Australasian Transport Research Forum 2021 Proceedings
8-10 December, Brisbane, Australia
Publication website: http://www.atrf.info

# The influence of weather on bus ridership for different passenger types in Canberra, Australia

April Alcock[1], Milad Ghasri[2], Nathan Urban[3], Emily Moylan[1]

[1]School of Civil Engineering, University of Sydney, Sydney NSW
[2]School of Engineering and IT, UNSW Canberra at ADFA, Canberra ACT
[3]Transport Canberra and City Services Directorate, ACT Government, Canberra ACT
Email for correspondence: emily.moylan@sydney.edu.au

## 1. Introduction

The ability of transportation agencies to respond to short-term fluctuations in travel demand is central to the provision of resilient and reliable mobility. Weather may induce these intra-day and day-to-day variations in demand through its composite influence on travel behaviour, activity behaviour and socio-psychological attributes.

The impact of weather on urban public transport demand has been demonstrated to vary according to the weather parameter, mode choice, destination choice or activity type and geographic area of study (Guo, Wilson and Rahbee, 2007; Clifton, Chen and Cutter, 2011; Böcker, Dijst and Prillwitz, 2013; Singhal, Kamga and Yazici, 2014; Tao *et al.*, 2018). Whilst some earlier studies have utilised stated preference surveys to assess the role of weather on public transport demand (Khattak and De Palma, 1997; De Palma and Rochat, 1999; Cools *et al.*, 2010), there is an emerging body of research utilising smart card data to study passengers' revealed preferences.

Public transport plays an important social role in providing mobility to groups that may have lower access to private cars due to age, income, or disability status. Although this function is important for transport operators to maintain across diverse weather conditions, few authors have explored the relationship between weather impacts and socio-demographic groups (Ngo, 2019). The recent deployment of smart card technologies has provided the opportunity to utilise embedded socio-demographic passenger information within public transport data.

This study analyses the relationship between socio-demographic characteristics, weather conditions and bus ridership in Canberra, Australia. It is part of a broader investigation into the impact of disruption of public transport ridership. This study will provide insights into the weather- ridership relationship to ultimately inform the design and operation of equitable transportation systems with social functionality that is resilient to weather-induced fluctuations in demand.

## 2. Data

The focus of this study is the bus network in Canberra, Australia in 2017 and 2018. During the study period, Canberra's primary form of public transportation was a bus network comprising 437 vehicles servicing approximately 2,500 bus stops (ACT Government, 2018) and accounting for 4.3% of Canberra's modal share (ACT Government, 2017). Canberra has a high rate of walking trips (approximately 13.6% of trips) and the highest rate of cycling participation of Australia's major cities (approximately 2.4% daily of trips) (ACT Government, 2017).

Bus patronage data was obtained from Transport Canberra. The number of bus boardings were calculated for each hour within each day of the study period at the network level. This was achieved by aggregating the boardings by date, hour of day and counting the number of data points within each hour for each passenger type on weekdays and weekends (Figure 1). Boardings for trips marked as special events (3723 trips or 0.01% of the data) were removed.

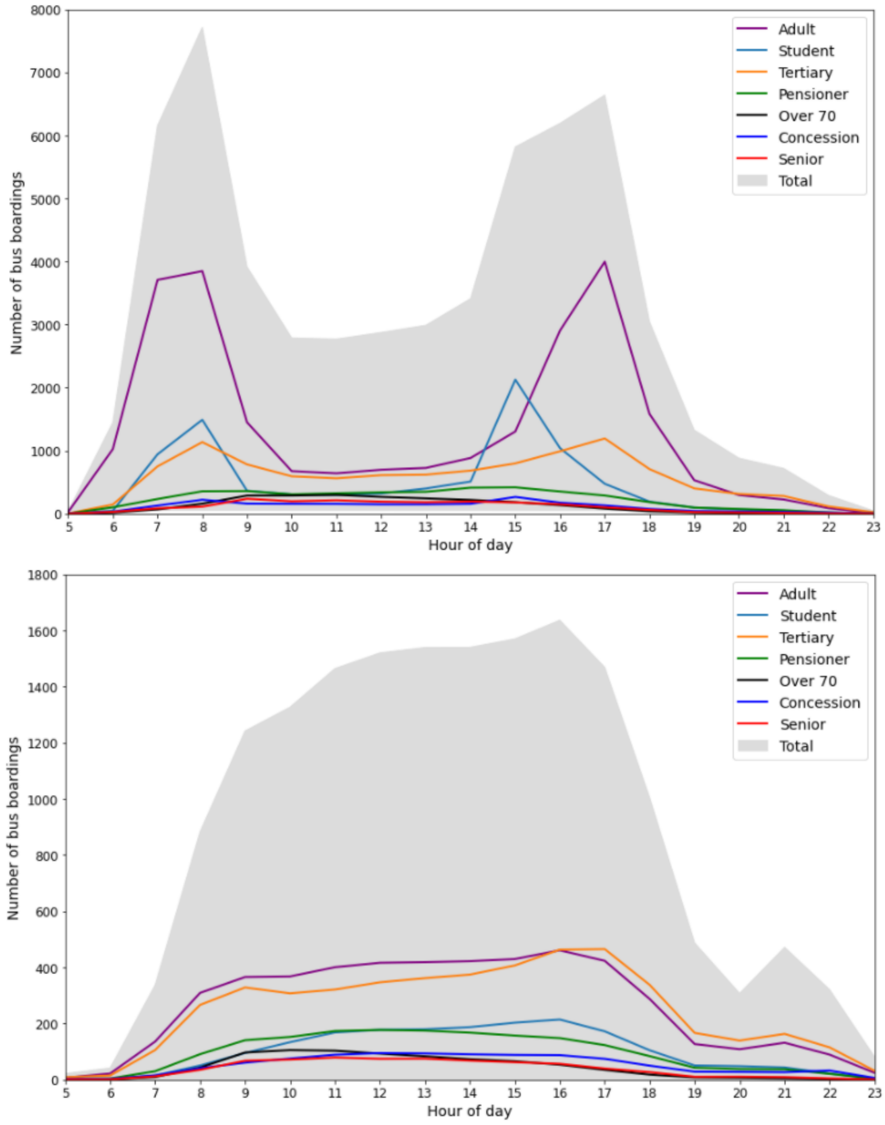

**Figure 1 Average boardings by hour of day for weekdays (top) and weekends (bottom)**

Weather data for 2017 and 2018 was sourced from the Australian Bureau of Meteorology (BOM). The data comprises observations of air temperature (C°), wind speed (km/h), maximum wind gust (km/h) and precipitation (mm) recorded at one-minute intervals by two weather stations located within the Australian Capital Territory, including Canberra Airport (ID: 070351) and Tuggeranong AWS (ID: 070339). Hourly weather measurements were assigned to the study area using the average of the two weather stations.

Canberra is characterised by warm to hot summers (from December to January) and cool to cold winters (from June to August) (Bureau of Meterology, 2019). The hourly temperature observations for Canberra during the study period are shown below in Figure 2 (left). Averaging the rainfall records of the Tuggeranong and Canberra Airport weather stations, the Canberra region experienced 116 days of rainfall in 2017 and 86 days of rainfall in 2018, resulting in an annual rainfall of 557 mm and 438 mm, respectively. During the study period, a greater rainfall intensity was observed to occur during the summer months, as shown in Figure 2 (right).

The average wind speed in Canberra was observed to exhibit mild seasonal variability. The windiest month was October, where the 9am average wind speed was 8.1 km/h and the 3pm average wind speed was 13.5 km/h). Wind was calmest during the autumn months.

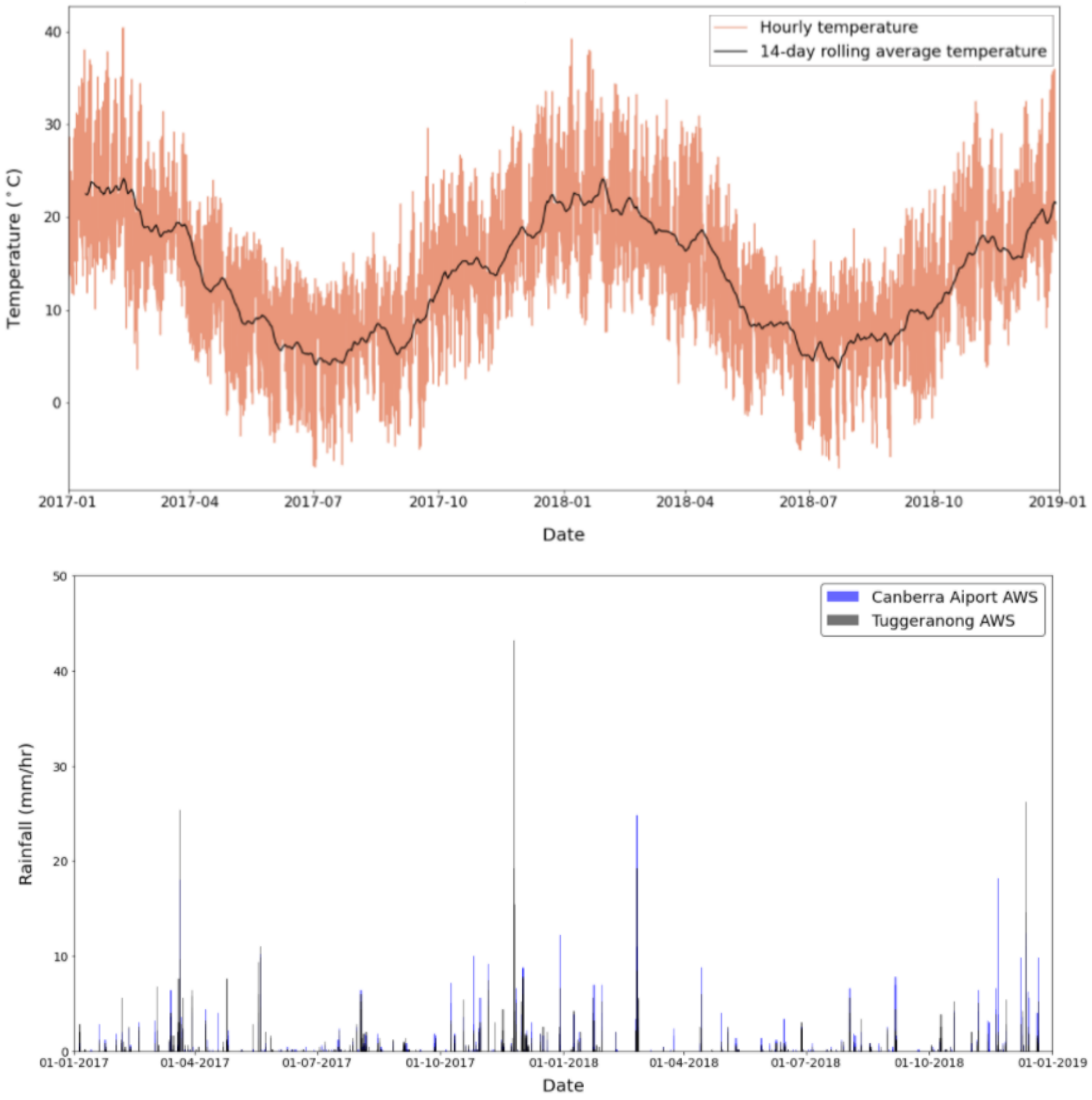

**Figure 2 Seasonal weather patterns in Canberra showing hot summers (top) and dry winters (bottom)**

# 3. Methodology

This study seeks to determine if weather conditions induce discernible differences in bus ridership across varying socio-demographic groups by utilising the 'passenger type' details within the bus patronage dataset. The Transport Canberra classifications of bus passengers are used as a proxy to classify the groups in this study given the distinct eligibility requirements of the passenger types. This classification comprises seven passenger groups of adults, students (full time primary or high school students), tertiary (full time university students), concession (aged under 66 and receiving income support from the Australian Government), pensioner (aged 66 and over and receiving income support from the Australian Government), senior (ACT or interstate Senior Card holder), and over 70 (aged 70 and over).

A series of ordinary least square (OLS) regression models are employed to assess the influence of weather on bus ridership according to passenger type. The dependent variable in this study is the change in hourly bus boardings by each passenger type occurring at the network level in response to weather conditions.[1] To account for the intraday and daily variations in bus ridership, the change in hourly bus boardings is defined as the deviation between the observed

---

[1] Stop level analysis produced less significant results comparatively to the network level analysis, likely due to the low bus patronage at outer bus stops and small populations of some passenger types.

number of hourly boardings and the average number of boardings for the corresponding day of the week and hour of day.

Pursuant to existing literature, the independent weather variables in this study are defined as air temperature, rainfall and wind speed. A temperature increase is defined as the increase in the hourly temperature relative to the seasonal average temperature for the corresponding hour. Similarly, a temperature decrease is defined as the decrease in the hourly temperature relative to the seasonal average temperature for the corresponding hour. In addition, several indicator (dummy) variables are utilised to capture the impact of 'severe' temperatures including hot days in summer, cold days in summer and their lagged values. Rainfall (0.1-3.8mm per hour), heavy rainfall (more than 3.8mm per hour) and heavy rainfall lagged by one hour and one day are included as precipitation variables. Wind speed and the presence of strong winds (greater than 50km/h) and strong winds in the previous hour are included for the wind variables. The weather variables are complemented with indicator variables for public and school holidays which have a strong impact on ridership and also follow seasonal patterns.

# 4. Results

The regression is repeated for each card type to understand how each socio-demographic group responds to weather in their ridership patterns. For card types associated with peaked travel (adult, tertiary, student as shown in Figure 1 left), the models are presented for the weekday AM peak period in Table 1. For card types without distinct temporal trends (concession, pensioner, senior and over 70 as shown in Figure 1 left), the models are presented independently from temporal periods.

**Table 1 Regression results for the different card types. Asterisk (*) indicates p-values less than 0.05.**

| | **Peaked travel** | | | **Non-peaked travel** | | | |
|---|---|---|---|---|---|---|---|
| ***Variable*** | *Adults* | *Tertiary* | *Student* | *Concession* | *Pensioner* | *Senior* | *Over 70* |
| Constant | 111.25* | 54.86* | 115.12* | 3.18* | 4.16* | 2.04* | 2.79* |
| Temperature increase | 50.78* | 45.88* | 34.47 | 2.37* | 2.31* | 1.45* | 2.06* |
| Temperature decrease | 60.47* | 8.97 | 80.67* | 0.41 | 1.85* | 0.29 | 0.73* |
| Wind speed | 3.30 | 3.48* | 3.74 | 0.12* | 0.30* | 0.14* | 0.16* |
| Hot day in summer | -292.89* | -203.02* | -208.64 | -6.92* | -27.5* | -14.46* | -18.74* |
| Follows hot day in summer | 55.69 | -136.64* | -97.68 | 6.13* | -10.62* | -1.94 | -3.07* |
| Cold day in winter | 54.70 | -1.74 | -226.03 | -0.40 | 1.41 | 0.07 | 0.17 |
| Follows cold day in winter | -14.92 | -136.64* | -275.04* | -3.11 | -2.80* | -1.87* | -4.67* |
| Rainfall | -13.25 | -67.30* | -73.28 | -6.41* | -13.55* | -7.69* | -12.99* |
| Heavy rainfall | -33.99 | 72.33 | -357.59 | -16.13* | -24.57* | -9.12* | -17.76* |
| Heavy rainfall in previous hour | -134.85 | -249.23 | -323.25 | -11.35* | -13.83 | -12.86* | -19.55* |
| Heavy rainfall in previous 24h | 201.49* | 4.99 | 126.76 | -1.13 | 1.11 | -0.37 | -3.18 |
| Strong wind | 36.83 | -38.88 | -22.39 | -4.01* | -2.65 | -2.23* | -4.10* |
| Strong wind in previous hour | -22.52 | -0.81 | -42.94 | -3.89* | -1.54 | -2.71* | -4.43* |
| School holiday | -147.41* | -88.11* | -615.00* | 0.52 | -9.57* | -2.52* | -2.15* |
| Public holiday | -3468.47* | -663.32* | -876.74* | -65.18* | -143.01* | -76.37* | -90.99* |
| Summer | -211.76* | -112.95* | -97.43 | -2.44* | -10.05* | -1.50* | -1.87* |
| Winter | -16.07 | -47.01* | 166.36* | -7.06* | 0.48 | -1.07* | -3.56* |
| Spring | -35.40 | -24.86 | 22.18 | -5.07* | 4.22* | 1.77* | 1.92* |
| Number of Observations | 1534 | 1555 | 1036 | 12747 | 12907 | 12070 | 11813 |
| Adjusted $R^2$ | 0.580 | 0.303 | 0.300 | 0.111 | 0.319 | 0.303 | 0.279 |
| F statistic | 125.6 | 40.65 | 27.06 | 94.94 | 357.1 | 310.2 | 269.5 |
| P-value for the F statistic | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | |

The models show improvements over the null model based on the F-statistics. As expected, public and school holidays have a statistically significant negative relationship on change in ridership, except for concession card holders who do not show a significant decrease during school holidays. Weather conditions are associated with ridership changes for all models, although different variables appear significant in each model. Unexpectedly, heavy rainfall and 1-hr lagged heavy rainfall are not significant in the peaked travel models and rainfall and 24-hr lagged heavy rainfall are each significant in one peaked travel model. However, these variables are significant at other times of day (inter-peak, PM peak, weekend) and when significant, the impact is negative as expected. These findings support the assumption that work and study trips in the peak period are not discretionary and are not likely to be foregone or deferred for bad weather. In contrast to the peaked travel models, rainfall, heavy rain, heavy rain in the last hour and heavy rain in the last day are statistically significant across concession, pensioner, senior and over 70. This indicates a stronger sensitivity to precipitation for these travellers. In addition, temperature and wind variables are statistically significant across the card types. Except for temperature changes and wind speed, all statistically significant weather variables have a negative sign.

# 5. Discussion

The results of this study suggest that differing socio-demographic groups possess varying levels of sensitivity to severe weather events. Students are the most resilient to severe weather suggesting that they have a limited ability to perform real-time responses to less predictable (in occurrence and duration) weather events. Socio-demographic groups tend to adopt travel behaviour patterns in response to weather according to their available travel ‘opportunities’, considering constraining factors such as cost, accessibility, physiological condition and authority restrictions (Hägerstrand, 1970; Chapin, 1974; van Acker, Wee and Witlox, 2010). The weather-resilient travel behaviour of students may be attributed to constraints associated with their socio-demographic characteristics, such as limited private vehicle access particularly for international students, age-based rules and restrictions and temporally rigid destination activities (i.e., school). This cohort demonstrates a ‘captivity’ to the bus mode given the presence of a spontaneous rainfall event. In contrast, passengers over 70 demonstrate the greatest sensitivity to severe weather variables, regardless of their stochastic or deterministic attributes. This weather-sensitive behaviour may be attributed to facilitating factors associated with their socio-demographic characteristics, such as private transportation access and temporally flexible destination activities.

We observed an increase in adult ridership during the weekday AM peak period given a heavy rainfall event in the previous 2-24 hours. Given the temporal and spatial fixity of essential travel, passengers may be more inclined to plan their travel in advance to ensure they arrive at their destination on time. Therefore, the temporal coordinates of passengers’ decision-making timeframes may be further from the point of travel to accommodate any anticipated obstacles. Consequently, this observation may be attributed to adult passengers altering their morning commute travel behaviours in response to the lagged effect of severe rainfall events. Specifically, given Canberra’s high rate of active transportation, it is reasonable to assume that the observed increase in bus ridership may be attributed to these passengers shifting away from weather-exposed active transportation in favour of the increased shelter and comfort provided by bus alternatives.

# 6. Conclusions and future work

This study investigates the influence of socio-demographic characteristics and preceding weather conditions on the weather-bus ridership relationship in Canberra, Australia, using a series of OLS regression models to analyse 24 months of transit smart card data and meteorological records.

The results indicate that differing socio-demographic groups demonstrate varying responses in bus ridership to weather conditions. Passengers over 70 are observed to be the most sensitive to severe weather events, while student passengers are observed to be the most weather resilient. As elderly passengers may be less resilient to weather events due to physiological considerations, comfort-based policy measures, such as more weather-resilient bus stop infrastructure in areas that possess large populations of elderly residents, may improve their ridership experience given adverse weather events and thus stabilise their ridership patterns, ultimately reducing associated fluctuations in demand and improving public transport system efficiencies.

There are three notable areas that should be explored in future research to further expand the findings of this study. First, a supplementary investigation into the weather-public transport ridership relationship in Canberra, Australia should be undertaken to capture potential changes in travel behaviour induced by the recently implemented light rail network. As the light rail network possesses differing infrastructure characteristics compared to the existing bus network, future research may observe differing ridership patterns in response to a change in weather conditions. Second, the influence of omitted variables, especially the preceding and anticipated weather conditions, on public transport ridership should be further investigated using fine temporal resolutions to identify closer relationships between temporally variable weather events and travel behaviour. Lastly, the impact of COVID-19 on travel has led to consequential impacts on ridership as the opportunity to engage in remote work and education has increased. As a result, future studies may observe demonstrably different ridership patterns in response to weather events compared to the existing body of literature.

# 7. References

Acker, V. V., Wee, B. V. and Witlox, F. (2010) 'When Transport Geography Meets Social Psychology: Toward a Conceptual Model of Travel Behaviour', *Transport Reviews*, 30(2), pp. 219–240. doi: 10.1080/01441640902943453.

ACT Government (2017) *Household travel survey*. Available at: https://www.transport.act.gov.au/about-us/planning-for-the-future/household-travel-survey (Accessed: 6 July 2021).

ACT Government (2018) *ACT Planning Strategy 2018*. Environment, Planning and Sustainable Development Directorate. Available at: https://www.planning.act.gov.au/act-planning-strategy (Accessed: 6 July 2021).

Böcker, L., Dijst, M. and Prillwitz, J. (2013) 'Impact of Everyday Weather on Individual Daily Travel Behaviours in Perspective: A Literature Review', *Transport Reviews*, 33(1), pp. 71–91. doi: 10.1080/01441647.2012.747114.

Bureau of Meteorology (2019) *Canberra: Climate and water*. Available at: http://www.bom.gov.au/water/nwa/2019/canberra/climateandwater/climateandwater.shtml (Accessed: 6/7/2021).

Chapin, F. S. (1974) *Human Activity Patterns in the City: What do People do in Time and Space*. Toronto: John Wiley.

Clifton, K. J., Chen, R. B. and Cutter, A. (2011) 'Representing weather in travel behaviour models: a case study from Sydney, AUS', in. *Australasian Transport Research Forum (ATRF), 34th, 2011, Adelaide, South Australia, Australia*. Available at: https://trid.trb.org/view/1136195 (Accessed: 6 July 2021).

Cools, M. *et al.* (2010) 'Changes in Travel Behavior in Response to Weather Conditions: Do Type of Weather and Trip Purpose Matter?', *Transportation Research Record*, 2157(1), pp. 22–28. doi: 10.3141/2157-03.

De Palma, A. and Rochat, D. (1999) 'Understanding individual travel decisions: results from a commuters survey in Geneva', *Transportation*, 26(3), pp. 263–281. doi: 10.1023/A:1005121605832.

Guo, Z., Wilson, N. H. M. and Rahbee, A. (2007) 'Impact of Weather on Transit Ridership in Chicago, Illinois', *Transportation Research Record*, 2034(1), pp. 3–10. doi: 10.3141/2034-01.

Hägerstrand, T. (1970) 'What about people in Regional Science?', *Papers of the Regional Science Association*, 24(1), pp. 6–21. doi: 10.1007/BF01936872.

Khattak, A. J. and De Palma, A. (1997) 'The impact of adverse weather conditions on the propensity to change travel decisions: A survey of Brussels commuters', *Transportation Research Part A: Policy and Practice*, 31(3), pp. 181–203. doi: 10.1016/S0965-8564(96)00025-0.

Singhal, A., Kamga, C. and Yazici, A. (2014) 'Impact of weather on urban transit ridership', *Transportation Research Part A: Policy and Practice*, 69, pp. 379–391. doi: 10.1016/j.tra.2014.09.008.

Tao, S. *et al.* (2018) 'To travel or not to travel: "Weather" is the question. Modelling the effect of local weather conditions on bus ridership', *Transportation Research Part C: Emerging Technologies*, 86, pp. 147–167. doi: 10.1016/j.trc.2017.11.005.