Australasian Transport Research Forum 2024 Proceedings
27-29 November, Melbourne, Australia
Publication website: https://australasiantransportresearchforum.org.au/

The New Normal: Leveraging opensource economic databases to inform consumer behaviour and safety across Sydney's tolled network

Gregory Aouad[1], Kasun Wijayaratna[2], Vinayak Dixit[1]

[1] Research Centre for Integrated Transport Innovation (rCITI), School of Civil and Environmental, Engineering University of New South Wales, Sydney, NSW, 2052

[2] School of Civil and Environmental Engineering, University of Technology Sydney, Ultimo, NSW, 2007

Email for correspondence (presenting author): g.aouad@unsw.edu.au

1 Introduction

Transitioning through global economic volatility, the rise of cost of goods and services, extreme weather events as well as a health crisis (COVID-19), the state of New South Wales (Australia) has continued to deliver major infrastructure amidst these disruptions. New infrastructure between 2016 and 2023 included NorthConnex, WestConnex, M4-M5, M8, Rozelle Interchange, North-West Metro, and the Newcastle and Sydney Light Rail projects. Studies conducted within Sydney during COVID-19 indicated a significant decrease in travel activities across all modes (Beck & Hensher, 2020) (Hafiz Suliman, et al., 2021), with a notable decline in public transport usage (15% lower, comparing February 2020 and 2024), an increase in remote working and an influx in online shopping (Transport for NSW, 2024). Despite these disruptions, recent data indicates that traffic volumes across Sydney's motorways have now exceeded pre-pandemic seasonality (RSM Australia Pty Limited, 2024).

In literature, factors such as regional economic growth, land use changes, and the development of toll roads have been shown to significantly influence the relationship between public transport and tolled road usage, as well as the level of commercial activity (Putra, 2023) (Marpaung, et al., 2021).The construction of toll roads, and their proximity to new housing developments can reduce transport and production costs, consequently increasing market efficiency and house prices (Fakhruddin, et al., 2020). However, toll roads may not always deliver value for money or effective risk management. Toll rates informed by consumer price index may not reflect actual time savings provided by toll roads, thus affecting their perceived value (Hensher, 2017). Efficiency investigations from a study conducted in Spain demonstrated that changes in tolling policy (i.e. a price cap model) did not significantly affect motorway performance (Albalate & Rosell, 2019). Link efficiency improvements could be achieved by regulatory reforms focusing on the quality and pricing strategies of motorways. (Albalate & Rosell, 2019). From a safety lens, the relationship between tolling and motorway safety performance is a complex and multifaceted issue. Some studies suggest that the quality of roads (Albalate & Bel, 2012) and economic incentives (Rangel, et al., 2013) are linked to reduced crash rates. Traffic parameters, such as annual average daily traffic and the proportion of heavy vehicles also significantly influence crash rates (Rangel, et al., 2013).

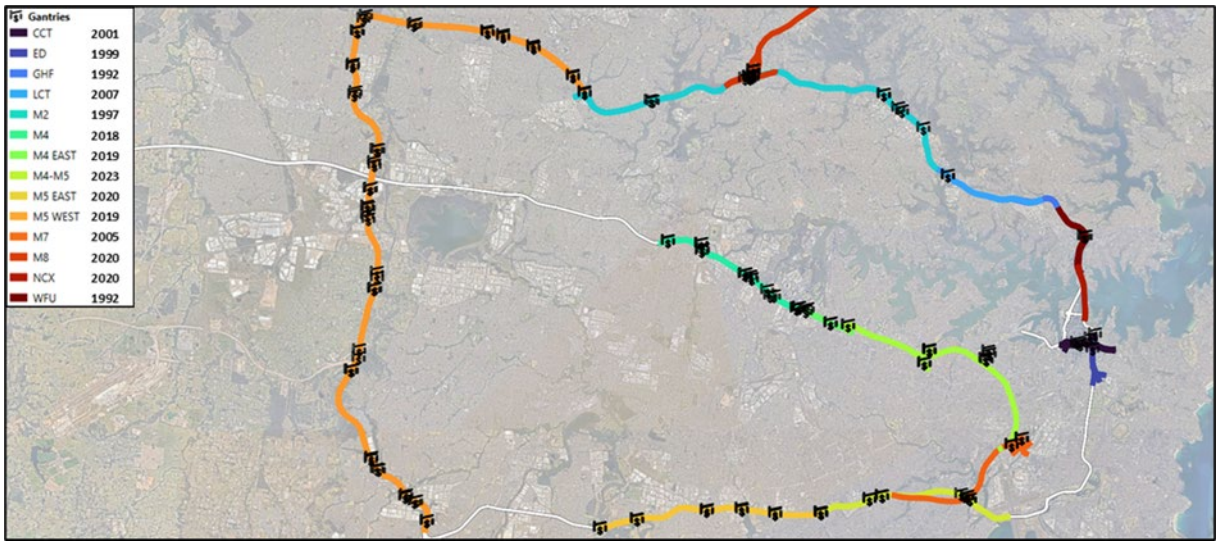
The objective of this paper is to undertake an eight-year disrupted time-series analysis of Sydney tolled motorway economic performance, based on vehicle composition, revenue, and willingness-to-pay per crash. To undertake this analysis, a novel database was developed by integrating opensource economic, tolling and transport data. A key finding from this research indicated that periods of statistically lower combined motorway volumes, led to an increase in crash severity and consequently an increase in internalised casualty costs. Despite the consumer price index in the transport and housing sectors residing at a 7-year high (Australian Bureau of Statistics, 2024) cost of living pressures has not deterred motorway usage. To the best of our knowledge and following consultation of recent literature, this is the first long-term macroeconomic case-study of tolled motorway crash behaviours and consumer activity.

2 Study Area and Data

2.1 Study Area

The Sydney motorway network contains 133 gantries, which capture light and heavy vehicle transactions (LV and HV), for the Cross City Tunnel (CCT), Lane Cove Tunnel (LCT), Eastern Distributor (ED), M2, M4, M5W, M5E, M8, M7, NCX and WCX. **Figure 1** provides the location of the corridors, their year of opening (or tolling) and the location of the gantries.

Figure 1: Sydney tolled motorway gantries.



The monthly database used for this study was prepared by integrating opensource data, published by various private and public agencies (summarised in **Table 1**).

Table 1: Summary of data acquired for the empirical investigation.

Dataset	Source	Variables	Resolution
Historical Crashes	Transport for NSW	Crash characteristics	Date and time of accident
Gantry Volumes	Transurban	Light and heavy vehicle volumes	15-minutes; entries, exits and origin-destinations.
Opal Patronage	Transport for NSW	Public transport usage, by mode.	Totals by mode and ticket type. (July 2016 – Feb 2024)
Economic Drivers	Australian Bureau of Statistics Reserve Bank of Australia	Consumer price index Inflation and Interest	Monthly, quarterly and annually.

3 Methodology

3.1 Road user movement and crash severity analysis

Descriptive statistics and box and whisker plots were used to examine the seasonality in motorway usage, crash severity, crash frequency and economic activity.

3.2 Z-score normalisation

Due to disruptions catalysed by new infrastructure, health-crises and economy change; all gantry entries within the database have been z-score normalised, to measure the standard deviation from the mean, over the observed 8-year period.

$$Z = \frac{X - \mu}{\sigma} \quad (1)$$

- X: is the value for which the z-score is calculated,
- μ: is the mean of the dataset,
- σ: is the standard deviation of the dataset.

3.3 Generalised linear models (GLMs)

Crash rates and vehicle class entries were modelled to see if a positive relationship persists, or if trends have shifted due to historical disruptions.

$$\eta = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p \quad (2)$$

- η: is the linear predictor.
- $\beta_1, \beta_2, \ldots, \beta_p$: are the coefficients.
- $X_1, X_2, \ldots, X_p$: are the z-score normalised independent variables.

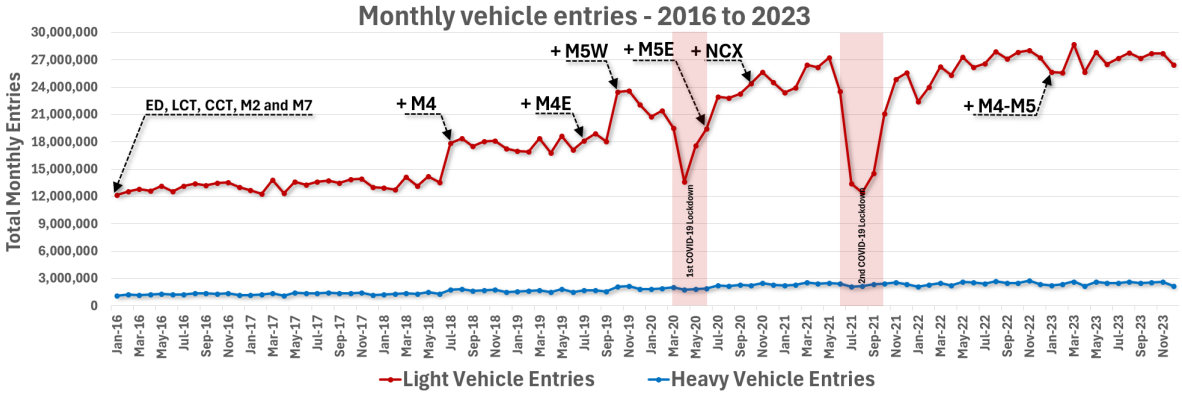
4 Main findings

4.1 Motorway volumes

Figure 2 presents the monthly light and heavy vehicle entries between 2016 and 2023.

Annual growth and new infrastructure induced 125% more observable traffic volumes, relative to the baseline aggregate of CCT, LCT, ED, M2 and M7.

Figure 2: Monthly motorway vehicle entries



- **COVID-19 April 2020:** a 30% and 12% reduction in light and heavy vehicles, respectively.
- **COVID-19 July 2021:** a 44% and 14% reduction in light and heavy vehicles, respectively.

4.2 Crash type and severity

Road user movements (RUM) are specific terms used to describe the trajectory and first impact for a reported crash. These definitions and codes have been summarised in **Table 2**, alongside the Casualty and Fatal-Serious Injury (FSI) crash counts that occurred.

Table 2: Road User Movement classifications

RUM Code	Codes	Casualty Count	Casualty %	FSI Count	FSI %
Same Direction	30-39	1233	80.3%	249	66.4%
Off-Path Straight	70-79	167	10.9%	68	18.1%
Off-Path Curve	80-89	72	4.7%	29	7.7%
On Path	60-69	38	2.5%	16	4.3%
Pedestrians	00-09	11	0.7%	8	2.1%
Manoeuvring	40-49	10	0.7%	4	1.1%
Miscellaneous	90-99	3	0.2%	1	0.3%
Opposing Direction	20-29	2	0.1%	0	0.0%
Total	-	1536	100%	375	100%

Casualty crashes (incurring an injury) accounted for 1,536 (62%) of all recorded crashes (2,479). FSI accidents, which are a subset of casualty crashes, accounted for 15% of the crashes. 353 serious crashes (14.2%) and 22 fatal crashes (0.9%) occurred across the toll network within the 8-years. 7 out of the 22 recorded fatal crashes were a result of speeding.

6 out of the 22 recorded fatal crashes were collisions with pedestrians (00-09). 3 fatal and 21 serious crashes (1%) occurred during the COVID-19 lockdowns.

Figure 3 presents the seasonal distribution of FSI crashes across all motorways.

Figure 3: Box plot for fatal and serious accidents

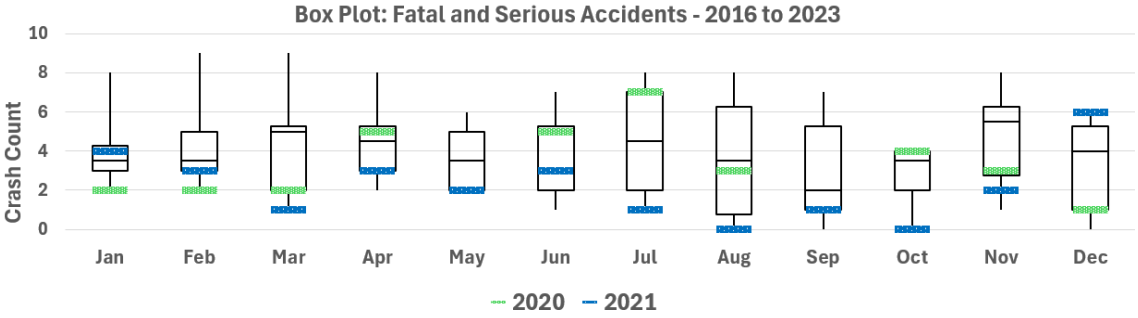


Figure 3 indicates a seasonally higher number of fatal and serious accidents during April 2020 (5 events), despite a 30% reduction in demand. Furthermore, post-lockdown (11 May 2020), experienced a historically higher number of FSI crashes in June and July 2020 (5 and 7, respectively), relative to previous years. Conversely, during the 107 days of lockdown in 2021, August experienced a 44% reduction in demand and the lowest casualty rates and FSI.

4.3 Inclusive Willingness-to-Pay (WTP) per casualty and revenue trends

Road safety benefits are estimated based on the Inclusive Willingness-to-Pay (WTP) values found within the Transport for NSW Economic Parameter Values (EPV) guidelines - see **Table 3** (Transport for NSW, 2023). These values represent the individual's WTP to avoid death or injury; as well as the cost to society borne from a crash.

Table 3: Costs per casualty – Inclusive WTP approach (Table 5.2 from 2023 EPV guidelines)

Accident Type	Fatality	Serious Injury	Moderate and Minor Injuries
Urban	$8,388,230	$505,028	$77,568

Typical safety analysis involves calculating crash exposure, i.e. crashes per million vehicle kilometres travelled. However, a complete evaluation could not be undertaken due to limitations in the opensource data. Instead, media releases on *Tolling Indexations* (Linkt Sydney, 2023) were used in conjunction with the escalation rates from *Figure 3.6* of the *Independent Tolling Report* (Fels & Cousins, 2024); to calculate the ratio between WTP and revenue for all motorways. Total 8-year WTP for each vehicle class is depicted in **Table 4**.

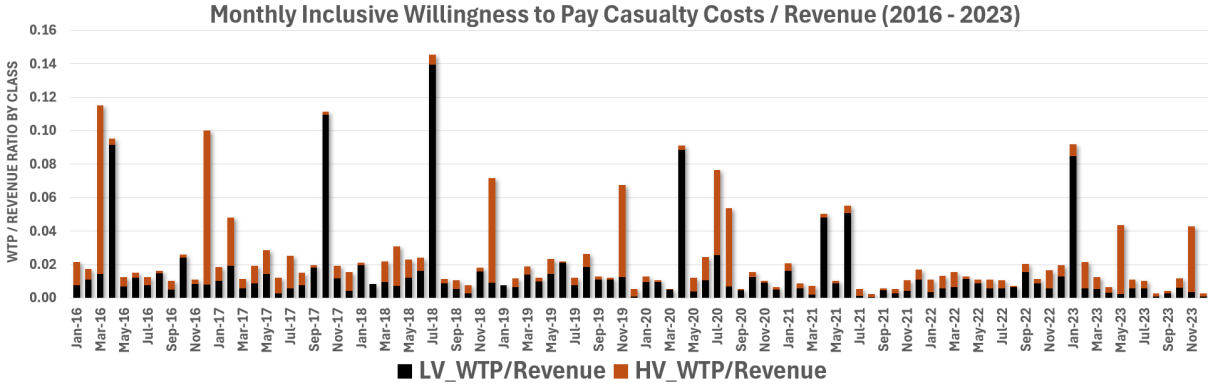
Table 4: Dashboard of summated tolled period crashes, casualties and WTP per motorway

Type	LV Crashes	HV Crashes	LV Casualties	HV Casualties	LV WTP	HV WTP
Total[1]	1,052	604	768	505	$210,456,062	$149,258,056

[1]Total crash counts align when revenue collection commenced, for each respective motorway.

Figure 4 presents the aggregated monthly ratio of WTP to total motorway revenue.

Figure 4: Aggregated WTP over revenue for light and heavy vehicles



The 2021 COVID-19 lockdown presented the lowest seasonal WTP casualty costs for July, August, September, and October. However, June 2021 experienced the highest seasonal WTP casualty costs, due to 23 out of June's 24 crashes occurring prior to lockdown.

- Due to low demand (revenue) and a historically high number of FSI crashes, April 2020 presented the seventh highest ratio of WTP to revenue: $1 of revenue to $0.09 WTP.
- A similar circumstance during June 2021, ranking 11th for $1 of revenue to $0.06 WTP.
- Amidst the second lockdown, which experienced the lowest observed traffic volumes; August 2021 was the better performing month, incurring $1 of revenue to $0.003 WTP.

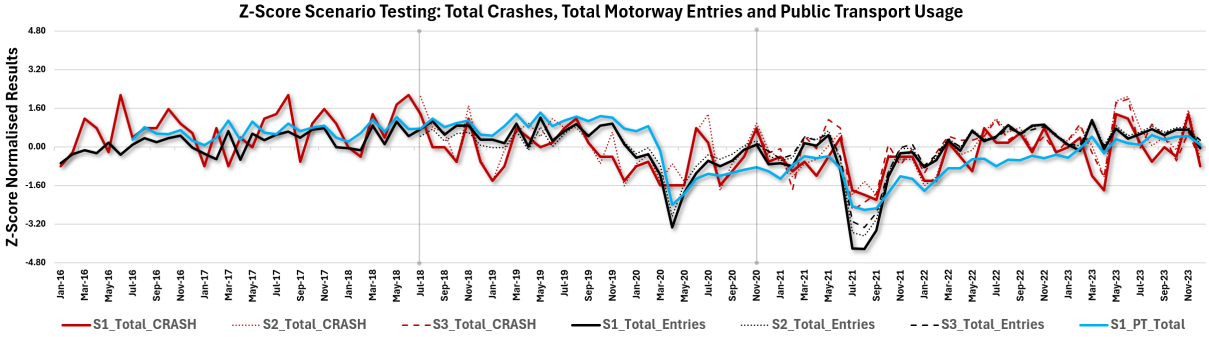
4.4 Z-Score normalisation scenarios

To account for varying gantry data collection periods and notable disruptions, three different scenarios of z-score results were plotted, as a disrupted time-series.

Figure 5 presents the disrupted trends over the observed eight-year period.

- **Scenario 1 (S1)**: CCT, LCT, ED, M2 and M7 only, which covers 2016 to 2023.
- **Scenario 2 (S2)**: CCT, LCT, ED, M2, M7 and M4 only, which covers July 2018 to 2023.
- **Scenario 3 (S3)**: All motorways, which covers November 2020 to 2023.

Figure 5: Normalised z-scores for motorway crashes, entries and public transport patronage



For each scenario and variable (S2 and S3), there was little change to the observed z-score, relative to S1. **Figure 5** indicates that all nine motorways followed a similar shift in normalised results between 2016 and 2023. Furthermore, they all stabilise around 1.0 standard deviation from their global mean. This may suggest self-similarity in relative macroscopic changes to volumes and crash rates. There is the possibility that monthly WTP can be forecasted based on vehicle composition and their contributory relationship to total frequency or severity.

For July 2020, *Total_Entries* remained 1.3 standard deviations below the mean, while *Total_Crash* was 1.0 standard deviation above the mean. For the same parameters, there was a non-linear shift below the mean during August 2021, highlighting unobserved heterogeneity into crash causality. Despite a statistically significant reduction in demand, crashes did not decrease proportionally; reflecting similar rates to May 2023, when demand was higher.

4.5 Generalised linear modelling scenarios

Model 1: $E(Total_Crashes) = exp(\beta_0 + \beta_1 \cdot LV_pc + \beta_2 \cdot Train_Bus_Metro_pc)$ (8)

Model 2: $E(Total_FSI) = exp(\beta_0 + \beta_1 \cdot LV_pc + \beta_2 \cdot Train_Bus_Metro_pc)$ (9)

The results of *Model 1* and *Model 2* are summarised in **Table 5** and **Table 6** below.

Table 5: Model 1: Generalised linear modelling results for Total_Crashes

Scenario	Pre-COVID-19			During COVID-19			Post COVID-19		
Output	**Coeff.**	**Std Err.**	**P-value**	**Coeff.**	**Std Err.**	**P-value**	**Coeff.**	**Std Err.**	**P-value**
Constant	2.65	0.16	-	2.33	0.21	-	3.04	0.21	-
LV_pc	-0.07	0.17	0.68	0.30	0.26	0.25	-0.08	0.26	0.77
Train_Bus_Metro_pc	-0.03	0.17	0.85	-0.03	0.25	0.90	-0.02	0.26	0.95
Pseudo R-squared	0.001			0.01			0.001		

Table 6: Model 2: Generalised linear modelling results for Total_FSI

Scenario	Pre-COVID-19			During COVID-19			Post COVID-19		
Output	**Coeff.**	**Std Err.**	**P-value**	**Coeff.**	**Std Err.**	**P-value**	**Coeff.**	**Std Err.**	**P-value**
Constant	1.08	0.18	-	0.54	0.27	0.04	1.13	0.24	-
LV_pc	-0.09	0.19	0.66	0.66	0.36	**0.07**	0.16	0.29	0.57
Train_Bus_Metro_pc	-0.03	0.19	0.89	0.34	0.31	0.26	0.03	0.29	0.91
Pseudo R-squared	0.001			**0.04**			0.001		

5 Discussion

Results from this study has raised questions regarding tolled motorway crash propensity and the impact of traffic composition has on regulating safety. While State Government's objective was to limit the transmission of COVID-19, the indirect impact of travel restrictions saw a non-linear decline in crash frequency, but a rise in crash severity i.e. the seventh highest month of crash severity or WTP (April 2020) occurred while servicing the second lowest demand (See **Figure 3** and **Figure 4**). Whereas the month of the lowest traffic volumes (August 2021) was the safest (lowest WTP). Furthermore, the ratio of WTP to revenue for April and July 2020, coupled with June 2021 were seasonally high, despite experiencing 4.22 standard deviations below the global mean in volume (**Figure 5**). This paradox suggests two possible outcomes:

1. Between the first and second lockdown, road users adjusted their driving behaviours to cater for travel restrictions, atypical traffic and surplus capacity across the network. Or,
2. During this time an optimum composition of total traffic volumes, composition and environment was exhibited, which minimised overall crash propensity.

The GLM results provide a glimpse into these hypotheses for Total_FSI (**Table 6**) where the p-value for LV percentage *(LV_pc)* shifted from 0.66 to 0.07, before and during COVID-19, respectively. The proportionality of LVs became statistically more significant during COVID-19 to inform fatal or serious injuries. Additionally, the relationship between *Total_FSI* and *LV_pc* changed, as its coefficient transitioned from negative to positive, as a higher proportionality of LV tended toward higher counts of FSI, while the *pseudo-R-squared* improved (0.001 to 0.04). P-values (while significant) reverted to similar 2016 - 2019 values, post-COVID (0.57 - 0.91). The delta from the two model scenarios indicates a shift in severity due to disruptions. These results point toward unobserved heterogeneity, which need to be reconciled, to verify how driver behaviour contributes to crash causality on tolled motorways.

At a magnitude level, total LV crashes across the CCT, ED, LCT, M2 and M7 decreased by 47% between 2021 and 2019, whereas HV crashes decreased by 7%, despite incurring historically low AADT. Whereas the delta of crash counts between 2019-2023 indicates that LVs have remained 10.4% lower, yet HV crashes have increased by 30%. If we interrogate aggregated casualties for the same corridors, casualties reduced by 34% for LVs and increased by 7% for HVs, between 2019-2021. However, between 2019-2023, LVs have remained lower, at 27%, yet HV casualties have risen by 72%. This trend suggests that the ratio of LV crashes to casualties are tending towards breakdowns, rather than casualty events. The opposite can be said for HV crashes, aggregated across CCT, ED, LCT, M2 and M7.

In July 2024, NSW Government released the *Toll Review* report (Fels & Cousins, 2024), to identify tolling reform options. Despite quarterly tolling indexation, it has not deterred motorway use, specifically, the millions of motorists in Western Sydney currently carrying the largest burden and have the fewest public transport alternatives. (Roads Australia, 2024).

While this study provides macroscopic insights into tolled motorway performance and economic trends; crash propensity cannot be measured unless driver behaviour, dynamics, composition and environment are evaluated. By using these parameters, it is recommended that a disrupted time-series analysis and a difference-in-difference approach is performed, to determine their statistical significance on crash causality. Outcomes from this type of study would allow the temporal derivation of a customer's value-for-money using tolled roads. Additionally, results can be globalised, to verify if tolled motorways exhibit transferable traits.

6 References

Albalate, D. & Bel, G., 2012. Motorways, tolls and road safety: evidence from Europe. *SERIEs,* Volume 3, p. 457–473.
Albalate, D. & Rosell, J., 2019. On the efficiency of toll motorway companies in Spain. *Research in Transportation Economics,* Volume 76, pp. 1-10.
Australian Bureau of Statistics, 2024. *Consumer Price Index, Australia.* [Online]
Available at: https://www.abs.gov.au/statistics/economy/price-indexes-and-inflation/consumer-price-index-australia/latest-release
Beck, M. J. & Hensher, D. A., 2020. Insights into the impact of COVID-19 on household travel and activities in Australia – The early days under restrictions. *Transport Policy,* Volume 96, pp. 76-93.
Fakhruddin, A., Nurlambang, T. & Sumadio, W., 2020. Spatial patterns of land prices changing around toll gates (Cipali Toll Road case study). *IOP Conference Series: Earth and Environmental Science,* 561(1), pp. 12-16.
Fels, A. & Cousins, D., 2024. *Independent Toll Review.* [Online]
Available at: https://www.treasury.nsw.gov.au/sites/default/files/2024-07/20240716_TollReview_FinalReport_MotoristsFirst.pdf
[Accessed July 2024].
Hafiz Suliman, M. et al., 2021. Insights into the Mobility Pattern of Australians during COVID-19. *Sustainability ,* 17(9611).
Hensher, D., 2017. Toll roads – a view after 25 years. *Transport Reviews,* 38(1), pp. 1-5.
Hensher, D., 2019. *New road pricing system needed after years of political neglect,* Sydney: The University of Sydney.
Hensher, D., 2023. *Tolling and price setting,* Sydney: The University of Sydney.
Johanson, S., 2023. *Drivers return to toll roads in post-pandemic increase,* Sydney: Sydney Morning Herald.
Linkt Sydney, 2023. *Notification of quarterly toll change – NSW motorways.* [Online]
Available at: https://www.linkt.com.au/content/dam/linkt/sydney/pdf/qpu/2023-jul-sep/media-release-quarterly-tolling-indexation-1-July-2023.pdf
[Accessed July 2024].
Marpaung, G. et al., 2021. Socioeconomy Conditions After The Development of Toll Roads in Salatiga. *Economics Development Analysis Journal,* 10(1), pp. 86-95.
Putra, A. P., 2023. Impact of Toll Road Development on Modern Retail Growth in Indonesia. *Journal Research of Social Science, Economics, and Management,* 2(8), pp. 1759-1778.
Rangel, T., Vassallo, J. M. & Herraiz, I., 2013. The influence of economic incentives linked to road safety indicators on accidents: The case of toll concessions in Spain. *Accident Analysis & Prevention,* Volume 59, pp. 529-536.
Roads Australia, 2024. *Independent Toll Review interim report released.* [Online]
Available at: https://roads.org.au/independent-toll-review-interim-report-released/
RSM Australia Pty Limited, 2024. *NSW Toll Data.* [Online]
Available at: https://nswtollroaddata.com/
Sydney Morning Herald, 2024. *Sydney Road Tolls Predictor.* [Online]
Available at: https://www.smh.com.au/interactive/2016/sydney2026/toll/index.html?8787
[Accessed July 2024].
Transport for NSW, 2023. *Transport for NSW Economic Parameter Values: For economic modelling, appraisal, and evaluation of the NSW Government Transport Cluster initiatives..* [Online]
Available at:
https://www.transport.nsw.gov.au/system/files/media/documents/2024/TfNSW%20Economic%20Parameter%20Values%202023.2%2C%20September%202023.pdf
[Accessed August 2024].
Transport for NSW, 2024. *Opal Tap On and Tap Off.* [Online]
Available at: https://opendata.transport.nsw.gov.au/dataset/opal-tap-on-and-tap-off