IPART
Independent
Pricing and Regulatory
Tribunal | NSW

Maximum Opal fares until July 2028

Modelling socially optimal fares

Technical Paper

August 2024

Transport »

Acknowledgment of Country

IPART acknowledges the Traditional Custodians of the lands where we work and live. We pay respect to Elders both past and present.

We recognise the unique cultural and spiritual relationship and celebrate the contributions of First Nations peoples.

Tribunal Members

The Tribunal members for this review are:
Carmel Donnelly PSM, Chair
Dr Darryl Biggar
Jonathan Coppel
Sharon Henrick

Enquiries regarding this document should be directed to a staff member:

Mike Smart	(02) 9113 7728
Jennifer Vincent	(02) 9290 8418

Invitation for submissions

IPART invites comment on this document and encourages all interested parties to provide submissions addressing the matters discussed.

Submissions are due by Monday, 16 September 2024

We prefer to receive them electronically via our online submission form.

You can also send comments by mail to:

Review of maximum Opal fares until July 2028
Independent Pricing and Regulatory Tribunal
PO Box K35
Haymarket Post Shop, Sydney NSW 1240

If you require assistance to make a submission (for example, if you would like to make a verbal submission) please contact one of the staff members listed above.

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The Independent Pricing and Regulatory Tribunal

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Contents

This is version 2 of this document. Some clarifications and corrections have been made to the original document as per the revision table below.

Table 1 Revision table:

Date	Revision	Notes
16 August 2024	1	First publication
30 August 2024	2	Clarifications and corrections made to: • Sections 1.1, 1.2, 2.4, 3.4, 4.2, 6.2 and 7.3 • Tables 2.1, 2.3, 3.2, 3.5, 3.6, 3.7, 4.2, 6.2, 7.3

1 Summary

This technical paper sets out the method we used to estimate socially optimal fares for public transport in Greater Sydney. We first introduced the method in our 2016 review of Opal fares. However, this time we have made some improvements to that method. We consulted a panel of experts on detailed aspects of the method and introduced some new approaches as a result. More information about the expert consultation process and outcomes is provided in other information papers published with the Draft Report.

We have also obtained more recent data on public transport costs, usage pre and post-COVID, and actual road traffic data on speeds and density. This new data has allowed us to make improved estimates of marginal cost of providing public transport services, and external costs associated with road congestion and accidents.

We explain the optimisation method, then go through the calculation of these input values in detail. Finally, we present results for a base case in the form of optimal public transport fares by mode, time of day and distance travelled. We also discuss sensitivity analysis of how these optimal results would be influenced by different estimates of cost and externality.

1.1 What does 'socially optimal' mean?

When we talk about socially optimal fares, we mean the level of fares which takes into account both the financial costs of running the service, and the costs and benefits of public transport journeys to other members of society who are not public transport passengers. It also recognises that the cost of a fare may shift a person's mode choice. This results in a fare that may be lower than the financial cost of the passenger's journey.

In a world where public transport only affects its passengers and the operators, the optimal fare would be the equilibrium price in the market for public transport services. This equilibrium price would be equal to marginal cost.

However, public transport also affects many groups in society who are not passengers. A well-used public transport system benefits automobile users by reducing road congestion. It benefits pedestrians and pedal cyclists by reducing their risk of death or injury in traffic accidents. It benefits public health by reducing air pollution from automobile exhaust and by requiring an active transport component (to get to and from trip start and finish points), and it benefits everyone on the planet by reducing greenhouse gas emissions.

These benefits, experienced by a wide variety of people, all depend on the ability of public transport to displace automobile use. We refer to them as external benefits because they are experienced by people other than public transport passengers and operators—people who are not party to the transaction of selling a ticket and providing a train, bus, light rail or ferry service.

The presence of these benefits leads us to a different type of equilibrium, in which the optimal fare is set equal to the marginal *social* cost of public transport. The marginal social cost is the marginal cost less the external benefits created by that extra trip.

Public transport also creates other external benefits. Chief among these are agglomeration benefits and the social inclusion benefit. While each of these is difficult to quantify, they are clearly important and material.

Our model does not include capital costs associated with infrastructure, as we consider they provide agglomeration benefits. The costs used in the model are used to calculate a marginal cost of transport journeys. The socially optimal fare calculation can take account of further agglomeration and social inclusion benefits indirectly by modifying the marginal cost calculation to exclude certain types of costs that should in principle be matched to the agglomeration and social inclusion benefits.

By doing this, we are effectively assigning these costs to beneficiaries other than public transport passengers.

The taxpayer is therefore asked to meet these costs on behalf of those other beneficiaries, who represent a broad cross-section of society. The use of taxation to raise funds for the public transport deficit involves external costs of its own through the adverse effect of taxation on other parts of the economy, and we take these taxation externalities into account, too, in our calculation. Our May 2016 Information Paper 8 on the public transport fare optimisation model describes our treatment of taxation externalities in detail, including the concept of GST leakage and how it affects the results.

1.2 How we apply socially optimal fares

The socially optimal fares we estimate below differ in some important respects from current fares. Generally speaking, they are lower than actual fares at the shortest distance bands, but higher than current fares at longer distance bands. The effect of distance on fares is more pronounced for the socially optimal fares; longer distance socially optimal fares are significantly higher than current fares, while shorter distance fares are more similar.

Given these differences, and the need to also consider affordability, we are not proposing to set fares at the socially optimal level estimated by our model. Nevertheless, it is useful to know the direction in which fares would go if efficiency was the main consideration.

It has long been accepted that public transport fares do not fully recover the cost of providing service. This funding gap is justified in principle on the grounds that public transport delivers external benefits of various types. However, the quantum of external benefit matters. Ideally, the public transport subsidy should equate to that quantum of external benefit. The strength of the socially optimal fare approach is that it makes the external benefits explicit and quantifies them. This allows us to determine how much subsidy is socially desirable.

Where fares are below the socially optimal fares, the subsidy is excessive compared to the external benefits. This causes the entire state economy to operate inefficiently, with consequences for households, businesses and the funding of other government services.

It is therefore useful to understand where fares would need to go, over time and making provision for affordability, to remove that source of inefficiency. The socially optimal fares provide that understanding.

1.3 How we calculate socially optimal fares

Our May 2016 Information Paper 8 - Public transport fare optimisation model provides a detailed derivation of the precise equations we use for the calculation of socially optimal fares. Below, we provide a version of these equations which has been simplified for ease of exposition. The simplified version shown below omits the taxation externality terms.

The socially optimal fare for a particular public transport mode at a particular time of day and for a trip of a particular distance is

$$p^{r*} = c^{r} + mec^{r} + \Sigma_{i<>r} [c^{i} - p^{i} + mec^{i}] (\partial X^{i} / \partial X^{r})$$

The superscript r refers to the particular combination of transport mode, time of day and distance travelled. The superscripts i refer to the other transport modes for the same time of day and distance travelled.

What this formula says is that the optimal fare is the marginal cost of that mode plus the marginal external cost of that mode, plus a series of terms that represent the influence of mode r on the other modes.

If these other modes are priced at a level equal to their own marginal costs plus their own marginal external costs, then they will not affect the optimal fare for mode r. However, if they are priced significantly below the sum of their own marginal cost and marginal external costs, then they will contribute to a lowering of the optimal fare for a public transport service.

To give a specific example, if mode i is automobile travel, it is often the case that car users do not pay the full external costs they impose on other members of society, such as traffic congestion, air pollution and accidental injuries to pedestrians and pedal cyclists. These facts lead us to reduce the public transport fares from their own marginal costs. But this fare reduction should only be done to the extent that the public transport mode actually displaces automobile use. This is where the final factor $(\partial X^{i} / \partial X^{r})$ comes in. This factor is negative and the marginal external cost (mec) is positive. It indicates the strength of the modal substitution away from cars to public transport.

1.4 Data

The main sources of data for the optimal fare calculation are:

1. Marginal cost of public transport – average incremental cost estimates based primarily on financial and accounting data provided by Transport for NSW
2. Marginal external costs of public transport
   a. analysis of road congestion based on actual traffic data: speeds from the data tool HERE and traffic density from publicly sourced traffic count data
   b. analysis of emissions impacts of road traffic based primarily on analysis of runs of the Sydney Strategic Travel Model (STM) and standard inputs (health and greenhouse impacts per vehicle kilometre travelled) published by Transport for NSW[1]

   c. analysis of traffic accident data provided by the Bureau of Crash Statistics

3. Demand elasticities for all modes of travel and quantification of modal substitution effects – inferred from analysis of STM runs

1.5 Calculation process

In simplified terms, the calculation method determines the optimal fare for each transport mode by setting it equal to the sum of its own marginal cost plus the marginal external costs it generates (noting that external costs may be negative – or in other words, an external benefit).

Complications arise because the external costs of one mode depend on the strength of cross-mode effects, and these depend on the prices charged for other transport modes. Therefore, it is necessary to solve a set of simultaneous equations to establish an internally consistent set of prices across all modes.

A further complication arises because we need to determine optimal fares for travel at different times of day (i.e. peak versus off-peak) and for trips of different distances.

We assume that the prices for private automobile travel are determined by events outside of IPART's control.

Finally, public transport services run at a deficit, which is funded by government subsidy. This subsidy funding creates a negative taxation externality that must also be taken into account in the estimation of optimal fares.

2 Marginal cost

2.1 Econometric method not used for marginal cost

We have made a draft decision not to apply econometric methods to the estimation of public transport marginal costs for the following reasons:

- The prime data source is annual accounts of Public Transport agencies, but inter-year comparability of costs is poor due to past structural changes within Public Transport delivery organisations
- The distinction between Operational expenditure (opex), Major Project Maintenance (MPM) and Capital expenditure (capex) in the annual accounts is not always consistent with the objective function of interest: total annual costs of delivering public transport services on a steady-state, life cycle average basis
- Bus contracts contain useful information, but they refer to contract payments, which may differ from resource costs of delivering bus services
- Assessing annualised vehicle capital costs from annual accounts is complicated by the fact that some vehicles are purchased and owned outright by the Government, but others are the subject of complex leasing arrangements
- For Light Rail and potentially Metro services, turnkey contracts may hinder the transparency of key inputs and outputs

Instead, our draft decision is to use an Average Incremental Cost approach. Actual costs of public transport delivery organisations have been collected for a representative year in specific categories that can be related either to providing **capacity** for peak services or providing for **usage** at any time of day. These were divided by a relevant quantum of demand—either peak passenger journeys, peak passenger kilometres travelled, total passenger journeys and total passenger kilometres travelled. These averages across these incremental cost categories form the basis of the marginal costs used in the optimisation.

One challenge is that finding a representative year could be difficult given our recent experience with COVID travel restrictions and subsequent increased working from home patterns (For more information on changes to patronage in recent years see our information paper on patronage).

2.2 Separate marginal costs for peak and off-peak times

One approach for calculating marginal costs during peak and off-peak periods is set out in in a paper by Crew, Fernando and Kleindorfer[a]. Under this approach, capacity costs are divided only by the number of peak journeys, but usage costs are divided by all journeys. The capacity cost pool is divided by peak usage to determine the average incremental cost of capacity. The usage cost pool is divided by all usage to determine the average incremental cost of usage at all times. Peak MC = AIC of capacity plus AIC of usage. Off-peak MC = AIC of usage only.

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[a] Crew, M.A., Fernando, C.S. & Kleindorfer, P.R. The theory of peak-load pricing: A survey. *J Regul Econ* **8**, 215–248 (1995).

We note in the post pandemic years, a shift in peak travel patterns has resulted in a more pronounced peak on certain weekdays (Tuesday to Thursday) than prior to the pandemic (Monday to Friday).

2.3 Allocating costs: # passengers (PJ) vs how far they travel (pkm)

We made a draft decision to follow the approach taken in 2016 of allocating costs between separate cost drivers. These are Passenger Journeys (PJ) and passenger kilometres (pkm). For example, public transport vehicle costs such as fuel or maintenance depend mainly on distance travelled so these costs would be allocated more towards pkm travelled whereas ticketing and station staff-related costs depend mainly on the number of travellers so these costs would be allocated to the PJ volumes.

Some cost category allocations are not as clear. These include maintenance of path infrastructure, e.g. train tracks, and network control, signalling and communications.

We considered how sensitive the optimal price is to the allocation between PJ and PKM. It is very sensitive, especially for externalities. Allocation of external costs to PJ and PKM had significant implication on the overall result in 2016. This highlights the importance of conducting sensitivity tests. To the extent possible we have made allocation decisions based on empirical data.

For vehicle fleet capacity, we assume it can expand or contract with patronage and we calculate the contribution of this cost to the overall marginal cost. We do assume infrastructure is fixed.

2.4 Marginal cost results

This section presents the draft estimates of marginal costs for public transport in our base case or “moderate” scenario, based on the Average Incremental Cost methodology.

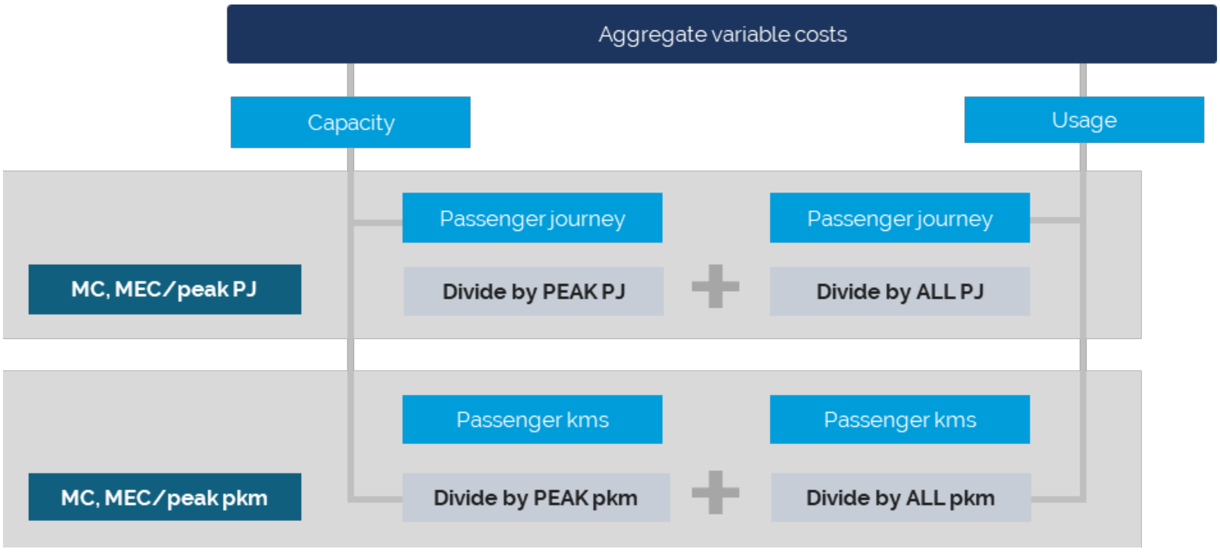
Table 2.1 presents the marginal cost results based on the data presented in this section.

Table 2.1 Marginal cost of public transport ($2022-23)

	Peak period		**Off-peak periods**	
	$/PJ	**$/PKM**	**$/PJ**	**$/PKM**
Sydney Trains	4.57	0.51	0.78	0.43
Bus	1.58	1.48	0.00	1.36
Ferry	1.69	2.51	0.00	2.02
Light rail	0.62	1.69	0.00	1.00

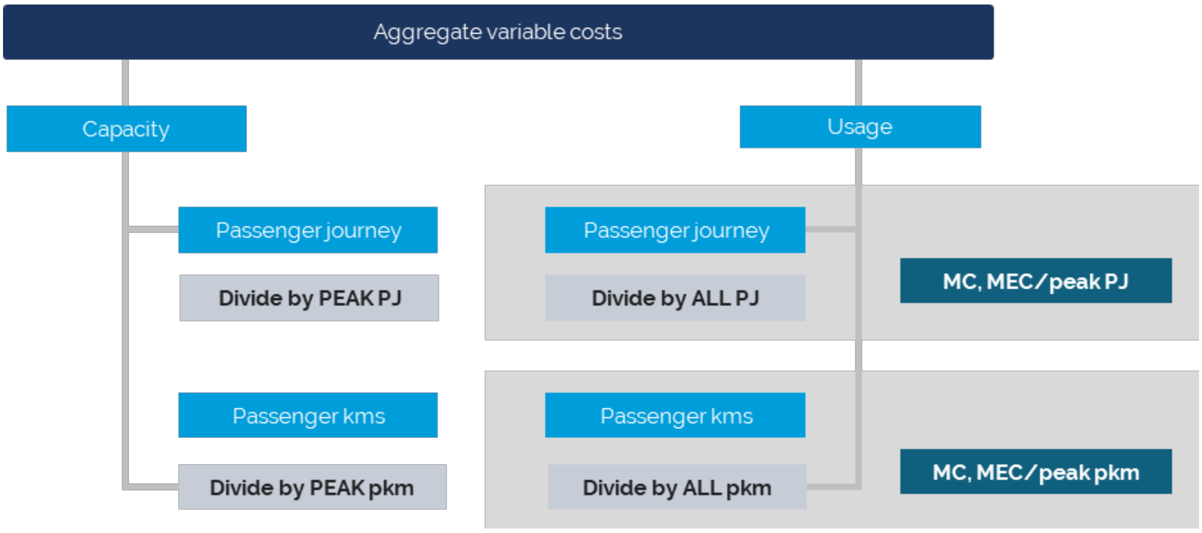
The Average Incremental Cost methodology is summarised in the two diagrams below.

Figure 2.1 Peak marginal financial costs



Source: IPART

Figure 2.2 Off peak marginal financial costs



Source: IPART

2.4.1 Public transport costs from accounts FY23

Transport for NSW provided accounting data for the 2023 financial year,. In our published fare optimisation model, we summarise that data. Some cost categories have been combined to protect commercially sensitive information.

We assume that the appropriate allocation of corporate overhead costs to passengers is 50% of actual overhead costs.

2.4.2 Vehicle ownership costs

The accounting cost data referred to in the previous section did not include costs of vehicle ownership. To calculate vehicle ownership costs, we referred to information provided by Transport for NSW.

For each train type, for a typical bus type, for a typical Sydney ferry and the Stockton ferry, and for light rail vehicles, we had the number presently in the fleet, the total replacement cost for that number of vehicles, the expected economic life of each vehicle, and the passenger carrying capacity of each vehicle type.

From this information, we were able to calculate an annuity at our standard rate of return over the economic life representing the average annual ownership cost of one vehicle of each type. This ownership cost was then expressed as a rate per passenger kilometre.

2.4.3 Usage data for FY23

The table below summarises the number of trips and passenger km travelled in FY2023 by mode.

Table 2.2 Usage data by mode in the 2022-23 financial year

	Trips			Passenger kms		
	AM Peak	**Off-Peak**	**PM Peak**	**AM Peak**	**Off-Peak**	**PM Peak**
Sydney Trains	56,981,500	97,063,643	76,934,305	945,093,479	1,461,376,040	1,203,174,718
Bus	47,686,056	82,173,046	61,643,443	231,647,675	350,949,842	279,734,121
Ferry	1,999,265	6,386,262	4,389,096	11,511,174	37,798,107	25,931,344
Light rail	5,213,650	15,238,657	10,527,744	14,903,314	35,913,911	26,183,291

Source: Transport for NSW

2.4.4 Marginal cost estimates

Using the information summarised in the earlier tables in this section, the table below summarises the inputs to the Average Incremental Cost calculation.

Table 2.3 Public transport cost allocations ($'000 2022-23)

	Capacity costs			Usage costs	
	by PJ	**by PKM**	**Annual ownership costs**	**by PJ**	**by PKM**
Sydney Trains	507,171	0	383,121	179,873	1,534,339
Bus	172,980	0	120,922	0	1,174,462
Ferry	10,775	0	36,694	0	151,778
Light rail	9,758	0	57,195	0	76,876

The model has been set up to allow for cost allocation choices to be made to reflect the agglomeration and social inclusion benefits discussed further below.

2.4.5 Agglomeration benefits reduce marginal costs

We consider that capital costs of owning dedicated public transport infrastructure (such as railway lines, train stations, bus stops and depots, ferry wharves and light rail track) to be costs that are incurred in order to secure agglomeration benefits. These costs have not been included in the model.

Some included costs, such as those of fleet ownership, may also achieve agglomeration benefits. The model is set up so that the user can allocate less than 100% of these costs to the optimal fare calculation. The resulting marginal cost calculation is proportionately reduced or in other words, we are assigning these costs to the beneficiaries of agglomeration (society as a whole), rather than to public transport passengers alone.

In our base case fare estimation, we have included half of the costs of ownership of public transport vehicles in the optimal fare calculation.

2.4.6 Social inclusion benefits reduce marginal costs

We consider that some of the costs of operating public transport services could be costs that are incurred to secure social inclusion benefits. For example, bus timetables may include services that are lightly patronised because there are social benefits to more frequent services in the urban fringe areas. This assumes that a bus timetable designed to maximise utilisation of the bus fleet would involve less frequent and fewer services than now.

The model is set up so that the user can allocate less than 100% of these costs to the optimal fare calculation. In other words, we can assign the costs of supporting social inclusion by running a higher cost, lightly utilised timetable to the beneficiaries (society as a whole), rather than to public transport passengers alone.

In our base case fare estimation, we included all bus operating costs in the marginal cost. We also explored a sensitivity case in which we excluded some bus operating costs from the marginal cost in order to take account of social inclusion benefits. In the sensitivity case those bus costs that vary by the number of bus kilometres travelled (vehicle maintenance, crew and fuel costs) were set at 60% of the total).

3 Externalities

3.1 Road congestion externality

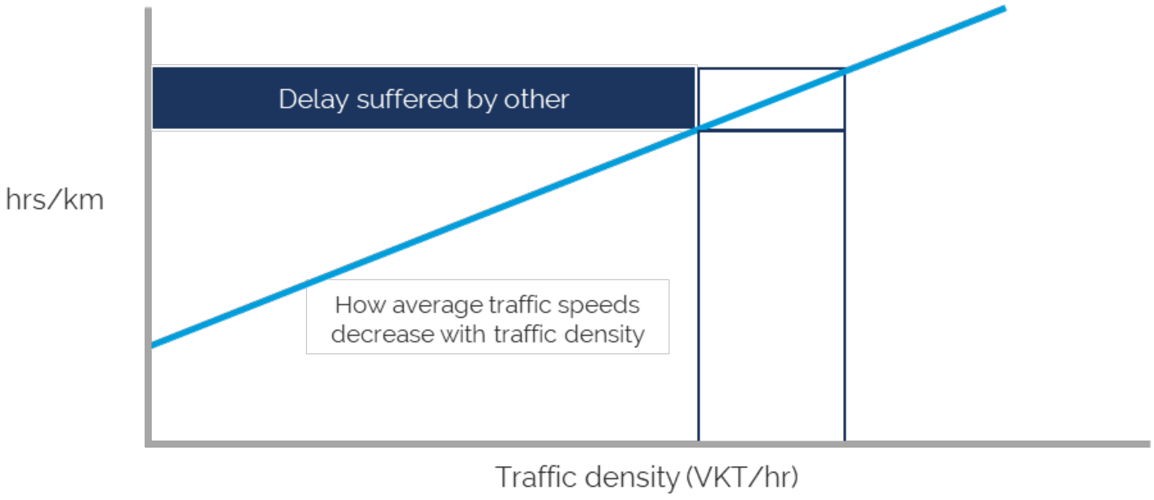
When a new motorist decides to join the traffic, that decision will lead to increased traffic density, which may lead to slower average speeds for all motorists. The marginal motorist (the new one) will experience this slower speed, too, but that cost is not an externality. Like the price of fuel, tolls and parking, this slower speed experience is just part of the price that the marginal motorist takes into account in reaching the decision to drive.

However, the impact on the inframarginal motorists (the existing ones) is an external cost. They take longer than before to complete their journeys and they suffer a disbenefit as a result of someone else's decision. This disbenefit is roughly proportional to the amount of extra travel time incurred by all inframarginal motorists.

The diagram below illustrates this reasoning. In order to calculate the road congestion externality we determine the relationship between traffic density and speed to calculate time savings achieved by diverting private vehicle journeys to public transport. This time saving is expressed in dollars per hour per vehicle occupant. We show the derivation of this relationship graphically below.

The dark blue rectangle is the external congestion cost experienced by the inframarginal motorists, and the unshaded vertical rectangle is the congestion cost experienced by the marginal motorist, which is not an externality.

Figure 3.1 External costs to car occupants (marginal approach)



Source: IPART analysis

The diagonal line in the diagram above represents the relationship between traffic density (horizontal axis) and hours per km (vertical axis). In reality, it is not a linear relationship, but has the shape shown in the macro-fundamental diagram below (Figure 3.3).

It is possible to empirically estimate the speed-density curve. In the next section we explain how we have performed new estimates to establish a different type of Macro Fundamental Diagram, which quantifies this relationship between average traffic speeds and density.

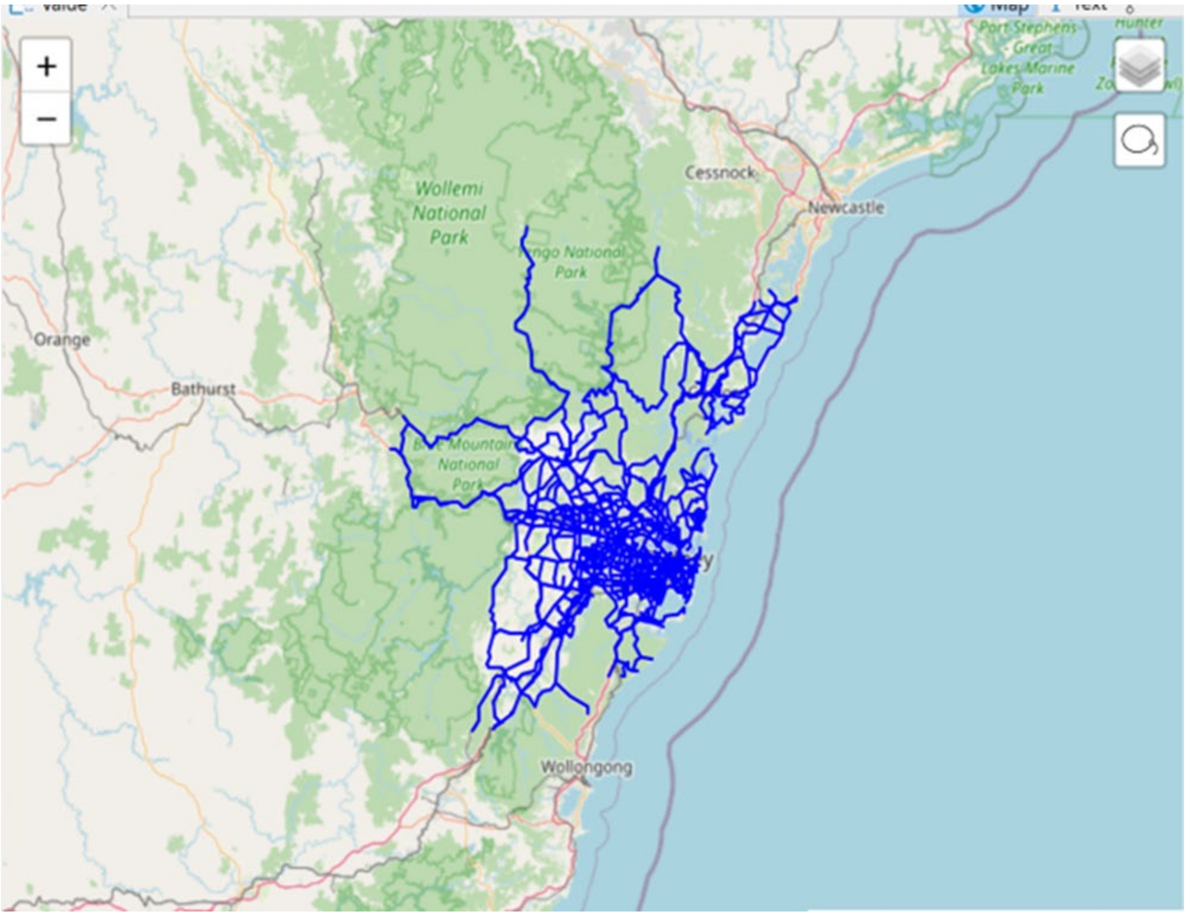
3.1.1 Data on the relationship between traffic density and average speed

At the suggestion of one of the participants in the technical workshops, we have incorporated the concept of Macro Fundamental Diagrams (MFD) for road networks to estimate the congestion effect. The aim is to establish an empirical relationship between traffic density and average car speeds for the whole Sydney GMA that can be used to estimate the congestion externality.

Our past estimates for the congestion externality have relied on runs of the STM, which is a simulation of traffic in Sydney. It is preferable to base these estimates on measurements of actual traffic. Fortunately, we have been able to do that.

Traffic speed data was sourced from a data tool called HERE, which monitors the speed of a subset of automobiles fitted with telemetry devices as they traverse the NSW road network. For the present study, we collected speed data for the physical road network shown in the diagram below (blue lines).

Figure 3.2 Traffic volume viewer traffic count



Source: Transport for NSW

Using traffic count data from the Traffic Volume Viewer

Traffic Volume Viewer (nsw.gov.au),

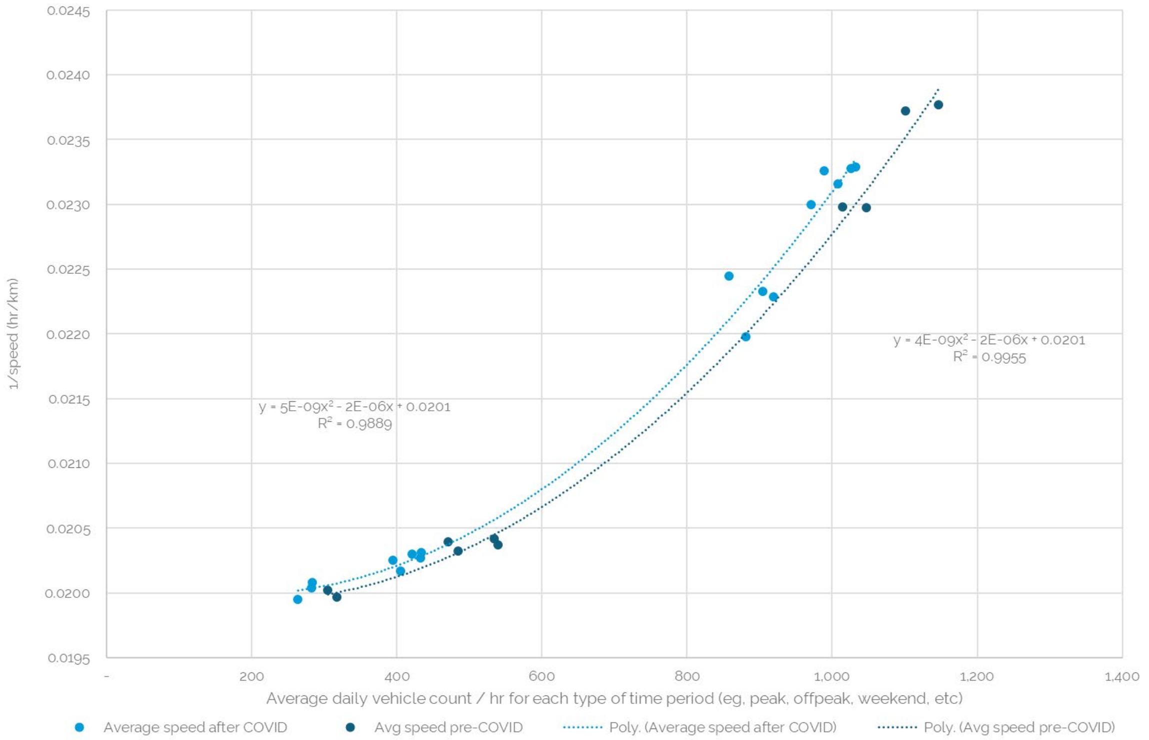
We were able to obtain a data set on traffic densities for the same road network and the same time periods.

The time periods we examined were AM PEAK, OFF PEAK, PM PEAK, and WEEKENDS for each of the years from 2018 to 2023. Year-to-date data for 2024 was also available.

3.1.2 Macro-fundamental diagram

Combining the two data sets we were able to generate the MFD shown below.

Figure 3.3 Macro-Fundamental Diagram for Sydney



Source: IPART analysis of speed and traffic count data

The data points each represent one of the time periods in one of the years. Data from the incomplete 2024 year were excluded.

We have plotted the quadratic line of best fit to each of the pre-COVID and post-COVID periods. The former (darker blue dots and line) comprise 2018 and 2019. The latter (lighter blue dots and line) comprise 2020-2023.

The parameters for the quadratic best-fit lines are shown on the chart.

3.1.3 Congestion externality calculation

Using these lines fitted to actual traffic data, we were able to generate distinct pre-COVID and post-COVID estimates of the marginal external cost of congestion. We assumed a value of travel time savings for automobile occupant in general of $20/person-hour.

For the pre-COVID period, the estimates were as shown in the table below.

Table 3.1 Pre-COVID estimates of congestion externality

Pre-COVID line fit	**4.29E-09**	**-1.59E-06**	**2.01E-02**		
	VJ/time period hr (AAHT)	**Vhr/VKT**	**VKT/VJ**	**Vhr/VKT**	**MECC ($/PJ)**
Peak	1,147.17	0.02	10.29	0.0095	1.95
Off-peak	485.24	0.02	10.29	0.0012	0.26

Source: IPART analysis

For the post-COVID period, the estimates were as shown in the table below.

Table 3.2 Post-COVID estimates of congestion externality

Post-COVID line fit	**4.99E-09**	**-2.24E-06**	**0.0203**		
	VJ/time period hr (AAHT)	**Vhr/VKT**	**VKT/VJ**	**Vhr/VKT**	**MECC ($/PJ)**
Peak	1,026.36	0.02	10.29	0.0082	1.69
Off-peak	432.70	0.02	10.29	0.0009	0.19

Source: IPART analysis

Note that the post-COVID marginal external costs were markedly lower than the pre-COVID values. We consider that is most likely a reflection of the overall reduction of peak vehicle density after COVID, meaning that traffic is flowing more freely and motorists spend less time waiting in traffic since COVID.

3.2 Emissions externalities – CO2 and air pollution

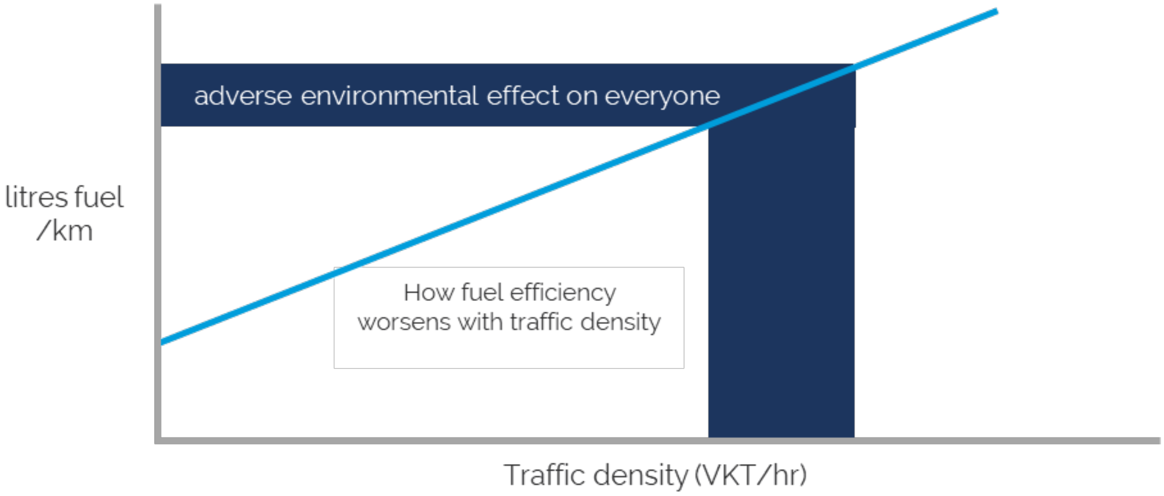
The main vehicle emissions of interest are CO2 and conventional air pollution. CO2 contributes to global warming and its effects are experienced by everyone on the planet. Conventional air pollution, including volatile organic compounds and fine particulates, have adverse health impacts on people who are close to transport routes.

Combustion of automobile, bus and ferry fuel generates these emissions in roughly constant proportions to the quantity of fuel consumed. To estimate the emission externality for cars, buses and ferries, we follow these steps:

1. Determine fuel consumption per vehicle km travelled at various speeds from engineering data on the vehicle fleets in operation
2. Determine average vehicle speeds at particular times of day (e.g. AM, PM, IP and EV) from the baseline STM runs
3. Determine litres of fuel consumed per vehicle km at each time period
4. Convert litres of fuel consumed to quantum of CO2 and conventional air pollution
5. Convert CO2 quantum to dollars using a current carbon price from world markets
6. Convert conventional air pollution quantum to dollars using existing studies of health effects of air pollution
7. Summing the results from steps 5 and 6, establish marginal external emissions cost in dollars per vehicle km travelled for each of the four times of day.

The diagram below illustrates the point that emissions from marginal motorists and from inframarginal motorists are all external costs.

Figure 3.4 Marginal external emission costs



Source: IPART analysis

The table below summarises our calculation of the marginal emission external cost, based on the June 2020 version of Transport for NSW's Economic Parameter Values for transport cost-benefit appraisals.

Table 3.2 Emission externality assumption values

Air pollution	3.92 cents per VKT
Greenhouse gas	2.61 cents per VKT
Occupancy	1.20 PKT/VKT
Overall	0.054 $/pkm

Source: Transport for NSW Economic Parameter Values June 2020 v2.0, Table 35 with CPI adjustment to FY23.

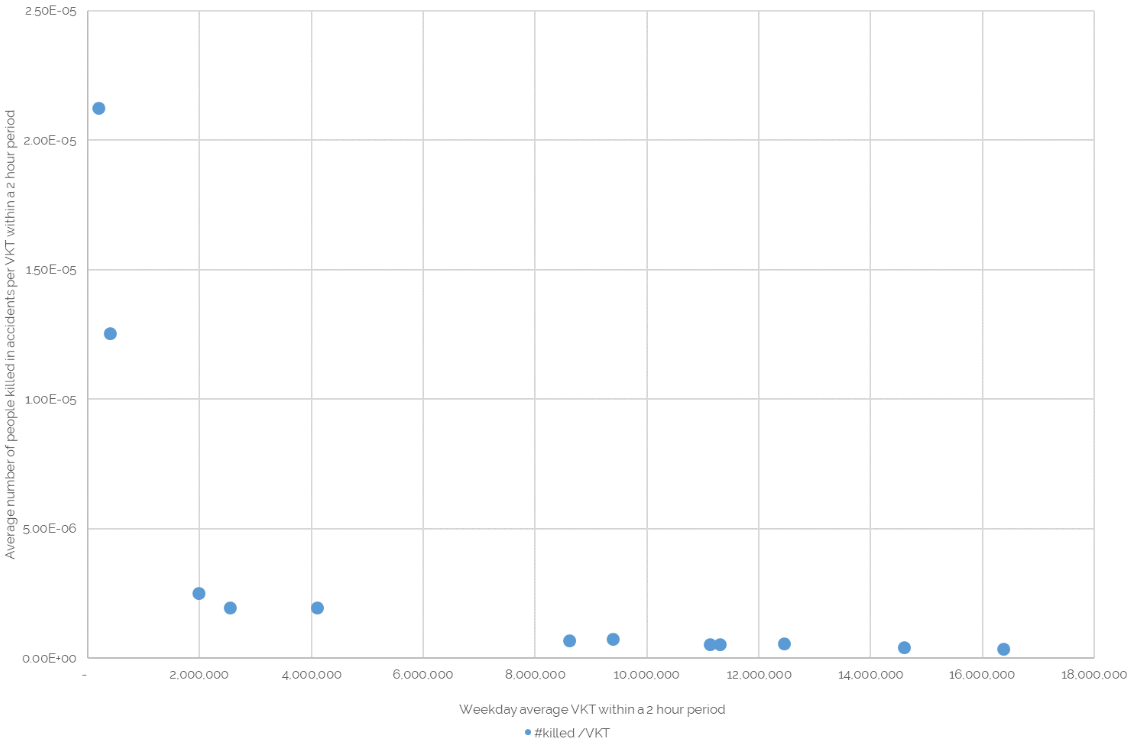
3.3 Accident externality

3.3.1 Accident costs faced by automobile occupants

IPART has had regard to recent statistical evidence that suggests the rate of car crashes per Vehicle Kilometre Travelled (VKT) is fairly constant across a wide range of traffic densities. The same conclusion applies for crash fatalities per VKT.

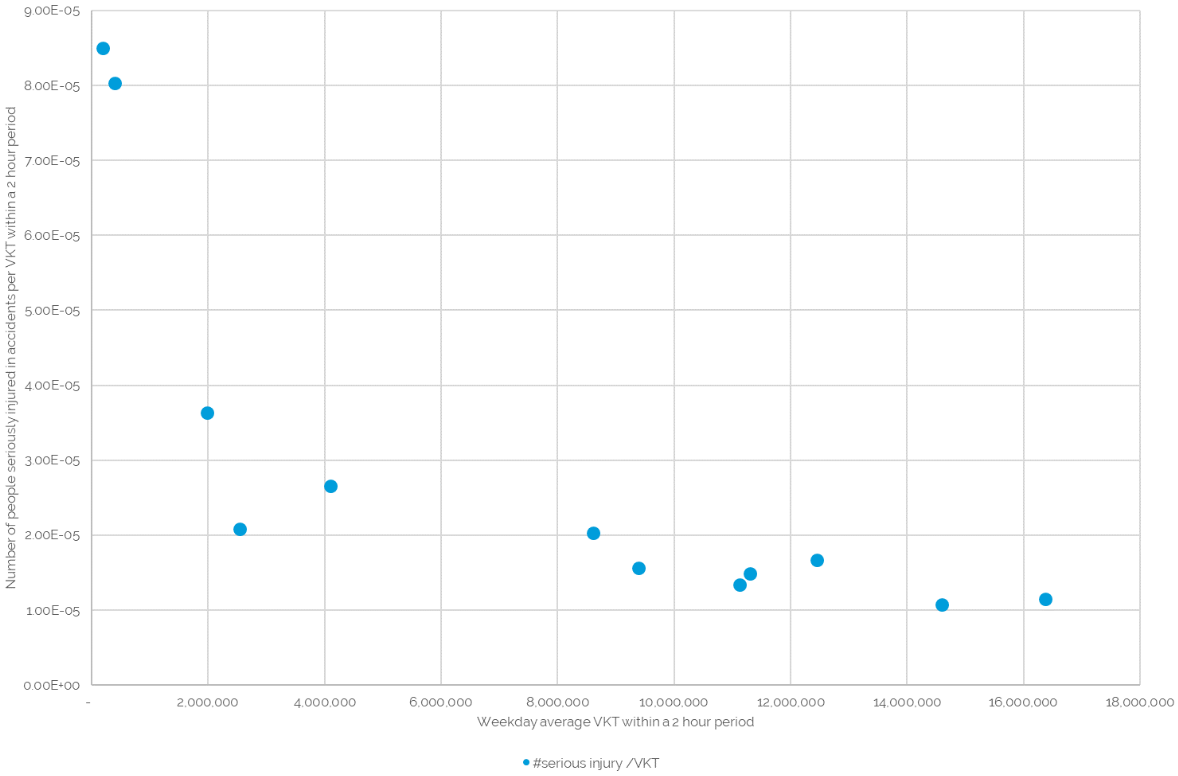
The data was collected for the period July 2019 to March 2020 for the Sydney, Newcastle and Wollongong conurbation. Over that period, data on VKT and fatalities were collected for each 2 hour period on weekdays. The figure below shows the number of fatalities per VKT (y-axis) versus the average number of VKT for each time period.

Figure 3.5 Fatal accident rate per VKT as a function of traffic density



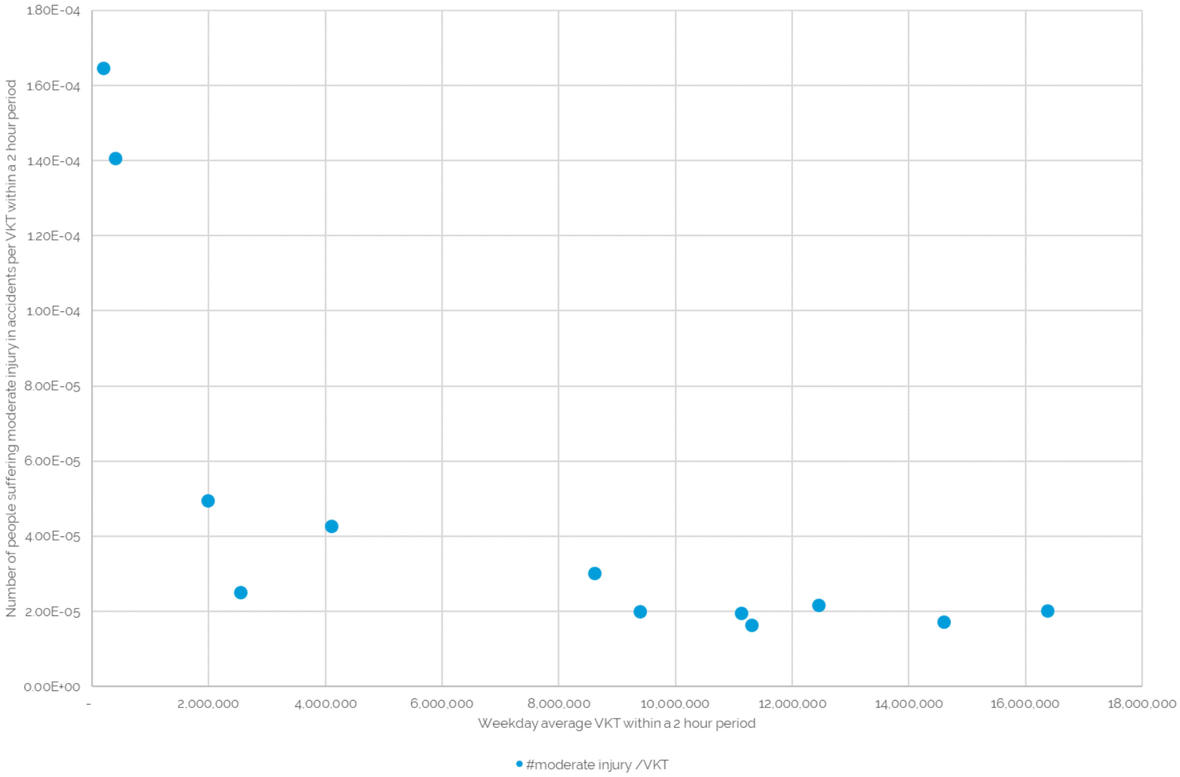
Source: IPART analysis

Figure 3.6 Serious injury accident rate per VKT as a function of traffic density



Source: IPART analysis

Figure 3.7 Moderate injury accident rate per VKT as a function of traffic density



Source: IPART analysis

There would be an accident externality if the likelihood that an existing driver will have a crash (i.e. the crash rate per VKT) increased when there are more cars on the road. In that case, one person's decision to drive would be making it more dangerous for other drivers.

But the data shows that is not the case. This chart shows that the fatal crash rate does not increase with higher traffic density. Therefore, there is no external accident cost experienced by car occupants.

This conclusion strongly suggests that the value of the accident externality for automobile occupants is negligibly small.

3.3.2 Accident costs faced by non-automobile occupants

Costs to injured pedestrians and pedal cyclists are external to the modal choice of motorists or people who would have been motorists but for their choice to use public transport. These costs are external costs of motor accidents.

The rate of pedestrian and cyclist injuries is relatively constant per automobile VKT, and this applies to all levels of severity. We use accident data for the period July 2019 to March 2020 and matched data on VKT for the Greater Sydney conurbation.

We estimated the social cost of accidents of various severity levels from the sources shown in the table below.

Table 3.3 Social cost of road crashes

	$2022-23
Social loss per fatality	5,400,000
Social loss per hospital injury	275,043
Social loss per non-hospital injury	29,660

Sources: BITRE, ANU, pmc.gov.au

Combining these unit costs with the accident probability data from the NSW Centre for Road Safety, we developed an overall external accident cost per VKT as shown in the table below.

Table 3.4 Automobile accident externality calculation ($/VKT, $2022-23)

	Accidents/vehicle km travelled	Social loss/accident	Social loss/vehicle km travelled
Pedestrian killed	1E-09	5,400,000	0.00661
Pedestrian serious injury	1E-08	275,043	0.00346
Pedestrian moderate injury	1E-08	29,660	0.00033
Cyclist killed	6E-11	5,400,000	0.00031
Cyclist serious injury	5E-09	275,043	0.00136
Cyclist moderate injury	6E-09	29,660	0.00018
Total external cost / VKT			**0.01226**

Source: IPART analysis

3.4 Social inclusion externality

Transport plays a key role in obtaining social inclusion benefits in a city by providing opportunities for equitable access to economic and social life. However, it is largely transport service planning and timetabling decisions, rather than fares policy, that provides these opportunities. While reduced fares might play some role at the margin, it is important that any fare subsidies for the purpose of social inclusion are targeted by means of fare concessions to at-risk groups.

While it may be hard to identify individuals as belonging to the at-risk group, it is sometimes possible to identify local geographies where social exclusion risks are high enough to justify a policy intervention. Reduced fares could potentially be offered on a concession basis to those geographical areas. For more information about affordability and concession fare policy see our information paper about affordability.

Another intervention may be to increase bus frequencies in those at-risk areas to improve transport accessibility for those who might need it. Ideally, the quantum of subsidy required to increase bus frequencies above the level that would achieve an efficient target vehicle utilisation would be commensurate with the social inclusion external benefit achieved by doing that.

As noted in section 2.4.6 above, we could take account of the social inclusion externality indirectly by modifying the marginal cost calculation to exclude certain types of costs that should in principle be matched to the social inclusion benefits. We have not done so in the base case fare estimation, but this has been explored through a sensitivity case.

3.5 Agglomeration externality

Transport plays a key role in obtaining agglomeration benefits in a city by allowing for a denser form of urban settlement. However, it is largely investments in transport infrastructure and public transport vehicle fleets, rather than fares policy, that induces other private firms to make the complementary investments needed for agglomeration to occur.

These sunk investments in infrastructure and fleet signal a commitment by governments to continue to provide the public transport services that enable the dense urban patterns of settlement that are central to agglomeration benefits. A fare change, without such a signal of commitment, would be reversible and so may fail to induce the complementary private investments in high-rise office buildings, etc, that are also necessary to achieve agglomeration benefits.

As noted in section 2.4.5 above, we could take account of the agglomeration externality indirectly by modifying the marginal cost calculation to exclude certain types of costs that should in principle be matched to the agglomeration benefits.

Public subsidies may also be applied to building transport infrastructure. Ideally, the quantity of infrastructure subsidy would be commensurate with the value of agglomeration that it helps to achieve.

3.6 External costs and benefits of public transport

3.6.1 Road congestion

Trains and ferries do not contribute to road congestion as they don't run on the roads. We have not quantified the contribution of light rail to road congestion, but we have assumed it is small, noting that large parts of the light rail routes are on dedicated sections, rather than the roadway shared with cars.

We have also not quantified the marginal external congestion cost associated with buses. To be precise, that is the additional road congestion cost suffered by car drivers and passengers when an additional passenger boards a bus service. This marginal external cost is hard to quantify, but there are reasons to suspect that it is relatively small. For example:

- If the marginal bus passenger does not lead to a timetable change or to a slowing of the bus service, then there will be no incremental effect on traffic—the change in bus passenger journeys may not lead to any change in bus vehicle journeys
- In many of the most congested parts of the Sydney road network, buses operate on dedicated bus lanes, separating them from the general traffic—for example, on the Sydney Harbour Bridge southbound.

3.6.2 Emissions and accidents caused by public transport

We adopted standardised values for emission externalities associated with conventional air pollution and greenhouse gases from Transport for NSW's Economic Parameter Values (June 2020) to derive the following estimates of marginal external emissions costs:

Table 3.5 External costs caused by public transport vehicles ($/pkm)

	Rail	Bus	Ferry	LR
Air pollution + GHG	0.0006	0.0301	0.1244	0.0128
Road accidents	0	0.006	0	0.006

Source: Transport for NSW, IPART analysis

Note also that the ferry emissions per passenger kilometre is an order of magnitude higher than for other modes. This difference is attributed to the lower fuel efficiency in litres consumed per vehicle kilometre travelled of a boat compared to a land vehicle.

Trains and ferries do not contribute to road accidents. Our calculation of external costs caused by road accidents involving buses is shown in the table below.

Table 3.6 Social cost of accidents involving buses (July 2019-March 2020 by time of day weekday Greater Sydney conurbation)

Bus accident parameter	key TU	+ other TU	= STA bus	bus accident /bus pkm	Social loss: $/crash	$/bus pkm
Crashes	18	13	31	2.21E-08		
Killed	1	0	1	7.12E-10	5,400,000	0.0038

Seriously injured	5	4	9	6.41E-09	275,043	0.0018
Moderately injured	5	10	15	1.07E-08	29,660	0.0003
					Total external cost	**0.0059**

Note: Weekdays in data period: 195; Bus passenger kms travelled on a weekday: 7,204,197
Note: TU means Traffic Unit
Source: IPART analysis

We have assumed that the accident externality rate for light rail is the same as for buses.

3.6.3 Active transport

Using data from the Transport for NSW Economic Parameter Values, we have estimated the following external benefits of public transport trips shown below.

Table 3.7 Active transport benefits of public transport

		Rail	Bus	Ferry	LR
Active transport	$/PJ	-1.69	-1.27	-1.78	-1.27

Source: Transport for NSW, IPART analysis

These active transport benefits arise because public transport passengers must generally walk to and from train stations, ferry wharves, bus and light rail stops. Public transport involves more walking than private car transport, hence there are net health benefits to public transport.

Our key assumptions underpinning these estimates are set out below. We assume that health benefits of walking are $1.44/km walked (based on TfNSW economic parameters 2023.2 '7. Active' worksheet, F29:F31). To apply this rate, we need to know how far public transport passengers walk on average to access their services and what proportion of passengers do walk to the bus stop, train station or ferry wharf. The relevant assumptions are tabulated below.

Table 3.8 Calculation of active transport benefits

	Bus	Rail	Ferry
Average walk distance access (m)	610	770	980
Average walk distance egress (m)	540	760	640
Share of passengers walking access (AM peak)	0.76	0.76	0.76
Share of passengers walking egress	0.77	0.77	0.77

Source: TfNSW economic parameters 2020 Table 45, p 41-44

4 Demand elasticity

All the relevant demand own-price elasticities[b] and modal cross-price elasticities can be calculated using the STM runs. The table below contains estimates of own-price elasticity and modal diversion fractions (Z)[c] based on the STM runs.

Own-price elasticity estimates were made by comparing percentage demand changes between scenarios that had the same percentage price changes on all public transport modes at once. These are the own-price elasticities we used in our optimisation analysis.

Table 4.1 Own-price elasticities used in the model

	Rail	Bus	Ferry	LR
AM	-0.35	-0.27	-0.37	-0.31
IP	-0.58	-0.49	-0.59	-0.51
PM	-0.41	-0.32	-0.43	-0.41
EV	-0.41	-0.32	-0.45	-0.39

Source: IPART analysis of STM results using scenarios where all public transport fares are changed by the same amount.

Modal diversion fractions were estimated by dividing the demand change on the "to" mode by the demand change on the "from" mode between scenarios.

Table 4.2 Estimated modal diversion rates (Z)

	Rail to car	Rail to bus	Bus to car	Ferry to car	Ferry to bus	LR to car	LR to bus
AM	-0.42	-0.21	-0.51	-0.61	-0.80	-0.56	-0.55
PM	-0.52	-0.21	-0.65	-0.83	-1.000	-0.72	-0.44

Source: IPART analysis of STM results using changes to the number of passenger journeys

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[b] Own-price elasticity is defined as the ratio of the percentage change in output to the percentage change in price.

[c] The model diversion fractions (Z) represent the proportion of trips diverted to each mode when the original mode is unavailable.

5 Other inputs

5.1 Integrating cars into optimisation

While we do not calculate optimal prices for automobile use, we need to know the difference between the price paid by a motorist for a car journey and the marginal cost of that journey in order to calculate optimal fares for other transport modes. This difference (p – c) will be approximately equal to the taxes on motoring if we make the assumption that all inputs to car travel are supplied in workably competitive markets. If that assumption is valid, then prices paid for fuel, repairs and the vehicle itself will be approximately equal to the long run marginal cost of supplying those inputs. Hence p – c = 0 for those inputs.

However:

- the parking space levy
- the fuel excise tax
- the difference between road tolls and the marginal pavement damage done by road use

represent taxes that account for a positive value of p – c. Each of these things can be estimated using the Strategic Travel Model (STM) and other data sources.

The tables below summarise the calculation of these inputs.

Table 5.1 Average tolls, parking space levy and fuel excise paid per trip

Toll revenue per vehicle journey	$/trip	$/passenger journey	$/passenger journey peak	$/passenger journey off-peak
AM	0.3000	0.2500	0.2299	0.2281
IP	0.2455	0.2046		
PM	0.2519	0.2099		
EV	0.3019	0.2516		
Fuel excise per passenger km				
Fuel excise (cents/vehicle km trip)	5.208			
Fuel excise (cents/passenger km)	4.3400			
Road damage (cents/passenger km)	4.1250			
Parking space levy per vehicle journey				
Vehicle journeys (million/weekday)	10.78			
Vehicle journeys (million/year (exc weekends & public holidays)	2,695.13			
Parking space levy/vehicle journey ($/vehicle journey)	0.0397			
Parking space levy/passenger journey ($/passenger journey)	0.0331			

Excise rate (cents/litre)	49.60
Fuel consumption (litres/vehicle km trip)	0.11
Road damage (cents/vehicle km trip)	4.95
Parking space levy ($m, $2020-21)	107.00

6 Optimisation process

To calculate optimal fares, we used the same optimisation logic and model that we used in the 2016 Opal fare review, but updated the input data. Below we summarise the inputs derived earlier in this technical paper and compare them to the inputs we used in 2016.

6.1 Marginal external costs and marginal costs

Table 6.1 New inputs for marginal external cost and marginal cost

	Units	Rail	Bus	Ferry	Light Rail	Car
Marginal external cost - peak	$/PJ	-1.69	-1.27	-1.78	-1.27	1.95
	$/pkm	0.00	0.04	0.12	0.02	0.07
Marginal external cost - off-peak	$/PJ	-1.69	-1.27	-1.78	-1.27	0.26
	$/pkm	0.00	0.04	0.12	0.02	0.07
Marginal cost - peak	$/PJ	2.97	1.03	1.10	0.40	-0.26
	$/pkm	0.33	0.96	1.63	1.10	0.00
Marginal cost - off-peak	$/PJ	0.51	0.00	0.00	0.00	-0.26
	$/pkm	0.28	0.89	1.31	0.65	0.00

Note: For Cars "marginal cost" = (marginal cost – p).

Table 6.2 Comparable inputs in our 2016 Opal review (per the original fare optimiser v7_5)

	Units	Rail	Bus	Ferry	Light Rail	Car
Marginal external cost - peak	$/PJ	-0.22	0.83	-0.23	-0.17	4.49
	$/pkm	0.02	0.08	0.14	0.02	0.34
Marginal external cost - off-peak	$/PJ	-0.22	0.59	-0.23	-0.17	1.05
	$/pkm	0.02	0.14	0.14	0.02	0.15
Marginal cost - peak	$/PJ	6.82	1.05	3.82	0.99	-0.14
	$/pkm	0.55	0.63	0.93	2.17	-0.04
Marginal cost - off-peak	$/PJ	2.21	0.63	1.06	0.65	-0.04
	$/pkm	0.16	0.47	0.93	0.54	-0.03

Note: For Cars "marginal cost" = (marginal cost – p).

6.2 Own-price elasticities and modal diversion fractions

The own-price elasticity values used here are shown in Table 4.1 above.

Some values for the modal diversion fractions Z have changed since 2016 based on the latest STM runs

Table 6.3 Estimated values of Z (same time of day, same distance)

	Rail to car	Rail to bus	Bus to car	Ferry to car	Ferry to bus	LR to car	LR to bus
AM	-0.42	-0.21	-0.51	-0.61	-0.80	-0.56	-0.55
PM	-0.52	-0.21	-0.65	-0.83	-1.00	-0.72	-0.44

Source: IPART analysis

7 Results

In this chapter, we briefly summarise the results from our base case - the “moderate scenario”. We do not present results for the sensitivity testing here. However, we have published a version of the optimisation model so that all stakeholders can trial their own preferred sensitivity cases to determine the effect on optimal fares of modified assumptions.

7.1 Base case – moderate scenario - results

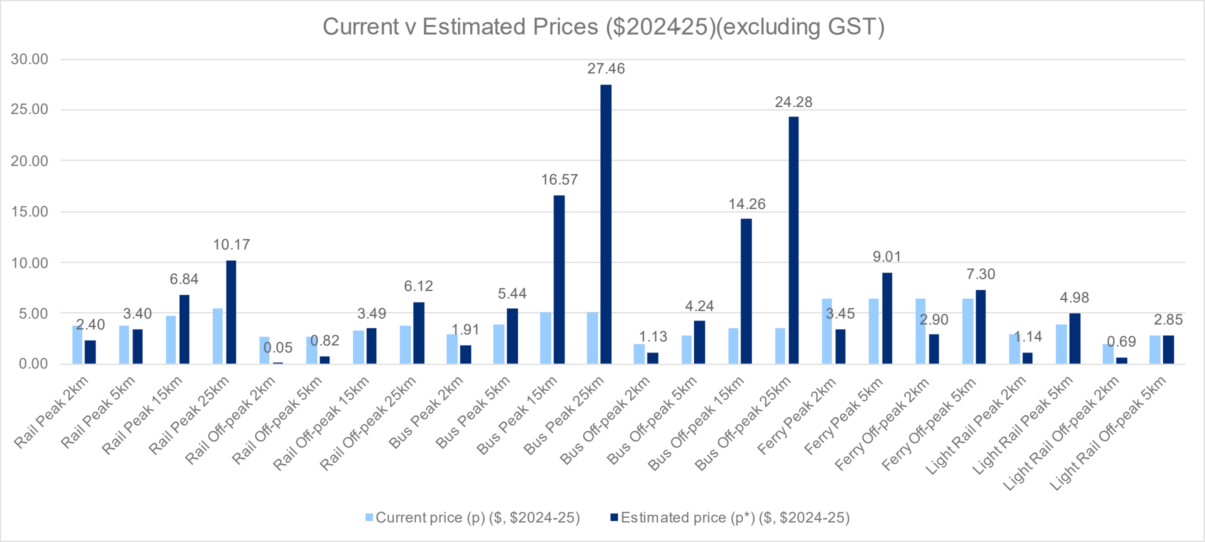
The chart below summarises the differences between the optimal fares calculated by our model and the current fares as at July 2024. The light blue bars represent current fares. The dark blue bars represent optimal fares.

The overall results are not very sensitive to the distance bands chosen for this calculation, since we fit a price-distance line to these points. We selected these particular distances to give us reasonable coverage of the most likely range of distances travelled on public transport.

From left to right, the fares shown are for peak rail (at distances of 2km, 5km, 15km and 25km), then off-peak rail for the same distances.

Continuing to the right, next are the peak bus fares at distances of 2km, 5km and 15km, followed by off-peak bus fares at the same three distances. Further to the right, next are the peak ferry fares at distances of 2km and 5km, followed by off-peak ferry fares at the same distances. Finally there are the peak LR fares at the same two distance bands as ferry fares, followed by off-peak LR fares at the same distances.

Figure 7.1 Current vs estimated prices ($2024-25) (excluding GST)



Source: IPART analysis

The general trend in all fares is that optimal fares, according to these estimates, are lower than actual fares at the shortest distance bands, but higher than actual fares, significantly in most cases, at the higher distance bands. In 2016, the optimal fares were somewhat closer to actual fares of the day, at least for shorter distance trips.

7.2 Moderate scenario – inputs for scenario analysis

This section sets out our selected inputs for the moderate scenario.

7.2.1 Public transport marginal costs

On the Scenario Analysis sheet of the model, we reduced the public transport marginal cost per passenger journey (PJ) and per passenger kilometre (PKM) to 65% of calculated estimates to account for two categories of additional patronage:

- patronage not measured because of fare non-compliance or failure to tap on or failure to tap off
- patronage recovery towards pre-COVID level of patronage compared to the actual patronage from 2022-23 used in modelling.

Higher patronage means lower cost per passenger.

7.2.2 Vehicle ownership costs

On the Scenario Analysis sheet of the model, we allocated 50% of vehicle ownership costs to the fare calculation. We considered that the remaining 50% should be paid for by taxpayers as providing for an agglomeration benefit.

7.2.3 Allocation to usage or capacity and journey or kilometre

On the Scenario Analysis sheet of the model the user can decide which category to allocate costs to, based on the user's view of the driver for each cost. The model has the functionality to split between the 4 categories but for the moderate scenario we allocated 100% to one of the four categories.

We allocated only 50% of corporate overheads and "other operational costs" to passengers on the basis that the rest is paid for by Government as an agglomeration benefit.

7.2.4 Marginal external costs

On the Scenario Analysis sheet of the model the user can input marginal external costs of car travel. We used values from Transport for NSW's Economic Parameter Values 2023.2.

7.3 Sensitivity testing

We undertook some sensitivity testing to evaluate the impact of changed estimates of marginal cost and marginal externality values. Rather than attempting to present this work in this technical paper, we are providing stakeholders with the means to test for themselves the effect of changed assumptions on the optimal fares. Stakeholders can do this using our public optimisation model.

Two key sensitivity cases that we explored were:

- Bus operating costs that vary by passenger-kilometres were set at60%. The intent of this sensitivity case was to explore how much the bus marginal costs would have been reduced if the timetable frequencies were reduced to reflect a higher target utilisation. This exploration would show the consequences for fares of a higher allocation of these costs to the social inclusion benefit.
- Public transport vehicle ownership costs were entirely excluded from the marginal cost calculation (as opposed to the base case assumption of 50% inclusion of these costs). The intent of this sensitivity case was to explore the consequences for fares of a higher allocation of these costs to the agglomeration benefit.

7.3.1 Sensitivity parameters

Model users can change inputs on the following sheets:

Scenario Analysis

The marginal external cost parameters we used were drawn from Transport for NSW's Economic Parameter Values 2023.2, but these can be varied by model users to test sensitivity to these parameters, or to draw from different sources of information about these costs.

Users can also vary the contribution of the overall marginal cost or marginal external cost to the fare calculation to test sensitivity or to make allowance for different assumptions about elements that might have been included or excluded from those costs (as we did for the moderate scenario to account for additional patronage over measured patronage).

Input sheets

There are 7 input sheets where we have set out the inputs we have used for different parameters of the calculation. The inputs are referenced to sources in the model. Users can vary these inputs to test sensitivity or where they wish to make different assumptions or have different sources of information.

8 Glossary

Term	Description
Agglomeration	is the benefit to individuals and businesses from operating in areas of high population density. Transactions of most types are facilitated by the minimisation of travel costs when buyers and sellers are located close together, as they may be in large cities. Public transport infrastructure investments help to minimise travel costs in and around cities, and therefore they contribute to the realisation of agglomeration benefits.
Average incremental cost	is one method of estimating marginal costs. Where a suitable increment of output can be defined, average incremental cost is measured as the ratio of incremental cost (the additional cost to achieve that increment of output) to incremental output.
Cross-price elasticity	is the percentage change in output divided by the percentage change in price for a different output. This elasticity is normally positive for products that are substitutes because price for one product and output of its substitutes tend to move in the same direction. For example, public transport use and automobile use are substitutes. We need to understand the strength of that substitution effect, which is indicated by the cross-price elasticity.
External benefit	is a benefit received by a third party as a result of a transaction between a buyer and seller, where the third party is neither buyer nor seller. For example, a car commuter receives a benefit in the form of reduced road congestion when a different car commuter decides to take public transport instead of driving.
External cost	is a cost experienced by a third party as a result of a transaction between two other parties. For example, a person with respiratory illness living near a busy road may become sicker as a result of breathing automobile exhaust.
GST leakage factor	For every dollar of GST paid by a taxpayer in NSW, approximately 31 cents is returned by the Commonwealth to the NSW Government, implying that 69 cents "leaks." The factor μ represents that leakage as a proportion of the GST-inclusive selling price of the relevant service: $\mu = 69\%/11$. Note that public transport fares are GST-liable.

Term	Description
Marginal cost	is the change in total cost caused by a small increase in output. In the present context, this is interpreted as the increase in cost when output is increased either by one passenger journey, or by one passenger-kilometre travelled.
Marginal excess burden of taxation	quantifies the extent of the effect of taxes on economic inefficiency. All taxes distort economic decisions in inefficient ways. For example, sales taxes reduce sales volumes, transactions taxes like stamp duty reduce the number and value of transactions, and labour taxes like payroll tax reduce employment. In our calculations, we have adopted a value of 8% for the marginal excess burden of taxation based on GST. This figure was established from general equilibrium modelling of the effect of various taxes on the Australian economy.[d]
Marginal external cost	is the increase in external costs as a result of a small increase in output. In the present context, this could include the additional contribution to global warming from a motorist's decision to travel an additional kilometre in their car.
Own-price elasticity	is the percentage change in output divided by the percentage change in price for that output. This elasticity is normally negative because price and output tend to move in opposite directions. For essential services, elasticity tends to be low (i.e. between 0 and -1) because demand is less price-sensitive than for discretionary services (having elasticity values less than -1).
Passenger journeys (PJ)	is the number of trips using a single mode between a departure point and a destination point
Passenger-kilometres (pkm)	is the number of kilometres travelled on the Opal network, calculated by multiplying the total number of passenger journeys by the distance travelled per trip
Social inclusion	is a benefit experienced by individuals as a result of being able to access opportunities to participate in society, either through employment, education, volunteering or socialising with others. Public transport services can play an important role in providing those opportunities to individuals who might otherwise face exclusion.

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[d] KPMG Econtech 2009, CGE Analysis of the Current Australian Tax System, KPMG, Canberra. Chart A on p 3 notes the 8% marginal excess burden of taxation for GST.

Term	Description
Social inclusion externality	is a benefit experienced by people other than the individual given the opportunity to participate. These external benefits might take the form of a more productive economy, and/or reduced costs to the health system and to the criminal justice system. Excluded individuals may not be able to participate in productive activity, and may suffer worse physical and mental health, and may be more likely to behave antisocially.
Socially optimal fares	are defined at the beginning of this technical paper. They represent the fares that maximise efficiency and economic welfare, taking account of certain specific external benefits of public transport.

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[1] Transport for NSW – Economic Parameter Values 2023.2