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Major urban transport expenditure initiatives: where are the returns likely to be strongest and how significant is social exclusion in making the case?

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TITLE: **Major urban transport expenditure initiatives: where are the returns likely to be strongest and how significant is social exclusion in making the case?**

ABSTRACT: This paper explores whether the benefits from major urban transport spending increases are likely to differ greatly, depending on whether that spending prioritises light rail, a mode with growing interest and several new services recently developed in Australia, major road network improvement or provision of additional bus services. It does this through a series of case studies based on Sydney, using MetroScan, an integrated transport and land use strategic model system. MetroScan is the most sophisticated strategic integrated land use, transport and economic system evaluation model in Australia, with the capability of exploring dynamic interactions between transport improvements, residential locations and job locations, among other things. We specifically focus on the impacts of major transport initiatives on reducing risks that people will be socially excluded because of poor mobility opportunities.

KEY WORDS: ***Integrated transport and land use strategic model system, MetroScan, Benefit-cost analysis, Comparison on rail, bus and road investments, Sydney***

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1. Context and the Sydney case studies

Growth in major infrastructure spending has been the dominant feature of Australia's transport landscape in recent years. For example, annual average capital expenditure by the Victorian State Government over the four-year budget period from 2021-22 will be more than four times the 10-year average to 2014-15 (Victorian Government 2021), with transport the major component. NSW has also had a rapid growth in its infrastructure spending, with the annual average for the four-year budget period from 2021-22 nearly double that from 2013-14 to 2016-17 (New South Wales Government 2021). Transport accounts for two-thirds of the NSW capital budget and urban transport spending has been a critical focus of infrastructure spending growth.

Nationally, the total value of road and rail projects being built across Australia exceeded $120 billion for the first time in March 2020, having fluctuated around $40-60 billion between 2007 and 2016 (Terrill 2021a). Terrill notes that most of the work is now being done on projects of $1 billion or more, with average project size having doubled in the last decade. Such spending programs have been partly about overcoming backlogs associated with rapid population growth. Melbourne, for example, added 475,000 (+12%) to its population size between the 2011 and 2016 census dates, and Sydney added 430,000 (+10%). These are high population growth rates for cities of 4-5 million population with a high level of economic development.

However, the large and growing transport infrastructure expenditures in Australia are frequently not supported by publicly available economic assessments of alternatives, including assessments that explore different ways of achieving intended outcomes. In Victoria's case, this concern has recently been highlighted by the State's Auditor-General, who found that:

> *"The absence of a transport plan as required by the [Transport Integration] Act, during a decade of unprecedented investment in transport infrastructure, creates risks of missed opportunities to sequence and optimise the benefits of these investments to best meet Victoria's transport needs."* (VAGO 2021, p. 1)

This paper explores whether the benefits from major urban transport spending increases are likely to differ greatly, depending on whether that spending prioritises light rail, given growing interest in this mode and several new services recently developed in Australia, major road network improvement or provision of additional bus services. It does this through a series of case studies based on the Greater Sydney Metropolitan Area (GSMA), making use of the Institute of Transport and Logistics Studies' MetroScan model (Hensher et al. 2020 and Appendix A). MetroScan is the most sophisticated strategic integrated land use, transport and economic system evaluation model in Australia, with the capability of exploring dynamic interactions between transport improvements, residential locations and job locations, among other things, for both passenger and freight movements.

One particular focus of the case studies is an assessment of the extent to which the different initiatives might contribute to reducing risks of mobility-related social exclusion. This has been an area of concern for transport policy makers, planners and researchers for about two decades, dating mainly from the time of the Social Exclusion Unit's pioneering work in the UK (SEU 2003). However, formal analytical tools that involve benefit monetization are still in their infancy, even though it is now a decade since the value of additional trip making to those at risk of social exclusion was demonstrated (Stanley et al. 2011a, b). The current paper shows why consideration of potential inclusion benefits can be crucial for project assessment outcomes, underlining the importance of taking it more seriously in appraisal. The heightened impact of COVID-19 during 2020 and 2021 in areas of social disadvantage in Sydney and Melbourne reinforces the importance of this issue.

Four Sydney case studies have been selected for comparison purposes: Parramatta Light Rail (Figure 1); M4 Outer Motorway upgrade (Figure 2); a doubling of the service frequencies of a large proportion of Sydney's urban route bus services, focussed in middle and outer suburbs (Figure 3, top panel) – this case study is called Bus Service Additions (1); and, a doubling of bus service frequencies in Sydney's outer west, an area of relative socio-economic disadvantage – this initiative is called Bus Service Additions (2) (Figure 3, lower panel).

Bus Service Additions (1) and (2) include upgrades to both trunk and local services, with the former accounting for about three quarters of route lengths. Analysis of the benefits and costs of Bus Service Additions (1), which are widespread, and the study's interest in the linkages between major transport improvements and the possibility of reduced risks of social exclusion, led to the more spatially focussed doubling bus service frequencies in Bus Service Additions (2), targeting Sydney's Outer West. As identified in Section 2, and shown in Figures 3 and 4, this part of Sydney has higher concentrations of people who are more likely to be risk of mobility-related social exclusion.

Light Rail is a relatively new mode in Sydney[1], accounting for only 12 million (unlinked) trips in 2019-20. By way of comparison, train plus metro accounted for 300m unlinked trips and bus a further 230m unlinked trips in that year. A major Sydney public transport network addition, Parramatta Light Rail Stage 1 will connect Westmead to Carlingford via the Parramatta CBD and Camellia, with its two-way track spanning 12 kilometres. The route is expected to open in 2023, with an estimated capital cost of $2.4 billion (Parramatta Light Rail - Infrastructure Pipeline). The NSW Government suggests that, 'By 2026, around 28,000 people will use Parramatta Light Rail every day and an estimated 130,000 people will be living within walking distance of light rail stops' (Parramatta Light Rail | Parramatta (nsw.gov.au)). A subsequent Stage 2 will connect the Parramatta CBD to Olympic Park. Detailed discussion of the study area and potential impacts of Light Rail is set out in reports such as HillPDA Consulting (2017) and Jacobs (2017).

For consistency of scale with the Parramatta LR project, the upgrade to the M4 Outer Motorway was chosen as a representative major road project. This is essentially a road widening project of around 37 kilometres in length, from the M4 East to the Nepean River, as shown in purple in Figure 2. This project is also estimated to have a capital cost of around $2.4 billion.

This paper explores some of the most important prospective strategic transport and land use impacts of the four major transport initiatives. The study areas for the two bus initiatives are shown in colour in Figure 3, to reflect the authors' relative assessment of mobility-related exclusion risk. Section 2 of the paper explains the derivation of that exclusion rating scale, which is applied across 80 zones in Sydney, as part of each of the four project assessments. Section 3 discusses predicted impacts of the initiatives on trip making, while Section 4 considers impacts on major government revenue flows. Most benefits are costs are discussed in Section 5 and Section 6 presents an assessment of social inclusion benefits. Section 7 sums up the overall assessments and Section 8 presents the paper's conclusions.

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[1] Although there was widespread tram service provision up to the late 1950s, and after that until recently there was a short light rail track in the inner area of Sydney going to the inner West. The CBD light rail commenced operations in the middle of 2020, extending to the Eastern Suburbs.

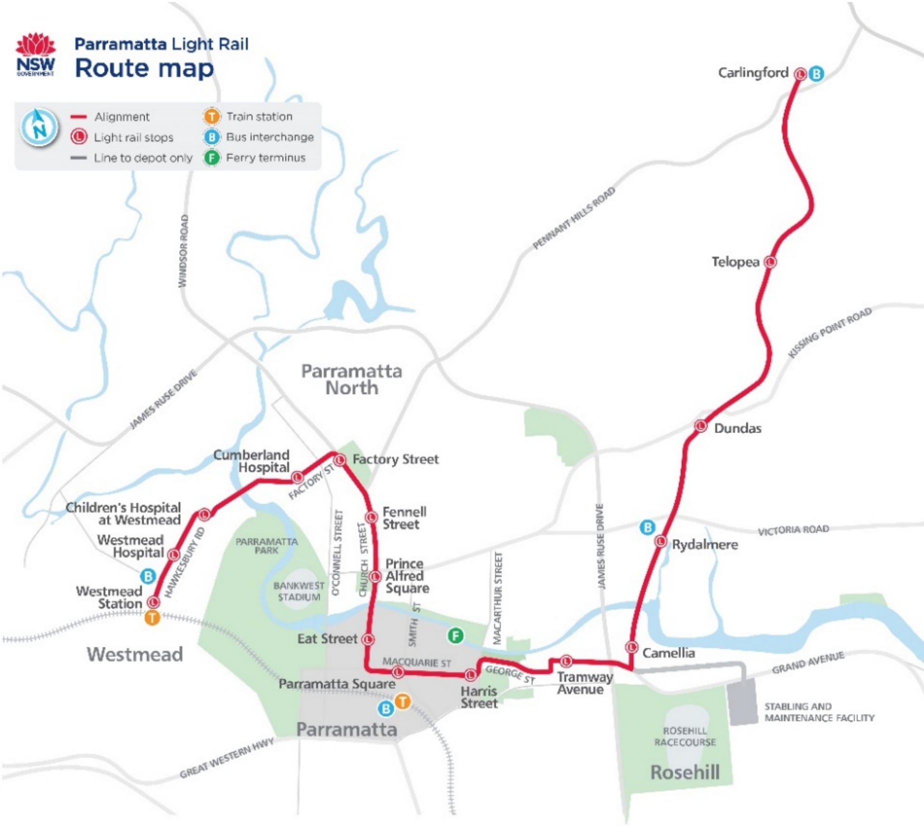

Figure 1: Parramatta Light Rail, Stage 1. (Source: [Maps | Parramatta (nsw.gov.au))](#)

Figure 2: M4 Outer Motorway. (Source: [Western Sydney road alignments - M4 Motorway (Sydney) - Wikipedia)](#)

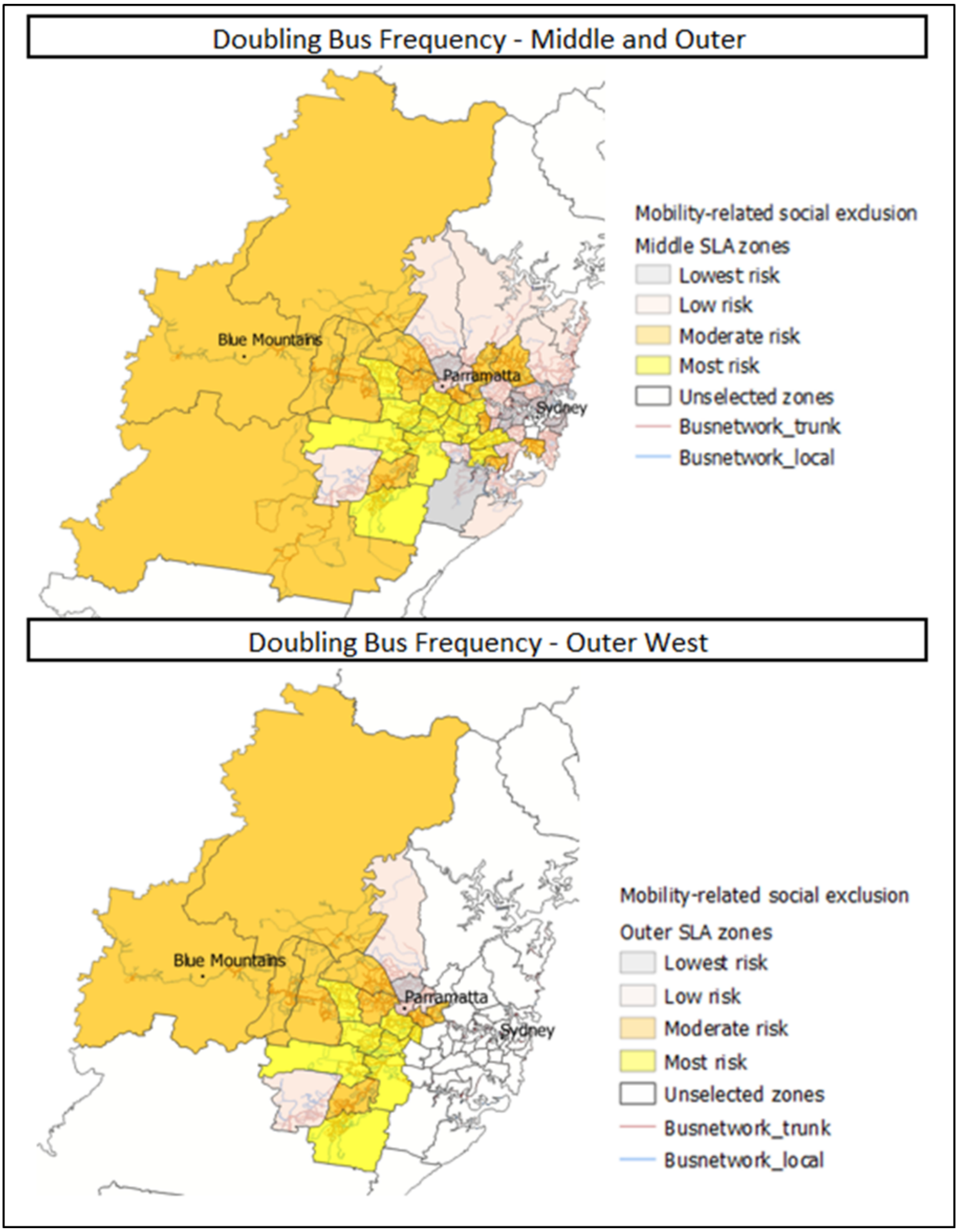

Figure 3: Service improvement areas for Bus Service Additions (1) and (2).

2. The Study Area and risk of mobility-related social exclusion

The study area for this analysis was defined as the GSMA, stretching from Newcastle to Wollongong (Figure 4), with a wide range of socio-economic and traffic data being assembled for this area. Given that an important focus of this report is mobility-related social exclusion, Figure 4 shows the authors' broad categorisation of the study area in terms of likelihood of mobility-related risk of social exclusion, from 'lowest risk' to 'most risk', based on readily available zonal data (largely census data). This means that the approach is replicable across different Australian jurisdictions. However, it has the disadvantage of socially excluded people being lost amongst zonal averages.

Categorization of the relative risk of people from each of the 80 study area zones being at risk of mobility-related social exclusion was determined by how each zone measures up in terms of four indicators:

- The proportion of its population aged 0-19, since children and youth tend to be more reliant on others, and on public transport (PT), to access opportunities (Currie, Stanley and Stanley 2007).
- The proportion of its population aged 75 or more, since older people also tend to be more dependent on others, and on PT, for accessibility (Hensher 2007; Alsnith and Hensher 2003).
- (Median) family income, since those with higher incomes are more readily able to purchase mobility solutions. This was a measure of exclusion risk in Stanley et al. (2011a, b).
- Unemployment since this is a common indicator of disadvantage and of risk of social exclusion (Stanley et al. 2011a, b).

Each of the 80 Sydney study area zones was ranked on each of these indicators, each ranking then being divided in to four quartiles (i.e., 20 zones in each), representing from 'least risk' to 'most risk' of mobility-related social exclusion. Zones in the least risk quartile on each of the four indicators were (somewhat arbitrarily) given a score of 0, with the next quartiles then scored as 2, 3 and 4. The step from 0 to 2 (missing 1) was adopted to accentuate the gap between zones that are least likely to be at exclusion risk and zones where risk is more likely (given the selected indicators). The resulting scores were summed across the four indicators, (maximum possible score = 16). Zones were then put into four groups, based on their aggregate score, with:

- Scores from 0 to 5 = lowest risk of mobility-related social exclusion (= 14 zones)
- 6-9 = low risk (22 zones)
- 10-11 = moderate risk (= 22 zones)
- 12=16 = most risk (22 zones).

The zonal categorisations shown in Figure 4 are a broad way of identifying areas in which seeking transport solutions to reducing social exclusion risk might be a relatively high priority. It also provides some insight into whether those who benefit or lose from transport initiatives that are being assessed are likely to be at greater or lesser risk of mobility-related social exclusion. Such areal categorization thus provides one way of introducing an equity perspective on the relative merits of the initiatives under examination.

It is noteworthy that there is a high positive correlation between the unit values of the social inclusion index developed herein (which range between 0 and 16) and the incidence of COVID-19 by LGA across Sydney. The higher the social exclusion index (risk level) the greater the incidence of COVID-19, as reflected in the following relationship:

$$Y = 4.4278e^{0.2304x} (R^2 = 0.78815) \quad (1)$$

where Y = COVID-19 cases in Sydney recorded up to 9 August 2021, and X = the social inclusion index derived herein. This link to health risks illustrates just one of the reasons for seeking to do something about reducing social exclusion in areas of higher risk.

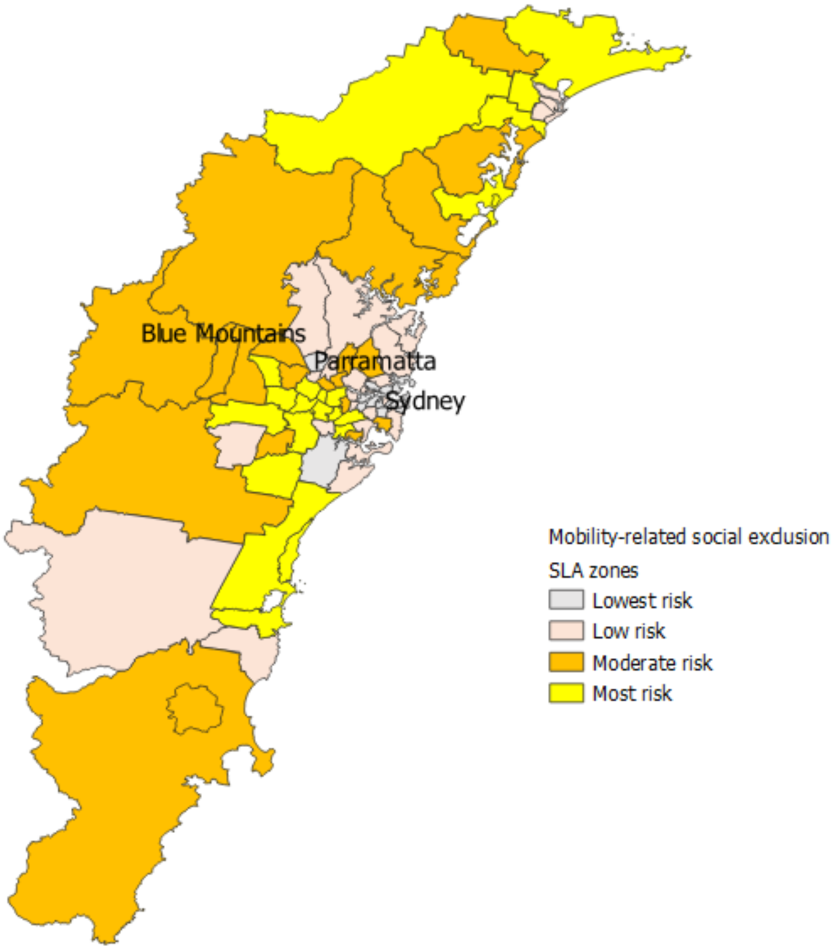

Figure 4: Sydney zones categorised by mobility-related risk of social exclusion (Authors' assessment)

Stanley et al. (2011a, b) showed that additional trip making by those at risk of mobility-related social exclusion has considerable benefit, with the value of that benefit increasing as household income declines. Zones coloured yellow in Figure 4 would thus be relatively high priorities for improved mobility opportunities for those interested in reducing risks of mobility-related social exclusion and zones coloured brown are also deserving of close consideration from this perspective. These more at-risk zones are mainly concentrated to Sydney's west, south-west and, with some exceptions, around the region's northern and southern extremities (around Newcastle and Wollongong). The central/inner area and inner/middle north shore are rated as being at lowest risk.

3. Predicted impacts of initiatives on trips

Impacts on trip making are a central part of transport initiative assessment. Table 1 sets out MetroScan's estimated trip numbers by mode, for 2023 and 2033, with and without each of the four initiatives under assessment (treated separately). For the Parramatta Light Rail (PLR), key points to note are that:

- The PLR is predicted to lead to a small net increase in the total number of trips across Sydney: 3.0 million in 2023, rising to 7.1 million in 2033.

- In the base case (no PLR but current committed transport improvements in place), annual trips as car driver alone are predicted to increase by 658 million from 2023 to 2033 and car passenger trips by 357m. However, with PLR this increase is predicted to slow to 642m for car driver trips and 351m for car passenger trips, a total reduction of 22m trips as car driver or car passenger in 2033 (numbers are not shown in Table 1), as the PLR attracts car users to switch to public transport (PT).
- Bus is predicted to lose passengers, by around 1.4m trips in 2023, rising to 3.4m fewer trips in 2033, showing that there is a degree of competition between these PT modes.
- Total annual train trips, which includes the PLR, are predicted to increase by 19.2m in 2023 and 47.1m in 2033 with the PLR in place, as compared to without that development.

As well as car trips being predicted to fall a little with the PLR, vehicle kilometres of car travel are also predicted to fall marginally, by 0.24% in 2023 and 0.53% in 2033 (not shown in Table 1). The reduced car traffic volumes, together with increased economic output stimulated by the PLR project (discussed below), are then projected to lead to a small increase in road freight volumes, of around 0.4%.

In contrast, the M4 upgrade is predicted to lead to a small decline in total trip numbers, by 1.2m in 2023 and 1.5m in 2033 (-0.02% in each year). Table 1 shows that car drive alone trips are predicted to increase, by 3.0m in 2023, rising to 3.6m additional trips in 2033. Part of this increase comes from people switching away from PT. Bus is predicted to lose 0.8m trips in 2023 and 1.0m in 2033, with train losing 2.2m in 2023 and 2.7m in 2033. Less expected is the predicted drop in car passenger trips, estimated to fall by 1.2m in 2023 and 1.4m in 2033, MetroScan predicting that the increased ease of travel with the Motorway upgrade will not only attract people away from PT but will also encourage more people to drive themselves, rather than going in someone else's car. Total car kilometres travelled are also predicted to increase marginally (not shown in Table 1).

Because of its widespread nature and relative scale, the extensive doubling of bus service frequency included in Bus Service Additions (1) (BSA1) is predicted to increase bus patronage substantially, by 29.1m trips in 2023 and 54.6m in 2033. Train patronage is predicted to fall a little, by around 4m trips in 2033, again suggesting some competition between bus and train. Importantly, however, car drive alone trips are predicted to fall significantly, much more than in the case of the PLR project. Some 14.6m fewer car drive alone trips are predicted in 2023 and 26.9m fewer in 2033, with car passenger trips also falling. The total number of trips by all modes, among the four projects assessed, has its biggest increase under BSA1, with 10.6m more trips in 2023 and 19.7m in 2033.

The more focussed doubling of bus service frequencies in Bus Service Additions (2) (BSA2) is predicted to increase bus patronage by 11.6m trips in 2023, increasing to 22m in 2033. Train trips are predicted to decline marginally but a substantial reduction in car drive alone trips is predicted in both 2023 and 2033 (6.3m and 11.7m trips respectively), suggesting a solid switch from car to bus. This was also the case for BSA1. Total trip numbers are predicted to increase by 4.4m in 2023 and 8.2m in 2033, reflecting the progressive roll-out of the service doubling assumed for this option (and for BSA1).

4. Predicted impacts on major revenue flows

The changes in travel tasks associated with the four initiatives are predicted to lead to changes in state government and federal government revenue collections and in toll road revenue collections, all of which are relevant to an assessment of project economic merit. This paper includes estimates of changes in State PT fare revenue collections and in Federal Government fuel excise collections, together with changes in toll road revenues. While these revenue flows are partly about who gains and who loses (benefit/cost incidence), they are also reflective of net value changes that reflect economic benefits and costs.

Table 1: Predicted impacts of the three initiatives on annual trip numbers in the Study Area (million trips) and on key revenue streams ($m; 2019 prices).

Indicator	Year	Base number	Changes in trip numbers/revenue flows			
			Parramatta LR	M4 addition	Bus service additions (1)	Bus service additions (2)
Car drive alone trips	2023	3063m	-10.5m	+3.0m	-14.6	-6.3
Car with passenger trips	2023	1651m	-4.3m	-1.2m	-2.3	-0.7
Bus passenger trips	2023	195m	-1.4m	-0.8m	+29.1	+11.6
Train passenger trips (incl. LR)	2023	253m	+19.2m	-2.2m	-1.7	-0.2
TOTAL TRIPS ALL MODES	2023	5161m	+3.0m	-1.2m	+10.6	+4.4
Car drive alone trips	2033	3721m	-25.7m	+3.6m	-26.9	-11.7
Car passenger trips	2033	2008m	-10.9m	-1.4m	-4.2	-1.0
Bus passenger trips	2033	234m	-3.4m	-1.0m	+54.6	+22.0
Train passenger trips (incl. LR)	2033	333m	-47.1m	-2.7m	-3.9	-1.1
TOTAL TRIPS ALL MODES	2033	6295m	+7.1m	-1.5m	+19.7	+8.2
State fare revenue gain	2023	$1482m	+$48m	-$9.4m	+$112m	+$46m
	2033	$1860m	+$118m	-$11.6m	+$208m	+$85m
Federal excise revenue gain	2023	$3302m	-$8m	+$0.3m	-$13m	-$7m
	2033	$4014m	-$21m	+$0.5m	-$26m	-$13m
Toll operator revenue change	2023	$867m	-$0.1m	+$0.1m	-$0.0m	+$0.0m
	2033	$1057m	-$0.8m	+$0.1m	-$0.0m	+$0.0m

As shown in the bottom sections of Table 1, the PLR is predicted to lead to an increase in total NSW state government fare revenue collections of $48 million in 2023, increasing to $118m in 2033. For translating these changes to benefit/cost estimates for purposes of cost benefit analysis, the change in state fare revenue collections is assumed to remain constant at this 2033 level (reflecting forecasting humility!). This approach is taken for all annual benefit/cost flows[2]. In present value (PV) terms over the 2021 to 2053 period (2019 prices; 2021 PVs; 7% discount rate), future increased fare revenues are estimated to be worth $1.0b. This is a solid number, relative to expected project operating cost, suggesting a better than break-even outcome on operating expenditures, as shown subsequently in Table 4.

Conversely, in the PLR case, federal fuel tax revenues are predicted to fall by $8m in 2023 and by $21m in 2033, due to reduced car use. This excise loss has a PV of $182m. Small losses in toll revenue collections are also shown in Table 1 and represent losses to relevant owners. Table 4 shows the estimated PV of the toll revenue loss at $6m.

While PLR is predicted to boost PT revenue but reduce federal fuel excise collections, the M4 project is predicted to have the reverse effects. NSW PT fare revenue is predicted to fall by $9.4m in 2023 with the M4 project in place, increasing to $11.6m less fare revenue in 2033. However, Federal fuel excise collections are predicted to increase marginally (<$1m annually), reflecting increased road traffic volumes following the M4 upgrade.[3] Toll revenue is also predicted to increase marginally

[2] Residual values are ignored, being typically minimal at a 7% real discount rate, as used herein.

[3] Based on an ongoing full ICE petrol and diesel fleet but with electric cars this will change (Hensher et al. 2021). The NSW government has proposed to remove stamp duty on electric cars and will impose 2.5c/km from 2027, or once electric car sales have reached 30% of new car sales. Source:

(<$100K p.a.). In PV terms, the PT fare revenue loss is estimated at $120m, while the Federal fuel excise gain is valued at $5m. The PV of increased toll revenues is estimated to be only $1m (Table 4).

Doubling bus service frequencies as in BSA1 is predicted to increase PT fare collections by $112m in 2023 and $208m in 2033, reflecting the strong predicted bus patronage gains. This fare revenue boost has a PV of $1.9b (Table 4). However, fuel excise collections are predicted to fall, but far less than the increase in fare revenues. Excise collections are estimated to be $13m lower in 2023 and $26m lower in 2033, with the PV of excise collections being valued at a cost of $238m (Table 4). Toll revenue collections are predicted to fall by a very small amount (e.g., <$20,000 in 2033).

The less comprehensive but more targeted doubling of bus service frequencies in BSA2 is predicted to increase PT fare revenue collections by $46m in 2023 and $85m in 2033, with a PV of $786m, about 40% of the increase predicted for BSA1. Federal excise collections are predicted to fall by only half as much as for BSA1 and there is little change expected in toll revenue collections.

5. Key benefits and costs

User benefit estimates are critical to assessing the economic worth of major transport initiatives, typically being the primary rationale for those initiatives. MetroScan (Hensher et al. 2020) enables estimation of these benefits as increases in trip maker consumers' surplus, which represents the difference between what people would be willing to pay for the trips they make and what they actually pay, based on changes in constituent elements of generalized travel costs[4].

Table 2 sets out user benefit estimates for 2023 and 2033, for public transport (PT) users, car users and freight traffic, with totals subsequently being shown in PV terms in Table 4. Appendix B details the key parameter values used in this assessment. User benefits in Table 2 are calculated in the conventional (rule of a half) way, derived from changes in generalized cost, with base traffic being accorded a full unit benefit per trip and generated traffic half this trip benefit.

For projects that are of similar scale in capital cost terms, the M4 is estimated to produce about double the level of user benefits for car users in 2033 ($533m) that PLR does for PT users in that year ($275m). Doubling bus service frequencies in BSA1 produces similar scale benefits for PT users in 2033 ($521m) as the M4 does for car users in that year, showing the value of widely spread bus service enhancement. The loss of road space for car use in the PLR case is estimated to cause large costs for car users, which exceed the estimated benefits created for PT users. The reduced scale of bus service improvements in BSA2 is estimated to generate PT user benefits of about half the scale estimated for BSA1 in 2033. However, the concentration of BSA2 in middle and outer western and south-western areas is predicted to have a considerably smaller adverse impact on car users than the more widespread BSA1.

Freight traffic is estimated to gain substantially from all four initiatives, from improved road capacity availability. Addition of freight benefits from the PLR improves its total user benefits considerably but not sufficiently for those benefits, in aggregate, to be positive in 2033. Importantly, however, Table 4 subsequently shows that, when social inclusion benefits from additional trip making are recognized

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https://www.smh.com.au/national/nsw/nsw-to-abolish-stamp-duty-on-electric-cars-in-an-effort-to-boost-uptake-20210619-p582g4.html

[4] The Full Generalised Cost for Public Transport includes public transport fares plus time costs using the value of travel time saving (VTTS) and the value of reliability (VoR). The Full Generalised Cost for Car includes fuel and other extra vehicle costs (e.g., toll, parking, and registration) and time costs using VTTS and VoR. The Total End Use Generalised Cost is the weighted average of the former two generalised costs, weighted by the total annual numbers of trips made by public transport and car. VTTS and VoR values we applied are included in Appendix B.

(an added user benefit, discussed in Section 6), the economic performance of the PLR improves very considerably, showing a good net economic outcome.

In a result that will surprise many, the comprehensive doubling of bus service frequency in BSA1 is predicted to be the most valuable of the four initiatives for freight, which is largely because of the predicted fall in car use associated with this widely spread improvement in bus service levels.

Table 2: Estimated transport user benefits from three initiatives ($m 2019 prices)

User category	Year	Parramatta LR	M4 Additions	Bus service additions (1)	Bus service additions (2)
PT user benefits	2023	115	11	469	142
	2033	275	14	521	250
Car user benefits	2023	-185	438	-136	-38
	2033	-426	533	-240	-63
Freight movement	2023	78	92	216	104
	2033	103	136	225	116
TOTAL USER BENEFITS	2023	8	541	549	208
	2033	-148	683	506	302

Australia is one of the world's highest per capita emitters of greenhouse gases and transport is a major contributor to those emissions (18% of total emissions in 2018). Total transport sector emissions were just over 100Mt in 2018 and road transport accounts for around five out of every six tonnes of these transport emissions. The performance of the road transport sector will thus be a key influence on how well Australia can contribute to international efforts to limit global warming.

The impact of the four projects on GHG emissions was assessed on two bases: first, an estimate that assumes no change in emissions intensity over the analysis period – a base case, with Table 3 setting out emissions predictions aligned with this base case; and second, a policy driven alternative that assumes emissions intensities improve by around 5% annually, as Australia reacts to inevitable international pressure to substantially improve its emissions performance. The impact of this tougher stance is reflected in the text, and subsequently in Table 4, but not in Table 3, which only sets out the base case estimates.

Table 3 shows that, in the base policy environment, the PLR is predicted to lead to a reduction of ~11,500 tonnes CO_2-e in 2023, this reduction increasing to 59,500 tonnes in 2033. Total emissions reduction over the period to 2053 is estimated at about 1.6 million tonnes, with a PV of $30m (Table 4). Because this assessment excludes changes in emission intensity, it is basically dependent on changes in travel volumes by vehicle type. If a policy-driven 5% annual improvement in overall transport emissions intensity was to be realized, the reduction in total emissions flowing from the PLR would be reduced to 650,000 (because the wider policy environment has reduced the GHG emissions available to be mitigated), with a benefit PV in this case of $15m (Table 4).

In the base GHG assessment, doubling bus service frequencies as in BSA1 is expected to reduce GHG emissions by a similar amount to that predicted for the PLR over the period to 2053 (1.4Mt compared to 1.6Mt for the PLR), implying a broadly similar monetary value for GHG emissions reduction benefits (Table 4). This benefit value halves if the background policy environment delivers a 5% annual reduction in road transport GHG emissions. BSA2 effectively halves the GHG impact predicted for BSA1.

In contrast, the M4 is predicted to be associated with an increase in GHG emissions and associated costs in both 2023 and 2033 in the base projection. Over the period to 2053, in an unchanged GHG policy environment, total GHG emissions are predicted to increase by ~850,000 tonnes, with a PV cost of $18m (Table 4). This cost reduces to $12m in a policy environment that leads to 5% annual reductions in base GHG emissions.

The NSW Department for Transport (TfNSW) price of $62.79 (June 2019) per tonne of CO_2-e, as shown in Appendix B, was used to value emissions reductions (TfNSW 2020). This value might be seen as conservative, in light of the conclusions of the High Level Commission in Carbon Prices, co-chaired by Professor Joseph Stiglitz and Lord Nicholas Stern, which proposed carbon prices of $US40-80/tonne of CO2-e in 2020, rising to $US50-100 in 2030 (Carbon Pricing Leadership Coalition 2017). $A62.79 is at the low end of this range.

Over 600 Australians are estimated to have died because of transport-related air pollution in 2015, a 2020 Draft Regulation Impact Statement showing strong economic returns if EURO VI emissions standards for heavy vehicles were to be implemented in Australia (DITRDC 2020). That assessment suggests that NOx emissions in 2050 could be reduced by 80%, against business-as-usual levels, and particulate emissions by 59%.

As with GHG emissions, two sets of air pollution benefits/costs were developed for the current assessment: a base case in which emissions per vehicle kilometre are assumed to be unchanged; and a policy driven setting in which air pollutant emissions are progressively reduced, to be 80% lower by 2050, in line with the DITRDC (2020) estimate for NOx from heavy vehicles. This presumes that further improvements in PM emissions will be achievable beyond those embedded in the EURO VI standards and that light vehicles will achieve similar improvements (e.g., via electrification). A 5% annual reduction (compounding) in air pollution costs was assumed for this setting, in accord with the approach taken for the policy driven GHG assessment.

In the base case, MetroScan predicts that there will be a small increase in local air pollution levels and associated costs in 2023 if the PLR is in operation, of around $5.8m (Table 3), mainly due to increased freight movements (air pollution costs attributable to freight are predicted to increase by $11.7m in that year, being partly offset by reduced air pollution costs from lower car use). By 2033, however, air pollution levels and costs are expected to become a small benefit for the PLR. In PV terms, the PLR is estimated to deliver marginal additions to air pollution costs in both the base case and the policy driven alternative (Table 4).

In the base case, Table 3 shows that BSA1 is predicted to increase local air pollution costs by $23.3m in 2023, reducing to an increase of $8.5m by 2033. As with the PLR, this is mainly attributable to increased freight traffic emissions/costs but, in this case, it is also due to more diesel bus use. The estimated PV of increased air pollution costs in this base case is $151m, reducing to $112m in the policy driven alternative (Table 4). Initiatives such as that by the NSW Government to electrify its bus fleet by 2030 is an example of how the policy driven alternative might be achieved. BSA2 is predicted to about halve the air pollution cost increase estimated for BSA1.

Table 3 shows that the base case cost implications of the increased air pollution levels associated with the M4 project are about ten times as high as the costs of its increased CO_2 emissions for the years shown, Table 4 subsequently showing these increased air pollution costs amount to an estimated PV of $178m for the M4 upgrade, a significant sum. This reduces to a cost of $114m in the policy driven alternative, still a significant sum.

Table 3: Some transport emissions implications of the Parramatta LR project: base emissions assumptions only

Indicator	Year	Base value	Parramatta LR	M4	Bus service Additions (1)	Bus service additions (2)
CO_2 emissions base:	2023	16.7 Mt	-0.011Mt	+0.023Mt	+0.003Mt	-0.003Mt
passengers + truck	2033	20.4 Mt	-0.059Mt	+0.028Mt	-0.055Mt	-0.026Mt
CO2 emission costs - base	2023	$1052m	-$720K	+$1.5m	+$0.2m	-$0.02m
	2033	$1279m	-$3.7m	+$1.8m	-$3.4m	-$1.7m
Local air pollution costs	2023	$5110m	+$5.8m	+$14.0m	+$23.3m	+$10.7m
	2033	$6222m	-$2.9m	+$17.2m	+$8.5m	+$4.6m

The MetroScan analysis assumes that Sydney's total population size will not be affected by the major transport initiatives under assessment but that population distribution can change. With PLR in place, MetroScan predicts that residential population numbers as at 2033 will increase in the vicinity of the facility, with Parramatta Inner, Parramatta NE and Holyroyd adding a total of ~32,000. This is a little over one-third of the projected total population growth across the three zones from 2023 to 2033, which is substantial. Figure 5 shows predicted changes in population distribution in 2033 for each of the four projects.

In contrast, the M4 upgrade is primarily predicted to spur faster population growth in the corridor from around Parramatta to the outer west of Sydney (Figure 5). Thus, for example, Penrith East and West are predicted to add ~5,400 by 2033 and Blue Mountains to add 4,600, with Blacktown SE and SW adding 3,400. This suggests people are taking the opportunity provided by going faster to go further, encouraging increased urban sprawl.

Figure 5 shows that the extensive doubling of bus frequencies in BSA1 is predicted to lead to more residential consolidation in inner/middle Sydney, including north of Sydney Harbour, where many parts are relatively bus dependent for public transport service. By 2033, places such as Warringah (+3684), Pittwater (+1114), Manly (+1057) and Ryde (+1103) are predicted to have notable population increases, as are Randwick (+1166) and Hills Shire (+1378). With total population numbers fixed, that means small population losses across outer areas, including extremities to the north.

Conversely, BSA2 is less widespread, with its residential location impacts being concentrated in the corridor from around Parramatta to the west, then extending north and south. Notable population increases are predicted by 2033 for Liverpool East plus West (+3200), Blacktown (+2100), Penrith East plus West (2000) and Fairfield (+1700). The corollary is small losses elsewhere, given the assumption of a total fixed population number.

While the analysis assumed that total population numbers at any future point in time would not change following the introduction of the major transport initiatives, total employment numbers were allowed to change, as the major transport initiatives stimulate development. MetroScan predicts net employment increases in Greater Sydney of ~16,000 by 2033 associated with introduction of the PLR (excluding construction stage effects for this project and for the M4). These are the largest gains in employment numbers predicted for any of the four transport improvements analysed. Figure 6 shows predicted percentage changes in job numbers in 2033 for each of the four projects. Even though the PLR is located around Parramatta, the strongest gains in job numbers associated with that project are predicted to be in inner Sydney, showing the network benefits of the project and the strong economic pull of the inner area. This implies increased effective economic density in the inner area and associated agglomeration economies (discussed below). Some outer northern and southern areas are predicted to shed a small number of jobs.

In contrast, MetroScan predicts that the M4 upgrade will not add to total job creation but will lead to some job redistribution. Figure 6 shows that employment gains in 2033 are predicted in the Parramatta area and corridor to the west, partly reflecting the predicted changes in population distribution, while small job losses are predicted across large parts of Sydney. The relative accessibility advantages conferred by the M4 upgrade are thus predicted to affect the distribution of jobs but this is not predicted to lead to a net increase in total employment – predicted zonal gains marginally fall short of predicted zonal employment losses at 2033 (-3330 jobs in total).

Doubling bus service frequency as in BSA1 is predicted to lead to 7420 additional jobs in 2033, which is stronger than the M4 upgrade but not as strong as the PLR. Like its predicted impact on residential population distribution, this doubling bus service frequencies is predicted to support some job consolidation in inner/middle Sydney, including north of the Harbour, with small reductions further out, particularly to the outer north and south. Numbers involved in the latter locations are small. BSA2, being smaller in scale and concentrated in lower density areas, is predicted to lead to a marginal reduction in total jobs in 2033 (-5000). Job numbers are predicted to increase around Parramatta, Fairfield, Liverpool, Penrith, Blacktown and the Hills but with some small losses in inner areas (Figure 6).

Discussion of changes in job locations leads to consideration of how the transport improvements under consideration change the effective economic density (EED) of Sydney and how this, in turn, flows through to changing economic productivity, through agglomeration effects. EED is a measure of the accessibility of each zone to employment in other zones, weighted by the generalized cost of movement between that zone and each other zone.

MetroScan estimates that the EED of Greater Sydney will increase by 0.398% by 2033 with the PLR in place, but the relative increase in several inner areas is larger. Figure 7 shows the broad pattern of changes in EED at 2033 associated with the PLR (and the other three projects), with some job relocations to more accessible locations, but also with some predicted small movement away from locations where accessibility has declined in relative terms. As noted previously, there is also a small increase predicted in total job numbers with the PLR. Figure 7 shows the agglomeration strength of the inner/central areas.

Conversely, MetroScan estimates that Greater Sydney's EED will decline by 0.085% by 2033 with the M4 upgrade in place, reflecting the influence of relative accessibility improvement in lower density outer suburbs. For the comprehensive doubling of route bus service frequencies of BSA1, MetroScan predicts that EED will increase by 0.203% by 2033. These gains are less than for the PLR, suggesting smaller agglomeration economies. The smaller set of bus frequency increases in BSA2 is estimated to reduce Sydney's EED by 0.127% in 2033. This reflects the pattern for the M4 upgrade, with the focus on outer suburbs reducing agglomeration tendencies. Figure 7 shows the predicted changes in EED across Sydney for this bus frequency increase, with inner areas again the main winners.

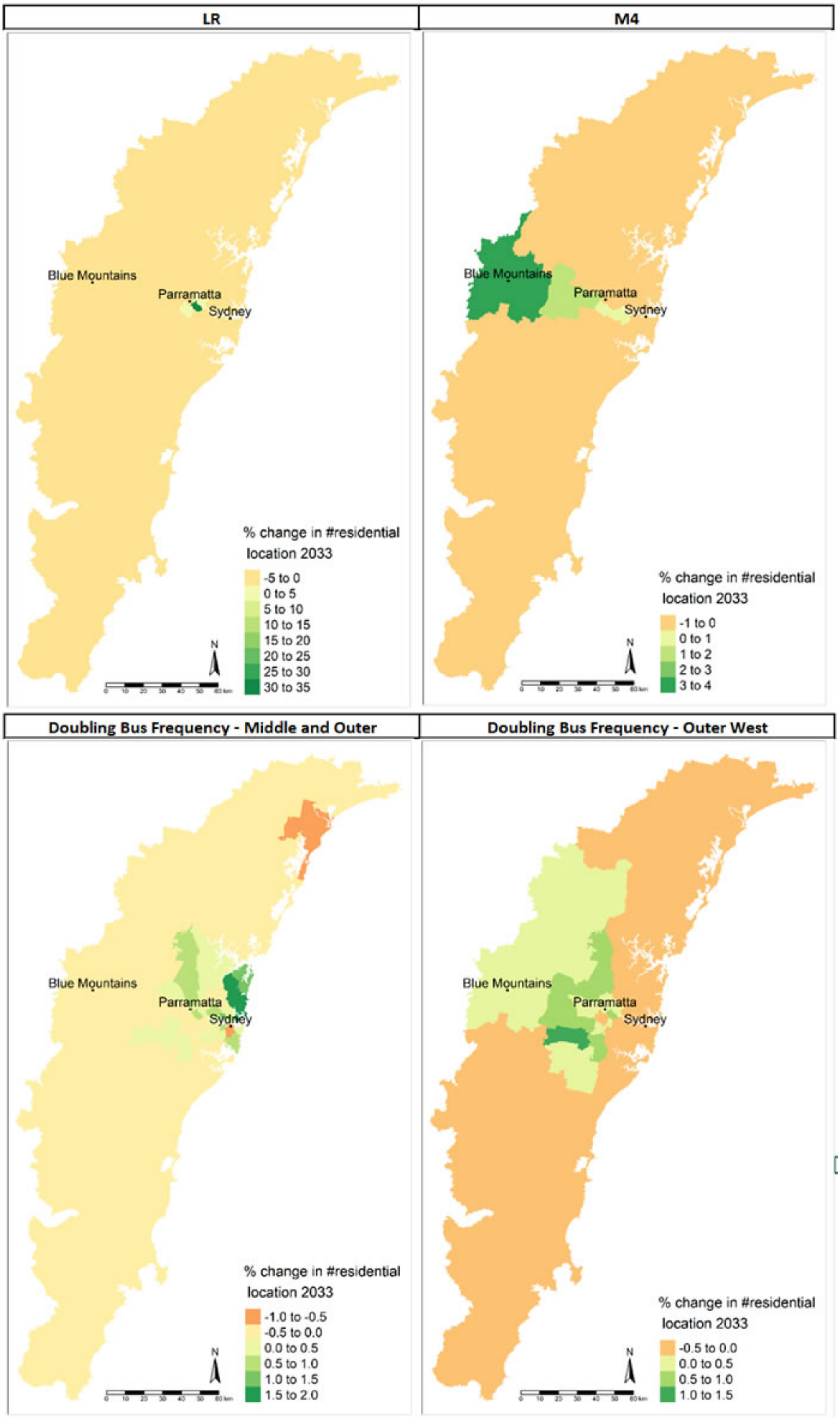

Figure 5: Predicted changes in residential location associated with the four projects for 2033 (% changes)

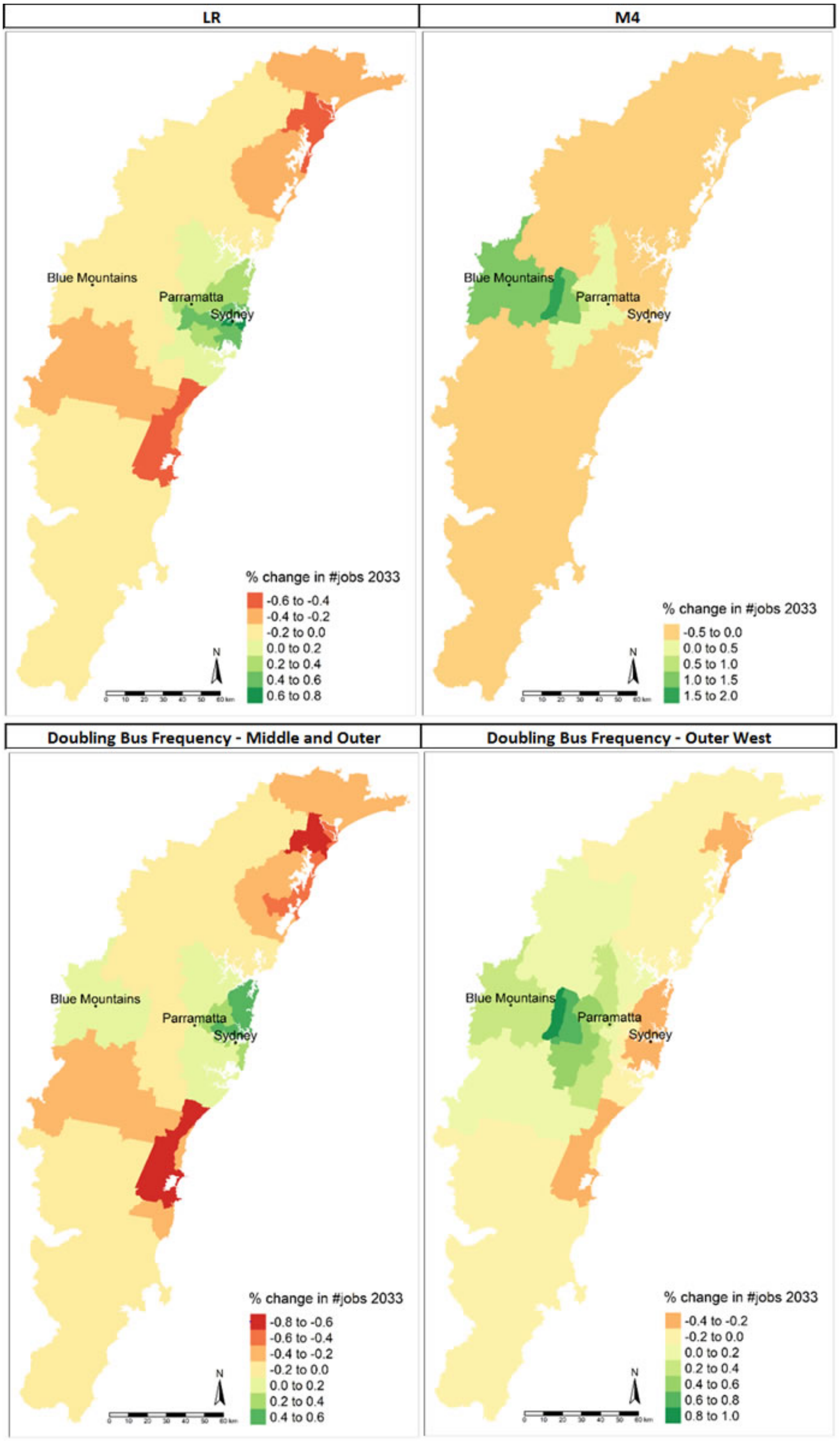

Figure 6: Predicted changes in job locations associated with the four projects for 2033 (% changes).

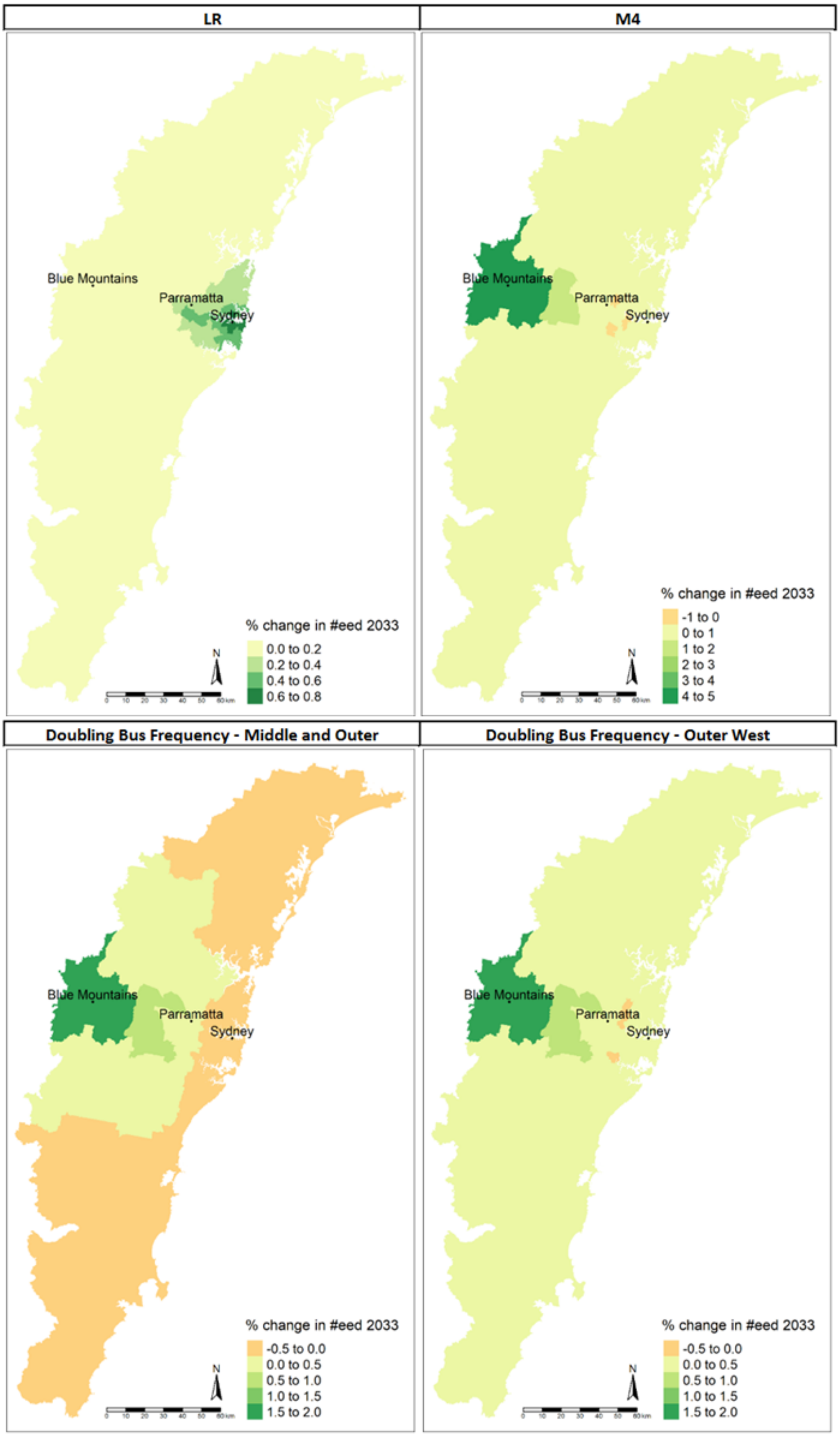

Figure 7: Predicted EED changes in job locations associated with the four projects for 2033 (% changes).

Drawing on predicted changes in EED at the zonal level (80 zones), agglomeration economies were estimated for each of the four initiatives in line with the UK Department for Transport Webtag approach (DfT 2020), using the formula set out in Stopher and Stanley (2014), as follows

$$\Delta \text{ GDP} = [(EED_{after}/EED_{before})^{\xi}-1]*GDP_{initial} \qquad (2)$$

where ΔGDP = change in GDP for the Greater Sydney Region ($577b was used as the initial GDP figure for 2023, pre-transport improvements, based on data provided by the National Institute of Economic and Industry Research); ξ = the elasticity of productivity with respect to effective economic density (a value of 1.0021 was used, based on Hensher et al. 2012); and, EED = effective economic density (a measure of the accessibility of each zone to employment in other zones, weighted by the generalized cost of movement between that zone and each other zone).

Applying this formula for the PLR implies agglomeration economies (benefits) of $7.1m in 2023, increasing to $35.6m in 2033, with an estimated PV of $282m (Table 4). Conversely, the M4 is predicted to generate agglomeration costs, of $12.1m in 2023 increasing to costs of $14.1m in 2033, with a negative PV of $147m. The doubling of bus service frequencies for BSA 1 is an intermediate result, producing estimated agglomeration benefits of $10.0m in 2033, for a PV of $81m (Table 4). The BSA2 is predicted to generate agglomeration costs of $4.9m in 2023 increasing to $18.9m in 2033, with a negative PV of $154m.

In terms of agglomeration benefits, it is noteworthy that the Queensland Government's Business Case evaluation of the Gold Coast Light Rail Stage 3 estimates wider economic benefits of $539m (of which agglomeration benefits are usually the largest component), with an additional $599m for urban regeneration benefits from that 6.7 km LR route extension project, both being larger individually than the estimated capital cost of that Gold Coast project (Infrastructure Australia 2019). This comparison makes the estimate in the current paper, which includes only agglomeration benefits, conservative.

Walking is recognized as being beneficial for health, with Australia's transport appraisal guidelines enabling attribution of a monetary value to **walking** associated with some transport initiatives (TIAC 2016). Unpublished research by one of the current authors has found that a bus trip is worth ~$3.25 in terms of incidental health benefits for adults, with a new generated bus trip being worth half this amount ($1.62, by the rule of a half). This value is conservative, being only about two-thirds of the value for walking set out in the Australian transport evaluation guidelines for active travel (TIAC 2016). Assuming that

- the same unit values apply to light rail use as to bus, which requires similar overall walk lengths as between LR and a bus per trip
- half the increased use of PT associated with any of the three projects being assessed herein is by adults and
- applying the conservative value of $1.62 to additional trips;

the walking benefits of the PLR are estimated to be worth around $35m annually in 2033, with a PV of $310m (Table 4). Conversely, the M4 upgrade is predicted to reduce PT use, which implies less incidental walking and consequential higher health costs (PV of cost is $5m; Table 4). The largest walking benefits are predicted for BSA1, which leads to the biggest increase in PT trips of the four options considered herein (50.7m extra PT trips in 2033). This converts to a benefit value of $381m in PV terms. The smaller, more focussed increase in bus service frequencies associated with BSA2, is estimated to deliver an additional 20.9m walking trips to/from PT in 2033 (PV of $157m).

MetroScan estimates accident rates and associated **accident costs**, including fatality, personal injury and property damage accidents (Appendix C). Using TfNSW unit values, accident costs were predicted to be $44.5m lower in 2023 with the PLR than without it (PV $379m; Table 4). The M4 upgrade, however, is predicted to increase accident costs by $4.7m in 2033, associated with the increased road use and lower PT use, with a PV of $48m cost. Doubling bus frequency as per BSA1 is predicted to reduce accident costs by $52.8m in 2033. In PV terms, the stream of accident cost savings in this case is valued at a substantial $462m, the largest of the four projects considered herein. This is halved in BSA2 (Table 4).

Operating costs for the PLR were not identifiable from any of the reports that were scanned for this case study. However, a review of reported operating costs for several other Australian Light Rail projects, planned or in place, suggests that PLR operating costs might be expected to be between $3m to $6m per track kilometre per year, or between $36-72m p.a. for the route. The low-end costs are in prices from studies of around 6-7 years ago and for service extensions, suggesting that a more realistic range is perhaps $50-$72m. We assume $60m p.a. keeping it constant in real terms, on the assumption that productivity gains will be sought by government to offset provider cost increases. This produces estimated operating costs equivalent to 25.7% of the PLR capital cost in PV terms (or ~20% of combined capital plus operating costs), which is similar to the share for the Gold Coast LR extension (Infrastructure Australia 2019) and to the proportion estimated by Hensher et al. (2019) in an evaluation of a hypothetical LR to Sydney's Northern Beaches. This may be a little favourable to the PLR, however, Douglas and Cockburn (2019) presenting data showing that the Canberra operating/capital costs ratio was 1:3, which would take the PLR operating costs to $800m in PV terms, or around $180m more than assumed herein.

Operating cost estimates for the M4 upgrade were derived in a similar manner, by examining costs for some other major road projects, particularly the relative proportions of operating costs to capital costs. Infrastructure Australia project evaluation sources were relied on for this information, which uses evaluations undertaken by the relevant responsible authority[5]. The projects used for this purpose were three NSW road projects (Newcastle Inner City Bypass, Western Harbour Tunnel/Warringah Freeway upgrade and M12 Motorway) plus Melbourne's proposed NE Link. Based on the range of the operating to capital cost ratios for these projects, it was assumed that operating costs for the M4 would be five percent of capital costs in discounted terms. Capital costs have been assumed to be $2400 in both discounted and undiscounted terms (2019 prices), because the authors have no knowledge of the construction timetable. That suggests discounted operating costs of $120m.

Costs for the doubling of bus frequencies have been based partly on research by the NSW Independent Pricing and Regulatory Tribunal (IPART 2014). IPART estimated that the net costs of bus service provision by Sydney's private bus operators was $611m in 2013 prices, based on the costs of efficient operators and excluding school service costs (which are not relevant to the doubling of frequency considered herein). These costs were increased by 3% p.a., to put them in approximate 2019 prices, which amounted to $730m. Doubling service frequencies will not double these costs, since not all privately operated routes are included, some additional kilometres will be achievable from the base fleet and some costs will be fixed. Based on the authors' knowledge of route bus service delivery costs in Sydney, Melbourne and elsewhere, It has been assumed that doubling service frequencies over the broader network of BSA1 will add $500m p.a. to service costs, once fully rolled out (from 2033), building to this over the preceding decade. The smaller bus service upgrading option (BSA2) has been assumed to cost $325m when fully in place, also building to this from 2023. In PV terms, the cost of BSA1 is an estimated $4632m and that for BSA2 is $3010m (in 2019 prices and 2021 PVs).

[5] Project Evaluations | Infrastructure Australia

6. Changing travel patterns and implications for social exclusion risks

One of the purposes of this paper is to explore possible impacts of major transport initiatives on reducing risks that people will be socially excluded because of poor mobility opportunities. Sydney's different zones have been categorized in terms of relatively more/less risk of mobility-related exclusion, using widely available indicators (Section 2 above). Changes in trip making by people living in the two most at-risk zones is used as the indicator of the prospective reduction in exclusion risk, providing a basis for valuing that risk reduction. Changes in the total number of trips in 2023 and 2033 were thus assessed for all zones categorised as being at *most risk* or at *moderate risk* of residents experiencing mobility-related social exclusion.

Table 1 indicated that MetroScan predicts the PLR will lead to an increase in total trips of 7.1 m in 2033, which suggests substantial potential for social inclusion value. The largest changes in predicted travel patterns for this project, particularly PT trips and total trips, are unsurprisingly in the vicinity of the route. For example, Parramatta-Inner is predicted to gain 130,000 train trips a day in 2033 and Holyroyd an additional 40,000. Parramatta-Inner is in the zones that were categorized in Figure 3 as being at moderate risk of mobility-related social exclusion and Holyroyd is in the zones categorized as at most risk. This is where the greatest reduction in car trips is also expected (car driver plus car passenger). Looking at trips overall, while trips increase in areas close to the PLR, they decrease slightly elsewhere. Thus, while there is likely to be a reduction in risks of mobility-related social exclusion in zones close to the LR, risks may increase a little in some other areas.

Overall, in 2033, the PLR was predicted to lead to 2.7m fewer annual trips by residents from zones categorised as being *at most* risk but 17.8m additional trips were predicted to be made by residents living in zones categorised as being at *moderate risk*. Adding these predicted changes in trip making together suggests a net additional 15m trips in 2033 which are likely to be associated with reduction of risk of mobility-related social exclusion.

The values of additional trips for those at risk of mobility-related social exclusion, as most recently estimated by Stanley et al. (2021) were updated to 2019 prices and applied to these reduced/increased trip numbers respectively. The resulting additional trip value was $22.75. No social inclusion value was put on increased/reduced trips from zones categorized as being at lowest risk or low risk. For the PLR, the resulting social inclusion benefits were valued at $344m in 2033. However, including social inclusion benefits creates a risk of double counting benefits from increased trips, since generated traffic benefits (which will be part of the inclusion benefit) already form part of the user benefit estimate. To avoid this risk, all generated traffic benefits were deducted from the social inclusion benefit measure ($8.8m in 2033).[6] In present value terms, the social inclusion benefit value of the PLR, after deducting generated traffic benefits, was estimated to be a hugely significant $2752m at 7% discount rate (Table 4), which exceeds the project capital cost.

Stanley et al. (2011a, b; 2021) showed that the value of additional trips to those at risk of mobility-related social exclusion increases in inverse proportion to household income. The benefit estimates outlined above, however, do not include this income adjustment, since such weighted assessment has not been used for other benefit/cost items. If allowance had been made for varying household income

[6] Strictly speaking, generated traffic benefits to trips from zones with least or low exclusion risk could be retained since there were no inclusion benefits counted for these zones. However, the figures involved are sufficiently small to ignore for the purpose of the current study.

levels between zones, the social inclusion benefit figure for PLR would have been increased by one-fifth, adding an extra $500 million to the project's value.

The M4 is also predicted to generate some social inclusion benefits (benefits relate to trips rather than modes), with a net additional 1.3m trips in 2033 from the two categories of zones where mobility-related social exclusion risk is likely to be relatively high, particularly through added trip making supported in western areas, such as the Blue Mountains, Penrith and Blacktown and also around Parramatta and Holyroyd. These numbers are much smaller than the additional trip making predicted from more at-risk areas attributable to the PLR (e.g., a net additional 15.1m trips for PLR in 2033). PLR is thus assessed as being much more important in terms of potential social inclusion benefits, its exclusion benefits being valued at $2.75b in PV terms, compared to a PV of $353m for the M4.

Doubling bus frequency as in BSA1 was predicted to lead to a larger increase in PT use than building the Parramatta LR, so there is potential for significant social inclusion benefits from this bus initiative. However, the widespread nature of this improvement suggests that it will benefit citizens across most parts of the city, irrespective of whether they are at risk of mobility-related social exclusion or not. MetroScan modelling suggests that there will be an additional 3.3m trips from zones categorised as being at most or at moderate risk of mobility-related social exclusion in 2033, with numbers split broadly equally between the two categories of risk. These numbers are considerably smaller than for the PLR in 2033 (at 15 million additional trips), the PLR being more focussed on zones where exclusion risk is likely to be higher. As a result, the social inclusion benefit expected from BSA1, while very significant at $628m in PV terms, is considerably less than has been estimated for the LR ($2.75b) but it is substantially larger than the inclusion benefits estimated for the M4 upgrade ($353m).

Aiming the doubling of bus service frequencies more clearly at areas of higher exclusion risk can increase exclusion benefits. BSA2 was developed for this purpose. It increases the number of trips from zones categorized as being at most risk or at moderate risk by 10 million in 2033, three times the number estimated for BSA1, even though BSA2 is only about 60% the overall scale of BSA1 (in terms of annual cost). PLR was estimated to generate 15m trips in 2033 from such zones. The PV of social inclusion benefits for BSA2 was estimated at a substantial $1.92b, three times the value for BSA1.

7. Summing up the evaluation

Table 4 sets out a summary of the economic assessments undertaken on the four major Sydney transport initiatives. All four projects show good economic returns overall. PLR has the lowest BCR, at an acceptable 1.4, with the two bus projects both having stronger BCRs, each at 1.9. The M4 upgrade achieves a BCR of a higher 2.7. The differences between the base and policy driven environmental assessments make little difference to the BCR of any of the projects.

User benefits are the main reason for the good economic outcome of the M4 upgrade and for the doubling of middle/outer urban bus frequencies (BSA1). In the case of PLR, the good economic result is highly dependent on social inclusion benefits, which is also a key component of the benefits for BSA2, the bus upgrade aimed at areas assessed as being at higher exclusion risk. Freight benefits are important in all three evaluations, showing the value of having an integrated analysis and assessment model like MetroScan on which to base the analysis and assessment.

Increased economic density, with associated agglomeration benefits, are handy positive contributions from two of the PT projects, the PLR and BSA1, but are a negative for the M4 upgrade and BSA2 because of the encouragement to lower density development in outer areas that the latter two projects provide. This shows the value of having an analytical capability that can predict changes in residential and job locations as a function of transport system changes. Reduced accident costs and the health benefits from increased incidental walking are notable positives for the three PT projects but small negatives for the M4 upgrade.

Table 4: Overall transport benefit/cost estimates ($m; 2019 prices; 2021 PVs; 7% real discount rate)

Benefit/Cost item	Parramatta LR	M4	Bus service additions (1)	Bus service additions (2)
BENEFITS				
PT benefits	2416	144	5557	2341
Car user benefits	-3772	5523	-2250	-598
Freight benefits	1038	1332	2455	1231
Agglomeration benefits	282	-147	81	-154
Air pollution: local	-2 (-8)*	-178 (-114)*	-151(-112)*	-75 (-55)
GHG emissions	30 (15)*	-18 (-12)*	24 (12)*	12 (6)
Walking benefits	310	-6	381	157
Accidents	379	-48	462	231
Social inclusion benefit	2752	353	628	1916
State fare revenue	1028	-120	1923	786
Federal excise revenue	-182	5	-238	-119
Toll revenue	-6	1	-0.1	2
Total Benefits	**4273 (4252)***	**6841 (6911)***	**8872 (8899)***	**5730(5744)**
COSTS				
Operating costs	663	120		
Capital Cost	2400	2400		
Estimated Total Costs	**3063**	**2520**	**4632**	**3010**
NET BENEFITS	**1210 (1189)***	**4321 (4391)***	**4240 (4267)***	**2720(2734)**
BENEFIT-COST RATIO	**1.40 (1.39)***	**2.71 (2.74)***	**1.91 (1.92)***	**1.90(1.91)**

Note: * The figures in brackets are for the policy driven environmental alternatives for GHG emissions and air pollution.

Net greenhouse gas emission and air pollution benefits/costs are shown on two bases, as described in Section 5: a base case and a policy driven alternative. The numbers shown in brackets in Table 4, for GHG and air pollution, are for the policy driven alternative. The three public transport projects are predicted to deliver small benefits from reduced GHG emissions but the M4 upgrade is predicted to lead to an increase in GHG emissions and associated costs.

Air pollution costs associated with the M4 project are substantial and much larger than its GHG emissions costs. The policy driven alternative reduces estimated air pollution costs from the M4 project by over $60m. Doubling bus frequency in BSA1 is predicted to increase air pollution costs by $151m in the base case, where bus fuel technology is assumed unchanged (reliance on diesel), but the policy driven alternative substantially reduces this effect (by about $40m). The smaller scale of BSA2 halves the air pollution impacts of BSA1. Increased freight traffic in all three cases adds significantly to GHG and air pollution costs.

The MetroScan estimates of changes in fare revenues associated with the PLR (Table 4) suggests that increased fare revenues can cover all the operating costs of the PLR, which are low relative to the project's capital cost, and about a third of total project costs. A slightly higher overall financial (fare) cost recovery rate (of about 38%) is estimated for the comprehensive doubling bus service frequencies (BSA1), with its predicted solid growth in patronage. The fare box cost recovery rate for the more focussed BSA2 is lower, at 24%, which is not surprising since this project is primarily aimed at social inclusion.

Social inclusion benefits are crucial for the economic worth of the PLR project and contribute significantly to the value of doubling route bus service frequencies in the outer west (BSA2). There is also a benefit of some importance here for the M4 upgrade, given the increased trip making it encourages from western zones at higher exclusion risk. Had allowance been made for different zonal household income levels in estimating inclusion benefits, the value of the PLR would have increased by $500m. This same sensitivity test was not undertaken for the M4 or for either of the two doublings of bus frequencies but increased benefit estimates are likely, particularly for BSA2 which is focussed on zones with higher exclusion risks.

Terrill (2021a) identifies how the larger Australian transport infrastructure projects tend to over-run their initial cost estimates more than lower cost projects, with projects costing a billion dollars or more exceeding their initial cost estimates nearly half the time and, when they do exceed these cost estimates, it is typically by more than $600m (Terrill 2021b). There is thus fair chance that either of both of the PLR and M4 projects might end up costing $3b, or more, rather than $2.4b. This would lower the BCR of the M4 from ~2.7 to ~2.2 (or less) also and lower the BCR of PLR from ~1.4 to ~1.2 (or less). Doubling bus frequencies are not an infrastructure initiative and should not be subject to such price pressures, making their estimated BCRs more resilient.

8. Conclusions

This paper has demonstrated the application of a land use and transport planning model system (MetroScan) for the assessment of four major transport initiatives in Sydney (a new Light Rail line, a major motorway upgrade and two alternative doublings of bus service frequencies), for the purpose of enabling a comparative assessment of these substantially different transport alternatives. All projects are shown to produce positive net benefits, user benefits the main contributor to this result for the motorway and both bus upgrade projects, with and social inclusion benefits the main justification for the Light Rail and a key benefit component of the bus upgrade project that is focussed on areas at relatively greater risk of mobility-related exclusion (BSA2). The dynamic modelling approach has also shown the importance of benefits to freight movement for each of the three initiatives.

Agglomeration benefits are one focus of many transport appraisals. This analysis suggests that major public transport upgrades that encourage inner/middle urban growth may deliver useful agglomeration benefits but that major road upgrades and PT upgrades that benefit outer areas run the risk of reducing effective economic density, with adverse impacts on agglomeration. The dynamic nature of the transport and land use interactions reflected through MetroScan have been important in illustrating these quite different agglomeration tendencies. The potentially negative agglomeration impact of a major road upgrading project is a cautionary finding in an Australian urban setting.

The assessments reported herein show some small benefits from reduced GHG emissions from the three public transport projects but increases for the M4. Increased air pollution is predicted for all four projects (albeit minimal for PLR), largely because of the impact of additional freight movement. Even with GHG emissions, however, it is important to note that, in 2033, in each of the four assessments the total CO_2 (project value) emissions for the base case environmental assumptions were still estimated to be at least 20% *higher* than the 2023 base level of emissions. This underlines that there is much to be done if Australia is to make serious inroads into reducing its high level of greenhouse gas emissions, with motor vehicles, including trucks, needing to be an important focus. The alternative estimates of future GHG emissions assumed herein, which embed a 5% p.a. policy-driven reduction in vehicular GHG emissions and air pollutant levels, is indicative of the scale of change needed in this regard. This requires initiatives such as regulatory-driven improvements in emissions performance at the motor vehicle level (e.g., fuel economy standards, tighter standards for PM emissions from diesel engines), carbon-pricing and other incentives to encourage a faster shift to electric vehicles and accelerating a switch away from cars to public transport and active travel. In this regard, it is notable that, by 2030, the NSW State Government wants all route bus services replaced with electric buses, so tailpipe CO_2 emissions will be zero and air emissions substantially reduced. This kind of policy leadership needs to be replicated and broadened.

The solid economic performance expected from both variants of doubling bus frequencies is notable. Rarely is such an option included as part of a city's transport strategy, often because governments and their treasuries dislike committing to ongoing service delivery costs: once-off outlays on big capital works seem to have greater political appeal. This assessment has shown that widespread upgrading of bus services can deliver good economic returns, suggesting they should be one option considered within integrated urban transport strategies for Australian cities, and that targeted improvements in frequencies can support social inclusion and deliver solid project economic returns.

A key finding from these Sydney case study examples is the importance of social inclusion benefits for targeted PT projects. Without those benefits the PLR would look like a white elephant. With their inclusion, it measures up well. These benefits were not adjusted for household income but, if such adjustment had been made, the PLR would have had an even better evaluation outcome, suggesting that taking account of who gains and loses is important in project appraisal. Bus frequency increases on services in areas of disadvantage have also been shown to support project viability.

Surprisingly, social inclusion benefits are currently not counted in Australian transport cost-benefit analyses, even though providing travel opportunities for transport disadvantaged people has long been a primary reason for provision of PT services. The estimation of social inclusion benefits in the current study shows that they are potentially very significant. Social inclusion benefits should form part of the assessment of all major transport initiatives, and particularly for public and active travel costs.

Appendix A: The MetroScan Structure

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. 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. We named the system MetroScan Transport Infrastructure, or MetroScan for short. MetroScan, a strategic-level transport and land use planning application system allows for mapping of passenger and freight activity, as well as an endogenous treatment of the location of households and firms. In short, MetroScan is 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.

Figure A1 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.

MetroScan 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 A2. MetroScan 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. MetroScan 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.

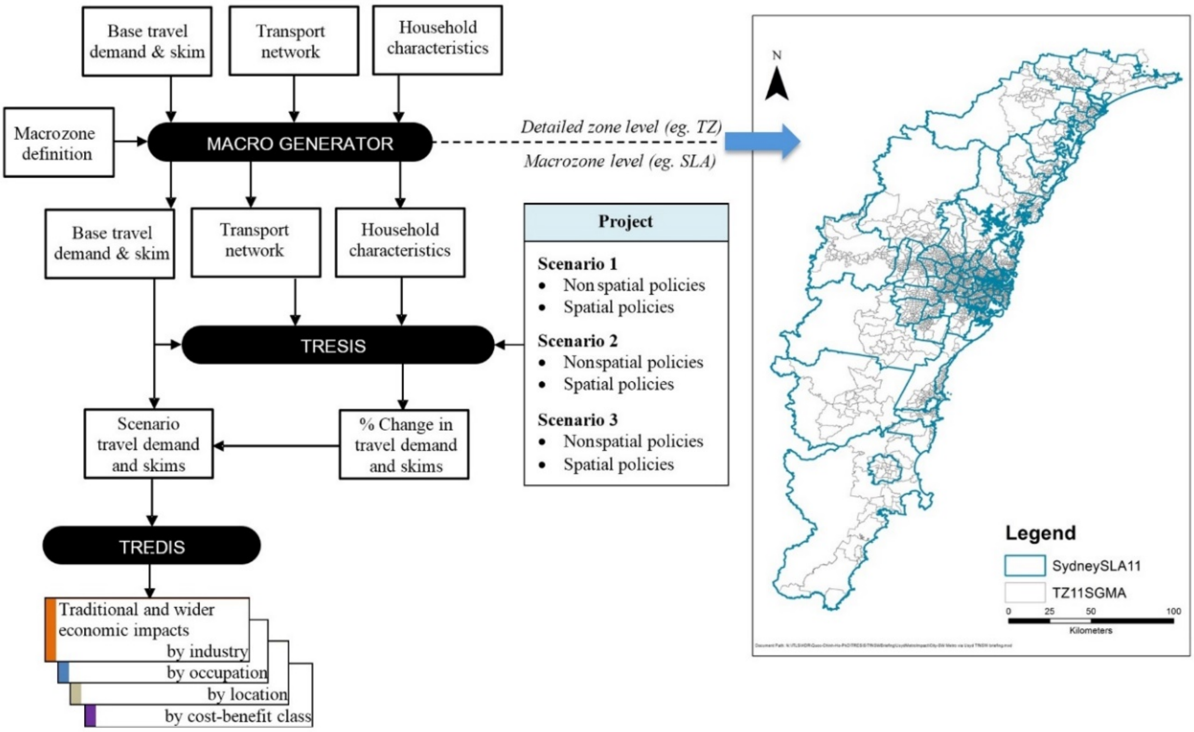

Figure A1. MetroScan framework.

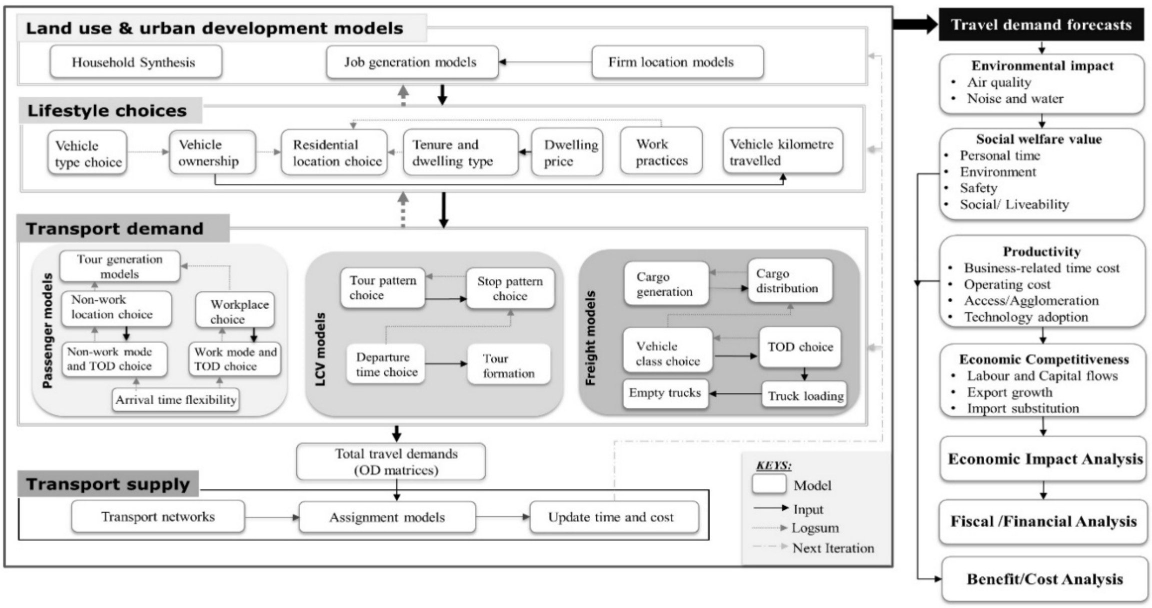

Figure A2. The demand-side behavioural model system for passenger, light commercial, and freight travel activity and the benefit-cost analysis (BCA) and economic impact modules. Source: Hensher et al. (2020).

Appendix B: Key evaluation parameter values

	Commute		Non-commute		Business		Freight	LCV
	Car	PT	Car	PT	Car	PT		
VTTS per person ($/person hour)	17.72	17.72	17.72	17.72	57.48	57.48	31.05	25.41
Average vehicle occupancy	1.7		1.7		1.3		1	1
Value of travel time reliability (VoR) ($/person hour)**	30.12	Bus only	30.12	Bus only	97.72	97.72	52.79	52.79
Value of out-of-vehicle time ($/person hour)	26.58	26.58	26.58	26.58	57.48	57.48	N/A	N/A
CO_2 emissions (c/km)	2.66	15.61 bus; 0.8 rail; 32.69 light rail	2.66	15.61 bus; 0.8 rail; 32.69 light rail	2.66	15.61 bus; 0.8 rail; 32.69 light rail	3.67 rigid, 14.64 articulated	2.35
Air pollution (c/vkm)	3.37	37.9 bus; 4.99 rail; 41.42light rail	3.37	37.9 bus; 4.99 rail; 41.42light rail	3.37	37.9 bus; 4.99 rail; 41.42light rail	16.5 rigid, 65.82 articulated	7.56
Air pollution (c/pkm)	2.39	1.89 bus, 0.04 train, 0.64 LR	2.39	1.89 bus, 0.04 train, 0.64 LR	2.39	1.89 bus, 0.04 train, 0.64 LR	N/A	N/A
Carbon dioxide equivalent (CO2-e) $/tonne*	62.79							
Carbon monoxide (CO) $/tonne*	3.95							
Oxides of nitrogen (Nox) $/tonne*	2.503.55							
Particulate matter (PM10) $/tonne*	398,451.75							
Total hydrocarbons (THC) $/tonne*	1,254.41							
Fuel excise (proportion of fuel price)	0.416							

Appendix C: Values used in MetroScan for accidents

	Fatal crash rate (per 100,000,000 km)	**Injury crash rate (per 100,000,000 km)**	
Rural	0.79	27.38	
Urban	0.54	69.45	
Rural proportion of total roads	0.3984	0.3984	
Urban proportion of total roads	0.6016	0.6016	
Reweighted crash rate (100 mil VKM)	**0.64**	**52.69**	
	Fatal crashes	**Injury crashes**	**Total Costs**
Total accidents	(TVKM+TVKMR+TVKMA)/100,000,000*0.64	(TVKM+TVKMR+TVKMA)/100,000,000*52.69	
Average Willingness to Pay (WTP) per accident	$8,590,000	$210,000	
Total costs for fatalities and injuries	Total accidents * Average WTP		Col2 + Col3
Average vehicle cost per accident	$16,908	$13,730	
Total costs for vehicles in accidents	Total accidents * average vehicle cost		Col2 + Col3
Non-vehicle costs (travel delays, police, property etc.)	$147,487	$71,447	
Total non-vehicle costs for other items	Total accidents * average non-vehicle costs		Col2 + Col3
Total vehicle and non-vehicle costs	Vehicle + non-vehicle costs		Col2 + Col3

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