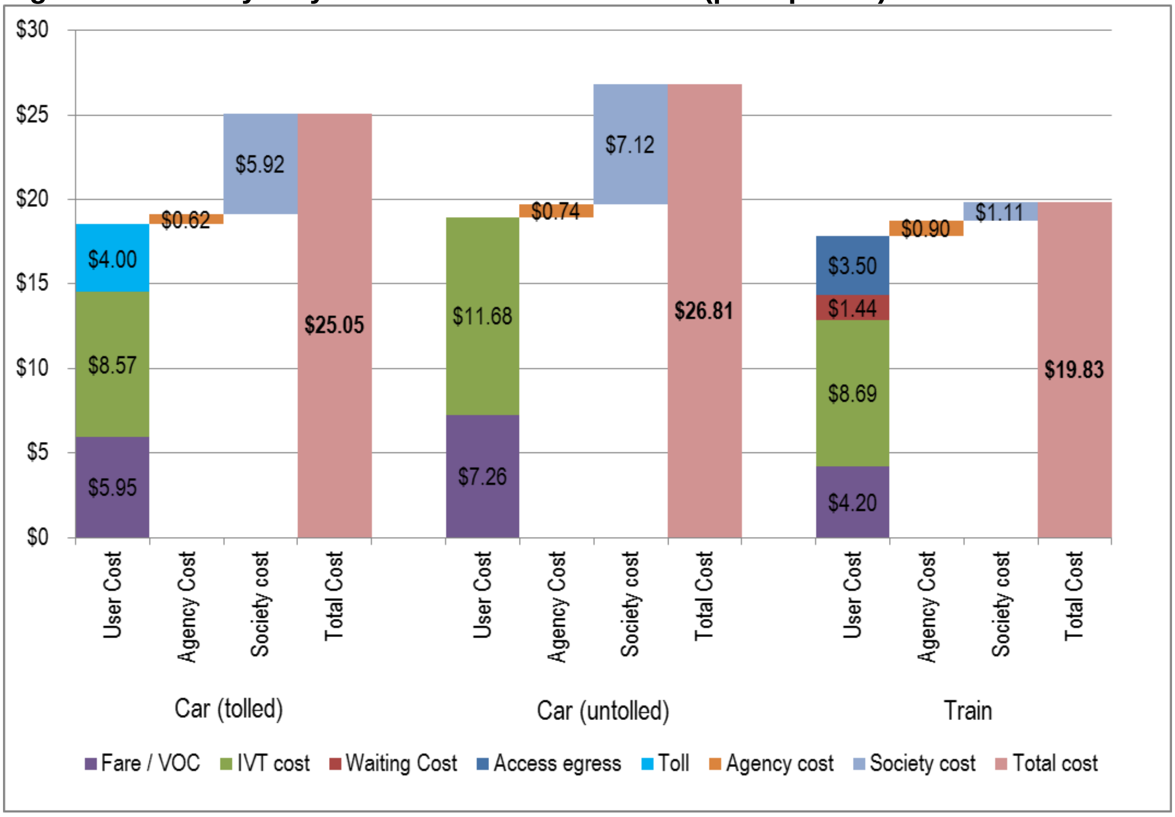
The figure shows that:

- Active transport incurs the least cost of all modes, with cycling the cheapest. Walking is more costly than cycling due to the high travel time cost;
- Of the motorised transport options, driving has the lowest user and total cost. In terms of in-vehicle travel (IVT) time cost, car travel is the least costly, followed by train and bus. This is unsurprising, given that travelling by car is more convenient for this short journey and does not involve any access, egress or waiting costs which public transport users incur;
- 'Out-of-pocket' costs are lowest for car users. However, this is partly due to vehicle operating cost (VOC) for car reflecting the actual distance travelled, while the public transport fare is reflective of the fare band pricing structure used in public transport. That is, short distance trips incur the minimum transport fare; and
- Society costs are more expensive for car and bus, reflecting higher road congestion costs.

North Sydney station to Ashfield station: comparing rail and car tolled and untolled

The fastest route from North Sydney station to Ashfield station is 14 km and involves crossing the Sydney Harbour Bridge, which reduces travel time but involves using a toll road. By using a tolled route, motorist save $3.11 and $1.31 per trip in terms of travel time cost and vehicle operating cost, respectively, compared with the untolled route of 18km length. Travel distance on a toll road is also shorter, resulting in savings of $0.12 and $1.20 per trip in agency and society costs, respectively. The results indicate that an additional $4 in toll cost saves $5.74 in economic costs. The net savings are $1.76/trip when using a tolled route. The trip cost results are shown in Figure 4.

Figure 4: North Sydney station to Ashfield station (peak period)



The only other practical alternate transport mode on this route is train, which is estimated to be cheaper than car travel. The user cost for train travel is lower than the user cost for car, whether or not a toll road is used. This is due to the short in-vehicle travel time and lower user costs.

Society costs are significantly lower than car travel. This is reflective of the cost efficiency exhibited by public transport, where society costs are spread across large volumes of users. In comparison, cars only carry a very limited number of occupants, resulting in much higher agency and society costs.

Comparison between the 2.7 km route in Figure 3 and 14 km route in Figure 4 reveals that costs are not necessarily proportional to trip distance. This is because there are some fixed cost components that are incurred regardless of trip distance, such as access and egress costs.

6. Further work and improvements

The purpose of this paper is to demonstrate a methodology to estimate the full cost of travel and provide insight into the working model developed. There are a few issues which warrant further discussion to refine and improve the model. Firstly, when comparing trip costs for long distance trips, bus travel is generally not a feasible option. This is because long journeys on bus require transferring onto different bus services, resulting in significantly longer travel times and higher costs. Future development of this model will consider limiting the number of transfers to eliminate unpractical bus journeys.

Secondly, parking cost has not yet been considered in the current model although the full end to end journey costs of public transport has been captured through access, egress and wait time cost. Determining a parameter for the parking cost requires further investigation as parking charges differ substantially by location and time. Inclusion of parking cost will improve the comparability between car and public transport options.

The introduction of Opal electronic ticketing system in Sydney in 2014 has created a rich database about commuter behaviour on public transport. Combining Opal passenger volume data with the total cost of each journey is an area of potential future work which will provide a deeper understanding of the full cost of public transport across the Sydney transport network. An additional consideration for future work would be to model point-to-point trips, instead of being limited to the current list of journeys from the Origin-Destination matrix. This may necessitate the use of spatial analysis and modelling along with the use of Geographical Information Systems (GIS) to fully understand the viable transport modes.

7. Concluding remarks

This paper provides a methodology to estimate the full economic costs of commuting and highlights that there are many costs generated by users in addition to out-of-pocket costs. The model developed is sufficiently flexible and detailed enough to quantify the full breadth of costs involved in each mode of travel. The results presented are broadly in line with previous studies on the cost of commute in Sydney that public and active transport is generally less costly than driving. Further refinements to the model and improvements in data will strengthen the results and improve comparability between modes.

The model is a useful tool to inform policy makers about the full cost of travel, which feeds into important debates about pricing structures and incentive schemes to encourage use of public transport. More accurate measures of the full cost of transport also facilitates the development of more efficient transport solutions and infrastructure which reflect their full costs.

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