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Public transport trends in Australia during the COVID-19 pandemic: An investigation of the influence of bio-security concerns on trip behaviour

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ARTICLE INFO
Keywords: COVID-19 Public transport Bio-security Working from home Australian evidence Patronage Concern

ABSTRACT
This paper draws on findings from an Australia-wide survey with data collected in three waves throughout 2020 to explore the impact of COVID-19 on public transport trends in metropolitan areas of Australia. Following consideration of the public transport sector response to the pandemic and the emerging literature context, we explore three principal questions: (i) How has weekly travel composition changed across the waves? (ii) How has level of concern with using public transport changed over the course of the pandemic given new bio-security concerns? and (iii) How has attitudes to risk been associated with the changes in PT use? A key finding is that concerns over bio-security issues around public transport are enduring, that concern about hygiene is significantly negatively related to public transport use and that those with higher concern about the hygiene of public transport also held higher concern about COVID-19 at work. Even as COVID-19 restrictions are eased, both concern about crowds and hygiene have a significant and negative correlation with public transport use. Concluding remarks are offered on what might need to happen for public transport patronage to start returning.

1. Introduction

This paper reports on an analysis of changing patterns of use and attitudes towards public transport, following the incidence of COVID-19. It has particular reference to bio-security concerns associated with public transport use among other factors, such as the tendency to work from home (WFH). The analysis is based primarily on data from a survey of household travel, working, and other activities such as shopping in Australia collected during the COVID-19 pandemic. We look at public transport trends during the pandemic with a focus on experience in the Metro regions of Australia. Data are drawn from three waves of data collection in 2020: Wave 1 (March); Wave 2 (June); and Wave 3 (September).

1.1. An overview of COVID-19 in Australia

Whilst Australia has recently been ranked number 8 in the world in terms of how COVID-19 has been handled based on a methodology that tracked COVID-19 case numbers in each country, as well as confirmed deaths and testing rates,¹ there have been unprecedented impacts on public transport patronage. Fig. 1 shows the aggregate mobility trends for Australia during 2020 derived from Apple mobility data. In aggregate we can see the sudden collapse in trip making by all modes from early to mid-March 2020 onwards as stay at home orders were implemented. Public transport use in Australia fell by about 80% (in some other locations the fall was greater still with New York reporting a 97% decrease in bus ridership by the end of April). Subsequently, the now familiar trend of car use rebounding much more quickly than public transport is apparent. In the case of Australia, from April to June public transport activity rebounded commensurate with the easing of restrictions, but a plateau was reached where from June to October use generally levelled out. This corresponds with the extended lockdown associated with the second wave of COVID-19 in Victoria from early July to late October. Public transport patronage growth continued again from the end of October but was impacted by the emergence of a new COVID-19 outbreak in Sydney in December 2020. The December outbreak in Sydney perfectly exhibits the vulnerability of public transport to public health concerns. Data provided by TfNSW shows that in Sydney, patronage in early December 2020 was at the highest levels since March’s lockdowns having returned to around 150,000 trips / day. However, only about 80,000 to 100,000 trips were taken during the peak morning and afternoon periods in Sydney on Monday 11th Jan

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https://doi.org/10.1016/j.jtrangeo.2021.103167
Received 19 March 2021; Received in revised form 25 July 2021; Accepted 16 August 2021
Available online 22 August 2021
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2021, when people would be expected to return to work after the summer break, which is less than half of the 200,000 to 250,000 trips on the corresponding day one year earlier.

The pattern of quick cessation in overall travel activity, followed by growth, and then a steady state for an extended period, exhibited by the aggregate Apple Mobility data (Apple 2020) shown in Fig. 1 is reflected in the disaggregate data we have collected over Wave 1 to Wave 3 (described in the section below on survey method).

2. Structure of the paper

Given the background of Australian experience with COVID-19 during 2020, this paper seeks to address three principal questions: (i) how has weekly travel composition changed across three survey waves? (ii) how has level of concern with using public transport changed over the course of the pandemic given new bio-security concerns? and (iii) how has attitudes to risk been associated with the changes in public transport use?

The paper is organised as follows: the next section provides an overview of the relevant literature, followed by a description of the survey tool and overview of the sample used in this paper. Following this the results are presented. The impact on trip making is considered through examination of changes in weekly travel composition. This is followed by investigation of concern about public transport which includes consideration of the relationship between concern about public transport and the use of public transport. Poisson regression is conducted to examine the role that bio-security concerns may have determining patronage. Finally, concluding remarks are offered on what might need to happen for public transport patronage to start returning.

3. Literature context

There is an emerging literature on COVID-19 and public transport. Several studies have taken a country-specific context. Eisenmann et al. (2021) in their analysis of experience in Germany during 2020, describe how public transport lost ground during times of greatest restriction while individual modes of transport became more important. They suggest that the long-term effects of increased concern about public transport (much of it explained by changed perceptions of “comfort”) and the new individual routines that citizens have adopted, now car-based in many cases, confirms the importance of health risk in reshaping transport demand.

The case of public transport in Poland is documented by Wielechowski et al. (2020) covering the first five months of the pandemic. Poland was one of the last European Union countries to experience the outbreak of COVID-19 and to date the experience has been relatively mild. Restrictions imposed by the government have however been severe. A key conclusion drawn, and one that resonates with the experience in Australia, is that government action (e.g., the implementation of forced lockdown) reduces public transport use more so than the perception of risk of the disease. In contrast to the Polish analysis Shibayama et al. (2021) adopt a multi-country approach in their analysis of changes in commuting patterns as a result of lockdown experiences in 14 countries. They find that among those who changed their commuting travel modes from public transport to other modes in response to COVID-19, avoiding risk of infection on public transport was their main reason for the change.

Many cities worldwide responded to their first lockdown by reducing service levels, particularly during peak hours (as an example DeWeese et al. (2020) report that public transport agencies across North America made significant adjustments to their services in the early months of the pandemic), this was much less prevalent in Australia, except for Perth which instituted a weekend timetable on its rail services. The decision to maintain services for essential workers and people without access to a car has served to emphasise the essential role of public transport for some citizens. To encourage a return to public transport discounted off-peak fares were introduced in Sydney from 6th July 2020 (a 50% discount for 3 months, reducing to a 30% discount thereafter), accompanied by slightly extended peak hours. A 30% off-peak discount has been introduced in Melbourne from January 2021 as part of a policy to encourage people to return to the workplace which may involve staggered start and finish times.

Measuring customer attitudes towards level of service has traditionally been a fertile area for research. Beck and Rose (2016), reiterating that the measurement of attitudes is relied on by public transport authorities the world over, proposed a dual version of best–worst scaling as an alternative measure of satisfaction. Such an approach is ideal for handling the comparative evaluation of a large number of attributes. Beck and Rose (2016) conducted a survey of bus users in Sydney, and it is interesting to note (and especially because this work was completed in a pre-COVID-19 context) that they found that the level of crowding and cleanliness of the bus stops at both ends of the journey, as well as having shelter at the end of the trip, all exhibited large positive correlations between satisfaction and importance. Somewhat preciently, given the context of the pandemic, Beck and Rose (2016, p121) suggest that the implications of “crowding may be something that needs to be emphasised by operators and that perhaps further research may be needed into what constitutes crowding and why those who find it

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**Fig. 1.** Aggregate mobility trends: Australia during 2020.  
Data source: https://covid19.apple.com/mobility
important are satisfied with the level of crowding”.

Dong et al. (2021), based on their cross-sectional study of eight Chinese cities, note that there is limited detailed understanding of how passengers’ perception of safety, as perceived in a public health crisis is influencing feelings of satisfaction towards public transport. They find that an individual’s state anxiety (a transient response that can cause feelings of apprehension) influences perception of public transport safety and may linger for months. The role of traveller information is thus an important measure in reassuring passengers and information about on-board crowding conditions has become increasingly available during the pandemic. Passenger reluctance to ride a crowded vehicle has been shown to be much higher in the pandemic than previously reported (Tirachini and Cats, 2020).

Whilst the link between public transport and the spread of COVID-19 is uncertain (Shibayama et al., 2021) there is evidence from Australia that the level of risk from public transport depends on the number of cases circulating in the community (Barrett, 2020). In their multi-country survey, Shibayama et al. (2021) report that 70 to 80% of respondents from Austria, Bulgaria, Germany, Hungary and Japan who changed their commuting travel modes from public transport to other modes referred to risk avoidance as their main reason for the change. Drisi and Dei (2020) note there is evidence from an operator perspective that policy on using masks in public transport has been more difficult to enforce (a contrast with policy on physical distancing). The compliance level associated with mask wearing has not been helped by conflicting official “messaging” around safety across jurisdictions (Nelson, 2021). Masks have been mandatory for public transport users in Melbourne in July 2020 (and in London from June 2020) but were only “strongly recommended” in Sydney until they became mandatory on 4th January 2021. Greater clarification would be helpful for commuters particularly as concerns around transmission of the virus continue (Dong et al., 2021). Recent experience from Switzerland, though, suggests that there is not a strong relationship between mask use and public transport patronage.

Other safety-related measures include increased cleaning measures, a shift to rear door boarding on buses and marshalling of queues of intending public transport passengers to maintain physical distancing and on-board vehicles. In Sydney “No dot, no spot” was introduced to indicate the safest places to sit and stand although Australian cities did not institute temperature checks for public transport users. In many locations across the world, journey planners have been modified to help travellers plan their journeys more safely by showing whether physical distancing can be observed (e.g., TfLGo has been introduced to help main physical distancing and help “get London moving again, safely and sustainably”); and COVID-19 travel advice web pages have become readily available.

A justification of the analysis of the effect of risk upon public transport utilisation lies in its relevance to managing future crises. Tardivo et al. (2021) propose an agenda based around five “R”s—resilience, return, re-imagination, reform, and research. Dong et al. (2021) argue that a better understanding of factors affecting passenger satisfaction, and particularly the perception of safety, can aid future disaster emergency management. Overall, it is clear is that public transport users are concerned about the health risks associated with public transport and this motivates the exploration of the trends in level of concern with public transport and its impact on use in this paper.

4. Survey method and sample

Fig. 2 provides the 7-day rolling average of new COVID-19 cases in Australia from January 2020 through to the start of December 2020, covering the key time periods where survey data was collected. Additionally, the Oxford Government Stringency Index is also charted (OxCGRT, 2021), to highlight the government response in Australia in dealing with COVID-19.

By mid-March 2020, it had become apparent that the COVID-19 disease, the result of the SARS-CoV-2 virus, was unlike any flu-like epidemic seen previously. In response to the rising threat, the Australian Federal Government began instituting a series of public health measures to curb COVID-19 infections, chief among which included closing the national borders to travel from 17th March, through to instituting a series of lockdown style measures on 23rd March, which reached a peak on 29th March with health orders issued by states restricting all movement with the exception of shopping for essentials; medical or compassionate needs; exercise in compliance with the public gathering restriction of two people; and for work or education purposes. Wave 1 of the survey entered the field at this point in time, gathering insight into the behaviour of respondents in the context of the first spike in COVID-19 cases in Australia.

Following four weeks of this lockdown, state governments in Australia began to ease restrictions (at a differing pace), following the decline in the average number of new cases to less than 20 a day nationwide. After an approximately two-month period of low case numbers, with large parts of the country having all but eliminated COVID-19 (to a large extent the disease was only circulating in Sydney and Melbourne), Wave 2 was collected from late May to early June following this relatively settled period where freedoms of movement were starting to return and many social activities were allowed. Importantly, during this time in many jurisdictions, the public health order that firms must allow those who can work from home to do so wherever practicable was still in effect.

By the end of June, not long after Wave 2 came out of field, it became apparent that COVID-19 was beginning to spread at an alarming rate in the city of Melbourne as a result of the disease escaping hotel quarantine. On 2nd August a state of disaster was declared, and metropolitan Melbourne was placed into a curfew from 8 pm to 5 am, in addition to an order that people must not travel beyond a 5 km radius of their home, with a permit required for those that still needed to travel to work outside of their 5 km radius. Wave 3 went into the field on 7th August and data collection was maintained up until the first week of September 2020.

The profile of each wave of data collection is shown in Table 1. The sample is broadly representative of the Australian population, though Wave 2 and Wave 3 have a relatively higher proportion of females. It should be noted that the Australian Bureau of Statistics (ABS) calculation of income is for all individuals 15 years or older, however the data collected by this project only includes individuals who are 18 years or older, which may explain some of the discrepancy in personal income. Additionally, where we define having children the ABS rather define a family, which includes any of the following categories: couple family without children; couple family with children; one parent family; other family. For the purposes of this paper examining the impact of COVID-19 on public transport, only respondents who live in a metropolitan area are used (as meaningful public transport alternatives only exist in such areas in Australia). An overview of findings is reported in Beck and Hensher (2020a) for Wave 1 and Beck and Hensher (2020b) for Wave 2.

It should be noted that each survey was conducted online making use of an online consumer research panel. The sampling strategy was such that respondents from previous waves were extended invitations to complete subsequent waves of the survey a few days in advance of main recruitment when new respondents were also invited to complete the survey. In this analysis, however, we treat the data as repeated cross-sectional data.

5. Results

5.1. Impact on trip-making

In this section we briefly look at disaggregate trends from the survey

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2 Personal communication from Kay Axhausen of ETH.
data to see how weekly travel composition changed across the three waves of the survey. Fig. 3 shows the average trips by mode (private car versus total public transport trips made), for respondents living in metropolitan regions of Australia. The slow return to use of public transport as seen in Fig. 1 is replicated: among all respondents, an average of 5.4 trips / week by all public transport (train, bus and ferry) was reported before the pandemic, a figure which has recovered to only 2.7 trips / week during Wave 3. The stronger recovery of active modes was also exhibited in Fig. 1 and this has been widely encouraged in many jurisdictions through provision of measures to support active travel (ITF, 2020; Shibayama et al., 2021).

With respect to trip purpose, while commuting is still suppressed (up until late 2020 the health order requiring those staff who are able to work from home be allowed to do so was still in effect for the largest two metropolitan centres of Sydney and Melbourne), there are signs that commuting is a trip-making activity returning more strongly, especially in Wave 3 where it was 50% of the before COVID-19 levels. Work business trips by public transport have returned to 60% of before COVID-19 levels but for most other trip purposes the recovery is slower. A steady return to the use of public transport for food shopping demonstrates the essential nature of public transport for some travellers. By way of background, respondents who list public transport as their main mode for commuting are more likely to be those who work for large businesses (200+ employees), have the ability to work more days from home, have a positive attitude towards more flexible work in the future, have greater concern about COVID-19 in the workplace, are less concerned about COVID-19 as a risk to health, have lower incomes, are younger, and live further away from work.

5.2. Bio-security concern about public transport

In this study, an attitude to risk is incorporated via passenger concerns about the hygiene of public transport modes in two ways. First, in Wave 1, 2 and 3 a proxy measure, relating to the fear of infection is used, while in Wave 3 the volume of people currently using public transport is also used as a proxy for the difficulty of maintaining physical distance from fellow travellers. Both measures emerged as a clear concern for
public transport travellers during the pandemic as can be seen in Fig. 4 which charts responses to the question “What would be your level of concern about hygiene on public transport today?”

As would be expected there is a dramatic difference in the concern about hygiene on public transport before COVID-19 and immediately after the first outbreak at Wave 1 in early to mid-April 2020 (the blue and orange lines are almost diametrically opposed). Concern in Wave 2 (late May to mid-June) had diminished, but still more than half the number of respondents reported moderate to extreme concern. While concern has decreased between the two Waves (consistent with an easing of conditions) average concern still remains at a level that is appreciably higher than that prior to COVID-19; 60% of respondents were extremely or moderately concerned at Wave 2 compared to 17% before COVID-19. Levels of concern remained largely unchanged from Wave 2 to Wave 3 (when the survey was in the field from early August to early October; thus, encompassing the second wave in Victoria). It might be expected over time that results could be influenced by the availability of better information. At the beginning of the pandemic, contagion through surfaces was deemed to be much more prevalent than today, when it has been established that air is the most critical path of virus spreading. In September 2020 the NSW Transport Minister announced that one million extra cleaning hours on public transport had been reached since the start of the pandemic. Thus it is expected that the relevance of cleaning surfaces has changed in the perceptions of people.

It is interesting to look at changes in the level of concern over time based on broad socio-demographics.

- **Before COVID-19**: There were no differences based on gender or income, however older respondents reported significantly less concern about the hygiene of public transport.
- **Wave 1**: There were no differences based on gender; however older respondents now reported significantly more concern about the hygiene of public transport (the reverse of before COVID-19), as did those on higher incomes.
- **Wave 2**: Males reported significantly less concern about public transport hygiene, older respondents continued to report significantly higher levels of concern, and income no longer discriminated between differing levels of concern.
- **Wave 3**: Neither gender, nor age, nor income was significant in differentiating between levels of concern.

In anticipation that confidence with using public transport might
Correlation between Concern about Public Transport and Trip Behaviour

In order to examine the possible influence of level of concern about public transport on trip-making behaviour in each wave of data, the correlation between the reported concern about public transport and the use of public transport was examined (Tables 2-4). The Wave 2 and Wave 3 survey also included a question about COVID-19 and the workplace (“How concerned are you today about COVID-19 and work, given the environment that you normally work in?”), and the correlation with this variable was also examined.

There was no correlation between concern about public transport and public transport use before COVID-19 or during the Wave 1 survey; however, there is a significant albeit weak positive correlation with concern during Wave 1, which indicates that a respondent who held a higher degree of concern before COVID-19 also held a higher degree of concern after the initial outbreak. The level of concern before is not related to any observed change in the amount that someone uses public transport.

Table 2
Correlation between Concern about Public Transport and Total Trips – Wave 1.

|                  | Total PT Use - Before | Hygiene Concern - Wave 1 | Total PT Use - Wave 1 | Change in PT Use |
|------------------|-----------------------|--------------------------|-----------------------|-----------------|
| Hygiene Concern - Before | –0.05                 | 0.23*                    | –0.003                | –0.07           |
| Total PT Use - Before | –                     | –0.11*                   | 0.54*                 | 0.82*           |
| Hygiene Concern - Wave 1 | –                     | –                        | –0.12*                | –0.09*          |
| Total PT Use - Wave 1 | –                     | –                        | –                     | 0.10*           |

Diminish again rather than continue to improve as more transport users return to the system, in Wave 3 a further question about concern regarding the number of people using public transport was added in addition to the question about concern with hygiene of public transport. The respondents’ expressed concern about the numbers of people (i.e. crowding) almost exactly mirrors that of concern about hygiene with 54% of respondents indicating that they were extremely or moderately concerned (Fig. 4).

5.3. Correlation between public transport concern and trip behaviour

Concern about hygiene is significantly negatively related to public transport use in Wave 2, indicating those with higher concern used public transport less during the Wave 2 period, as might be expected. In Wave 2, a question was included about respondents concern with the rise of COVID-19 in the workplace. We find a significant and strong positive correlation between both variables indicating those with higher concern about the hygiene of public transport also held higher concern about COVID-19 at work; again this is not unexpected.

As noted above in Wave 3, a further question about public transport was asked, examining the concern held about the numbers of people using public transport during the pandemic (“Imagine you had to catch public transport tomorrow, what would be your level of concern about the number of people using public transport?”). Unsurprisingly, there is a significant and strongly positive correlation between concern about crowds and concern about hygiene. As a result, factor analysis was used to reduce these two variables into one underlying latent factor termed “PT Concern”. Both concern about crowds and hygiene have a significant and negative correlation with public transport use during Wave 3 and are both positively correlated with concern about COVID-19 and the workplace. The PT Concern latent factor has a significant and strongly positive correlation between concern about public transport also hold concern about COVID-19 and the workplace, as indicated by the positive and significant correlation between these two variables.

5.4. A note on attitudes

Across the waves of data collection, respondents were given a differing series of attitudinal statements around perceptions of COVID-19 and associated business and government response were asked, as well as questions around the level of comfort respondents felt in engaging in different social and recreational activities, and also their experiences with working from home during the pandemic (where relevant). Prior to estimating models of public transport use, exploratory factor analysis was conducted to identify latent variables that, while not directly observed, could be inferred by the attitudinal indicators used. It was found that attitudes to COVID-19 were a function of three latent constructs (termed “Institutional Response”, “Societal Response” and the “Impact of COVID-19”) in Wave 1, but only two in subsequent waves (“Institutional Response” and “Societal Response”), comfort in activities were inferred by two latent constructs (“Large Group Comfort” and “Small Group Comfort”), and working from home attitudes driven by two latent factors (“Current Experience” and “Future Intentions”). More information on these attitudinal statements and analysis can be provided upon request.

Table 3
Correlation between Concern about Public Transport and Total Trips – Wave 2.

|                  | Total PT Use - Wave 2 | Work Concern - Wave 2 |
|------------------|-----------------------|-----------------------|
| Hygiene Concern - Wave 2 | –0.171*               | 0.515*               |
| Total PT Use - Wave 2 | –                     | 0.081*               |

Table 4
Correlation between Concern about Public Transport and Total Trips – Wave 3.

|                  | Crowding Concern - Wave 3 | Total PT Use - Wave 3 | Work Concern - Wave 3 | PT Concern Factor |
|------------------|---------------------------|-----------------------|-----------------------|-------------------|
| Hygiene Concern - Wave 3 | 0.869*                   | –0.148*               | 0.404*               | 0.977*            |
| Crowding Concern - Wave 3 | –                       | –0.134*               | 0.353*               | 0.952*            |
| Total PT Use - Wave 3 | –                        | –                     | 0.117*               | –0.151*           |
| Work Concern - Wave 3 | –                        | –                     | –                    | 0.394*            |

Societal Response

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5.5. Influence on public transport use

Further analysis is conducted to examine the role that bio-security concerns may have in determining patronage. A Poisson regression is used to predict a dependent variable that consists of “count data”. In an extension of this model type, the zero-inflated Poisson regression is used to model count data that has an excess of zero counts. Further, theory suggests that the excess zeros are generated by a separate process from the count values and that the excess zeros can be modelled independently. In the data on use of public transport, through Wave 1, Wave 2 and Wave 3, there are many respondents who make zero trips using public transport; hence the zero-inflated Poisson is chosen. Each model estimated is compared to an unaltered Poisson regression, and in every instance the zero-inflated (ZIP) model is found to perform significantly better than the Poisson regression.

Table 5
Explaining public transport use (Count Model Coefficients).

|                      | Before COVID-19 | Wave 1 | Wave 2 | Wave 3 |
|----------------------|-----------------|--------|--------|--------|
|                      | Par. t.value    | Par. t.value | Par. t.value | Par. t.value |
| (Intercept)          | -0.37 -1.18     | 2.41 13.40 | 1.89 10.95 | 0.50 2.45 |
| Days worked in week  | 0.23 7.46       | -0.03 -1.72 | --- --- | --- --- |
| Days worked from home| -0.18 -5.97     | 0.04 2.50 | 0.22 10.92 | -0.05 -3.71 |
| White collar occupation| -0.36 -3.46   | -0.38 -7.45 | 0.28 4.28 | 0.28 5.31 |
| Medium size business (20-199 employees) | na na na na | na na | na na | --- --- |
| Large size business (200 plus employees) | na na na na | na na | na na | --- --- |
| All my work can be done from home (Y) | na na na na | na na | na na | --- --- |
| Have my own space at home to work (Y) | na na na na | --- --- | --- --- |
| Main commute mode is public transport | 0.39 7.98 | --- --- | 0.65 11.76 |
| Relative productivity of work from home | --- --- | --- --- | --- --- |
| Concern about COVID-19 in the workplace | na na na na | -0.11 -4.48 | 0.18 6.01 |
| Current WFH Experience (latent factor) | na na na na | -0.10 -2.51 | -0.25 -5.49 |
| Future WFH Intentions (latent factor) | na na na na | -0.18 -4.74 | -0.29 -6.93 |
| Overall Comfort with Activities (latent factor) | na na na na | 0.31 9.26 | na na |
| Comfort with Large Group Activities (latent factor) | na na na na | 0.06 1.91 |
| Comfort with Small Group Activities (latent factor) | na na na na | na na | na na | 0.26 7.82 |
| Institutional Response (latent factor) | --- --- | --- --- | --- --- |
| Societal Response (latent factor) | -0.32 -6.87 | --- --- | -0.27 -8.21 | -0.16 -5.70 |
| Impact Evaluation (latent factor) | -0.34 -5.96 | -0.07 -2.60 | na na | --- --- |
| Risk of COVID-19 to health of someone known | -0.06 -2.57 | --- --- | --- --- | 0.12 8.45 |
| Risk of COVID-19 to health of general public | -0.07 -3.35 | -0.07 -4.45 |
| Risk of COVID-19 to own health | --- --- | --- --- |
| How long until life returns to something like "normal" | na na na na | --- --- |
| How ready is Australia to combat a future pandemic | na na na na | na na | na na | 0.10 5.46 |
| Satisfaction level with life nowadays | na na na na | --- --- |
| How worthwhile are the things you do in life | na na na na | --- --- |
| How happy did you feel yesterday | na na na na | 0.04 2.98 | 0.03 2.58 |
| How anxious did you feel yesterday | na na na na | 0.06 4.89 | 0.03 3.24 |
| Gender (male = 1) | --- --- | 0.34 5.21 | 0.28 5.82 |
| Income ($'000) | 0.01 7.32 | --- --- | 0.00 9.05 | -0.45 -7.83 |
| Age | --- --- | -0.01 -8.34 | -0.03 -9.67 | 0.01 4.73 |
| Concern about public transport hygiene - Before | 0.28 4.66 | --- --- | na na na na |
| Concern about public transport hygiene - Survey Wave | 0.09 3.98 | 0.14 5.19 | 0.31 7.30 |
| Concern about public transport crowds - Wave 3 | na na na na | na na | -0.26 -7.17 |
Better. The results of the models on each of the waves are shown in Table 5 (count model coefficients) and Table 6 (zero-inflated model coefficients). Within the tables (---) indicates a variable that was trialled but found to be statistically insignificant, and (na) indicates a variable that was not present in that survey wave and thus could not be used.

The ZIP model has two components: the count model which predicts increases or decreases in the use of public transport (not directly via the number of trips, rather changes to the odds of having higher number of trips), and the zero-inflation model which predicts membership of the zero group (i.e., the odds of not using public transport at all).

Findings relevant to explaining the role that bio-security concerns may have determining patronage may be summarised as follows:

- Before COVID-19 results from the zero-inflation model show that those who expressed concern about public transport hygiene as a result of COVID-19 have a higher probability of not using public transport before COVID-19. Those who use public transport as their main mode, obviously, have a lower probability of not using public transport, which represents the captive nature of public transport users.
- The count model coefficients show that individuals who express higher levels of concern about public transport hygiene both before COVID-19 and during the Wave 1 time period are more likely to be making a higher number of trips. It is perhaps more likely that higher public transport use and thus greater exposure, is driving the attitudes around hygiene and risk, rather than the other way around (i.e., those that use public transport a lot would be expected to be more concerned about its hygiene, particularly if they must use it, which is likely the case).
- The zero-inflation model indicates that those who express concern about the hygiene of public transport during the time of data collection, all have higher odds of making zero public transport trips in the last week during Wave 1.
- The count model coefficients show that individuals who express greater concern about public transport hygiene during Wave 1 have a greater chance of making more trips.
- In Wave 2, the positive coefficients in the zero-inflated model indicate that those who express concern about public transport hygiene have greater odds of making no public transport trips.
- The count model coefficients indicate that those who expressed higher concern about public transport hygiene were among the types of respondents more likely to make a higher number of public transport trips in Wave 2; thus reflecting the captive nature of some public transport users.
- In Wave 3 the zero-inflation component of the model indicates that respondents with a higher Concern about Public Transport (hygiene and crowds) latent factor have higher odds of not making public transport trips.
- The count model coefficients indicate that those who express greater concern about public transport crowd numbers in Wave 3 are more likely to make fewer public transport trips.

There is an interesting finding in Wave 3 that is somewhat similar over all the waves, in that those that express concern about public transport are more likely to not use it, but among those that do use it those who have higher concern about hygiene are more likely to make more trips. This suggests that they are captive travellers who are potentially having to use the mode to get around (typically commute), perhaps because of this feel they are more at risk, so are perhaps more concerned than others. It would also seem that it is perhaps more the numbers of other people that act as a barrier (crowding), than hygiene alone. Perhaps this also translates to the perspective that COVID-19 is of greater risk to them. The presence of captive travellers is also evidence of the value of public transport as an essential service.

6. Discussion and conclusions

This concluding section discusses the main trends and changes across the three waves with respect to changing levels of use and concern about public transport and considers some of the responses that may be required for a sustained return of public transport patronage.

| Table 6 | Explaining Public Transport Use (Zero-Inflation Poisson Model Coefficients). |
|---------|--------------------------------------------------------------------------------|
| Before COVID-19 | Wave 1 | Wave 2 | Wave 3 |
| (Intercept) | Par. | t.value | Par. | t.value | Par. | t.value |
| White collar occupation | 0.89 | 2.40 | --- | --- | --- | --- |
| Main commute mode is public transport | -2.16 | -5.87 | -2.90 | -9.41 | -2.68 | -8.94 |
| Days worked from home | --- | --- | --- | --- | 0.43 | 3.59 |
| Relative productivity of work from home | na | na | na | na | -0.44 | -3.25 |
| All my work can be done from home (Y) | na | na | na | na | 0.76 | 2.55 |
| Institutional Response (latent factor) | --- | --- | --- | --- | 0.46 | 3.54 |
| Overall Comfort with Activities (latent factor) | na | na | na | na | -0.37 | -2.65 |
| Future WFH Intentions (latent factor) | na | na | na | na | 0.38 | 2.00 |
| Risk of COVID-19 to own health | --- | --- | --- | --- | -0.22 | -2.99 |
| Risk of COVID-19 to health of general public | --- | --- | --- | --- | -0.21 | -2.19 |
| How worthwhile are the things you do in life | --- | --- | --- | --- | 0.12 | 2.03 |
| Age | 0.03 | 2.55 | 0.01 | 1.82 | 0.02 | 1.85 |
| Gender (male = 1) | --- | --- | --- | --- | --- | --- |
| Concern about public transport hygiene - Survey Wave | 0.31 | 1.73 | 0.23 | 1.71 | 0.55 | 4.26 |
| Public Transport Concern (hygiene and crowds latent factor) | na | na | na | na | 0.64 | 4.29 |
| Concern about COVID-19 in the workplace | na | na | na | na | -0.31 | -2.62 |
6.1. Concern about public transport and influences on use

The correlation results confirm that, generally speaking, until the onset of COVID-19 concern about public transport hygiene was not an issue that traditionally featured highly as a factor affecting perception of quality of service. Concern about hygiene is significantly negatively related to public transport use in Wave 2, indicating those with higher concern used public transport less during the Wave 2 period, as might be expected. In Wave 2, we find a significant and strong positive correlation between both variables indicating those with higher concern about the hygiene of public transport also held higher concern about COVID-19 at work; again this is not unexpected. Unsurprisingly, there is a significant and strongly positive correlation between concern about crowds and concern about hygiene. Both concern about crowds and hygiene have a significant and negative correlation with public transport use during Wave 3 and are both positively correlated with concern about COVID-19 and the workplace. The public transport concern latent factor has a significant and negative correlation with public transport use in Wave 3 also indicating that those with high concern about public transport during Wave 3, used public transport less during this time period. The regression model results provide further insights. The zero-inflation model coefficients are used to explain use versus no use of public transport. Concern about public transport is consistently positive over all waves with more concern translating into more likely to make zero trips.

The count model coefficients are used to explain the number of trips if public transport is used. Results show that concern about public transport exhibits consistent positive impact across all waves with higher concern equating with more trips; this could be an indication of captive use and an awareness by travellers that they may be more at risk because of their use of public transport.

6.2. Implications for public transport operations and policy

Given the experiences of 2020, it may not be a surprise if we see some serious rethinking of public transport planning and delivery. The pandemic has been a reminder of how important public transport is as a crucial part of society’s basic infrastructure, especially for those for whom public transport is their essential means of transport. In particular, the concern over bio-security issues around public transport use are enduring (Fig. 4). Our findings also show that travellers are as concerned about crowding levels on public transport as they are about hygiene. As a result, it may be that public perception will force operators to revise what is considered an acceptable capacity in public transport vehicles; for example, the ability to reserve a seat on certain services (perhaps over a certain trip length) could provide a more personalised and safer experience. Similarly, Gkiotsalitis and Cats (2020) suggest that the physical distancing measures introduced to combat the virus spread call for focusing on the need to avoid crowding by distributing passenger demand as evenly as possible in both time and space. This, they suggest, can be attained by means of re-designing services, re-allocating resources and re-distributing passenger flows. In subsequent work Gkiotsalitis and Cats (2021) have developed a frequency planning model, using the Washington D.C. metro as a case study that can be applied when the passenger demand has almost returned to its pre-pandemic levels yet public transport operators need to comply with the social distancing regulations to avoid the spreading of the virus.

Crowding on public transport must be mitigated as people increasingly return to using public transport. Crowding management via both physical and digital means is identified as a priority by Tirachini and Cats (2020) in their proposed future research agenda to promote the recovery of public transport. The flattening of the peaks (as a result of WFH) can save resources that might be used to strengthen the basic, off-peak transport services. But whereas we might have thought that we now have plenty of public transport capacity, it may be the opposite if we want to control crowding and hence future operations will need more capacity which could be a challenge for trains more than buses given track capacity limits. We need to rethink traditional approaches to peak vehicle availability. Those working from home have the flexibility to use public transport selectively and should be encouraged to do so. However, since there is no guarantee that subsequent local outbreaks of COVID-19 (as witnessed in both Melbourne and Sydney during both 2020 and 2021) will not occur and given the enduring nature of bio-security issues shown by our study, adaptation strategies must be sufficiently robust to cope with future outbreaks (Gkiotsalitis and Cats, 2020).

The issue of ventilation has been shown to be important as knowledge of COVID-19 has improved and must also be addressed by public transport operators. Since the virus is now known to spread through aerosols as well as droplets, maintaining airflow inside enclosed areas, while avoiding overcrowding, is important (Morawska and Milton, 2020). Shen et al. (2020) describing a series of precautionary measures to prevent the spread of COVID-19 within public transport vehicles highlight the importance of enhanced ventilation noting that mechanical ventilation can be adapted to clean air and that windows should be opened at low speeds or when a vehicle is stopped. This is echoed by Vuorinen et al. (2020) who, as a result of detailed simulations of aerosol transmission indoors, emphasise the risk posed by crowded public transport and that operators should pay careful attention to passenger densities and ventilation.

What does this mean for future policy? No government policy can attract unlimited funding and so it is clear that there must be a limit to the support given to public transport when patronage is so low. However, a future that maintains the pandemic’s response of lower service levels and lower quality will not only reduce equity but also lead to a downward spiral in public transport demand. Differential pricing of both public transport (and private car traffic), such as the 30% off-peak discount introduced in Melbourne from January 2021 as part of a policy to encourage people to return to the workplace by public transport, can be implemented to stimulate patronage growth. But public transport planners need to be innovative in the way they look forward. Innovative technology could bring the offers of different mobility providers together. Public transport contracts could become ‘mobility contracts’ forcing public transport operators to think about how to provide the mobility required, using a mixture of vehicle sizes and modes (Hensher, 2017). Vickerman (2020) makes a fundamental point arguing that urban transport and particularly commuting will need to be planned as a whole if public transport systems are to recover.

We will not fix public transport by concentrating only on the supply side. In Australia, where there are less COVID-related restrictions, the travel patterns being exhibited suggest that public transport customers have become both more adaptable and less predictable, probably as a result of the greater flexibility as to where and when they work, which has been supported by the breaking of managerial resistance to WFH (Beck and Hensher, 2021). As a result, a more personalised transport offer with elements of flexibility, supported by journey planning tools to facilitate COVID-safe travel, for example with information about crowding on public transport vehicles, should be expected to be seen as more attractive. In some locations it may be more efficient to run flexible and demand responsive services instead of conventional fixed route bus services on a larger scale to reflect this new demand.

This study has confirmed the enduring concern over public transport hygiene and crowding and like other studies (e.g. Shibayama et al., 2021) has confirmed that a major issue is bio-security and that public transport during COVID-19. Thus, it is imperative that all forms of public transport are supported by clear messaging from Government and operators to build confidence in using and remaining loyal to public transport.³ Such

³ Such as provided in New South Wales: https://transportnsw.info/covid-19/covid-19-what-you-can-do-#accordian-maintain-physical-distancing-content
an approach can reasonably be expected to reduce the level of concern associated with public transport use. As Tirachini (2020) notes, associating public transport indefinitely with the spread of coronavirus (as many official statements have done) will condemn it to be used only by those who have no choice.

Acknowledgments

This research is part of iMOVE Cooperative Research Centre (CRC) funded research projects 1-031 and 1-034 with Transport and Main Roads, Queensland (TMR), Transport for New South Wales (TNSW) and WA Department of Transport (WAdT) on Working for Home and Implications for Revision of Metropolitan Strategic Transport Models. The findings reported are those of the authors and are not the positions of TNSW or TMR; but approval to present these findings is appreciated. We also thank Andre Pinto of ITLS for his role in the iMOVE projects. We thank a referee and Kevin O’Connor, Associate Editor, for extensive comments and suggestions.

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