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Spatial Impacts of COVID-19 on Long Term Commuting in Melbourne

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Abstract

Although much research now concerns the impact of COVID-19 on travel, only a handful of studies have been based on individual cities. Few of these have explored variations in patterns in different geographic regions of cities or whether COVID-19 is having a long-term effect on future travel patterns.

This paper explores spatial patterns in the long-term post-pandemic impacts of the COVID-19 pandemic on travel within different parts of Melbourne, Australia. It considers long-term travel related behaviours and their impacts on travel after the virus has gone for inner, middle and outer parts of the city; the spatial focus of this paper. The research is based on an online survey of self-reported expectations of travel of residents when the virus is no longer a problem. The survey is designed to address 'under reporting bias' common in online surveys.

Several major spatial patterns of the long-term impact of COVID-19 on commuting were established. Post-pandemic reductions in commuting as a result of increases in working from home were found to be particularly large for inner Melbourne. A mode shift from public transport to other modes, mainly car driving, as a result of infection fear also occurs post-pandemic. This is larger for inner Melbourne where alternatives such as bike and walk are more feasible for commuting. In percentage terms, post-pandemic bike use increases considerably in all regions, but particularly for inner Melbourne where the volume of cycling to work will more than double. Overall, long term car ownership is likely to decline but car use increase. Inner Melbourne demonstrates the highest expected post-pandemic declines in ownership and increases in expected use. Finally, evidence suggests COVID-19 will result in peak spreading. This will be larger for middle and inner Melbourne than outer Melbourne.

Implication of findings for practice and research futures are discussed.

1. Introduction

The COVID-19 pandemic has seen significant shifts in local travel behaviour in cities. A range of research has explored reductions in travel during the pandemic Bucsky (2020); (Jenelius & Cebecauer, 2020; Molloy et al, 2020). Much less research has explored what travel might look like after the virus has gone and most of these have focussed on long-term Work From Home (WFH) behaviours (de Palma & Vosough, 2021; Lennox, 2020; Musselwhite et al, 2021).

The geographic perspectives adopted for published research on COVID-19 and local travel have been very limited to date. Most research discusses travel impacts at a very strategic/high level. There have been a large number of national studies e.g. Belgium (Baert et al, 2020), Germany (Anke et al, 2021) and even an International study (Medimorec et al, 2020). Surprisingly few researchers have explored travel in individual cities, but examples include Sapporo (Arimura et al, 2020), Tokyo/Nagoya and Osaka (Dantsuji et al, 2020), Toronto (Dianat et al, 2021), Santiago (Gramsch et al, 2020), Budapest (Bucsky, 2020), Chicago (Shamshiripour et al, 2020) and the authors own research in Melbourne (Currie G et al, 2021; Jain T et al, 2022). Yet even city-based studies have explored changes in local travel at a generally aggregate level.

A major gap in published research on COVID-19 and local travel is that there is limited coverage of geographic variation on impacts within cities. In addition, the research that does cover geographic detail tends to explore only travel patterns during COVID-19. Almost no published research considers geographic patterns of COVID-19 as they affected travel within cities from a long-term post-pandemic perspective.

This paper explores spatial patterns in the long-term post-pandemic impacts of the COVID-19 pandemic on commuting within different parts of a city. Melbourne, Australia, is the focus of the research which considers long-term travel related behaviours and their impacts on commuting after the virus has gone for inner, middle and outer parts of the city; the spatial focus of this paper. The research focusses on an online survey of self-reported expectations of commuting of residents when the virus is no longer a problem. A major feature of the survey is use of a robust survey sampling approach to remove under-representation bias, which is typical in online surveys, to ensure results are representative of the population.

The paper is structured as follows: the next section reports on the context for the research including an outline of published evidence to date regarding the spatial effects of COVID-19 on travel within cities. It also provides a background to Melbourne, the focus of the research, and how COVID-19 has impacted commuting in the city. The research approach is then outlined. Results are then presented followed by a discussion and conclusions which outline the implications of the research for practice and research futures.

2. Research Context

2.1. Travel Impacts of COVID-19

During the pandemic, most studies have reported considerable reductions in travel, notably during lockdowns, and some degree of return of activity as restrictions ease (e.g. Astroza et al, 2020; Jenelius & Cebecauer, 2020). The scale of reported impacts during the pandemic varies widely by city/study. Much of the published behavioural studies focus on increases in WFH during the pandemic (e.g. Shamshiripour et al, 2020). The few studies that have explored the long-term effect of the pandemic have almost exclusively focussed on WFH behaviours. For example, 63% of respondents of a survey in Belgium hoped for more teleworking in the future (Baert et al, 2020). In the Netherlands 37% of a national study wanted to increase WFH post-COVID although 18% did not expect that to be possible (Rubin et al, 2020).

2.2 Geographical Variations in Urban Travel Due to COVID-19

In general, most published research in the field lacks geographic detail on variations of travel behaviours within cities. Table 1 synthesises details of the available studies covering cities that report some degree of geographical detail. Most studies cover travel during the pandemic, and the main geographic variations identified are:

- Central Activity Areas/Central Business Districts (CBD) have larger reductions in activity than other parts of the city; a fairly consistent result in diverse contexts,
- Public transport use declines more than other modes including larger reductions in central area stations/services; several studies link this to infection fear; again a fairly consistent result between cities, and
- General increases in WFH which affect higher income cohorts/areas more than lower income cohorts/areas.

Only a few urban studies consider post-pandemic behaviours; those that do suggest that public transport ridership will return, but not entirely. Infection fear is likely to have a long-term lingering effect, with a return to public transport use also linked to vaccination rates.

2.3 The Authors' Melbourne Research

Table 1 (bottom) also reports some of the authors research on COVID-19 related impacts on travel in Melbourne (reported in detail in Currie G et al, 2021). This is directly relevant to this paper since we report geographical variation in travel within the city in this paper; however aggregate city-wide patterns of behaviour are also of interest and can assist in better understanding geographic variation. During the pandemic significant reductions in travel in Melbourne are reported including a 90% reduction in public transport use and 30% reduction in car use. Fear of infection and perceived crowding are new and significant concerns amongst public transport users. Travel reductions are significantly higher in the CBD during COVID. The paper reports respondent self-reported expectations of travel when the virus has gone. This indicates that:

- A post-pandemic reduction effect of around 20% in public transport commuting is expected including a mode shift from public transport use to mainly car driving; this will be particularly large for CBD/downtown areas and is likely to result in peak period traffic congestion after the virus has gone.
- WFH increased substantially during the pandemic; this will reduce after the pandemic as enforced WFH is replaced by voluntary WFH. Nevertheless, a sustained future ongoing increase in WFH above pre-pandemic levels is suggested, acting to reduce peak commuting by 6%
- Increased WFH is much larger for CBD jobs and results in a long-term reduction in commuting to Melbourne CBD of 20%.
- Infection fear is a new top concern of public transport users since the pandemic. This fear has transitioned from 'fresh infection fear'; the initial concerns when the pandemic started to 'residual infection fear' (Wang, 2014); a long-term effect when the virus has gone.

Table 1: COVID-19 and Local Travel Research on Cities - Findings with Geographic Insights on Urban Travel

Paper	Location/Approach	Findings with Geographic Insights on Urban Travel (During Pandemic and Post Pandemic)
City Based Studies		
Arimura et al (2020)	Sapporo, Japan/ Mobile phone data	*During-pandemic:* Decline in activity in central city and other typical attractors (shopping, education, entertainment) and increased density in residential areas of the city during the pandemic. In lockdown; 81% less people in the city on weekdays; 70 to 75% less at other times.
Dantsuji et al (2020)	Tokyo, Nagoya, Osaka, Japan/ Mobile phone data	*During pandemic:* Reduced trips to central parts of cities. Increased cross-city travel.
Gramsch et al (2020)	Santiago, Chile/ Smartcard data	*During-pandemic:* Reductions in PT use not uniform; higher in higher income zones where car use is greater (more alternatives available) and also in areas with higher shares of aged populations.
Bucsky (2020)	Budapest/ local traffic count data	*During pandemic:* PT use declined most (by 80%) while other modes decline by 64%. Fear of contamination mentioned as likely cause.
Brinchi et al (2020)	Rome/ traffic monitoring data AVL,traffic cameras	*During pandemic:* Significant reductions in travel of all modes. Biggest reductions in public transport in city centre stations.
Shamshiripour et al (2020)	Chicago/ online survey	*During pandemic:* Increases in WFH. Increased risk perceptions for PT/ Uber, Taxi use. Lack of alternatives noted in low income / racial minority suburbs.
Chang et al (2021)	Taipai/ Smart card data analysis	*During pandemic:* Larger decrease in Metro use at stations when businesses used WFH policies or where schools/Universities were still open
Hossain et al (2021)	Kelowna/ Small online survey verified strata	*During pandemic:* Higher income cohorts less likely to go out of home for work.
Nguyen (2021)	Hanoi/ Online survey; convenience sample	*During pandemic:* Increased WFH; preference for WFH for those living longer distances from work
Dianat et al (2021)	Toronto/ online survey stratified sample	*During pandemic:* Increased WFH. *Post pandemic:* Preference for on-site working increases with share of population vaccinated.
Przybylowski et al (2021)	Gdansk/ survey - method unknown, random sample	*During pandemic:* Reductions in PT use; most to private vehicle use; caused by increased infection fear *Post pandemic:* 74% PT users will return to PT after pandemic; depends on infection fear
(Currie G et al, 2021)	Melbourne/ online survey stratified sample	*During pandemic:* Reductions in all modes, PT more than others; increases in WFH. CBD activity significantly lower than suburbs *Post pandemic:* Long term -6% decline in commute as a result of increased WFH. Significantly higher for CBD (-20%) as a result of higher increases in post pandemic WFH for CBD workers. Mode shift from PT use to other modes, mainly Car Driving, results in a 20% decline in PT long term; caused by residual infection fear

2.4 The Melbourne Context

Melbourne is a low-density metropolitan area with a total population of 4.97 million people (2020) over nearly 2,000 km^2. The Central Business District (CBD) plays a dominant role for many forms of retailing, employment and recreation. As shown in Figure 1, Melbourne's PT system consists of train, tram, and bus services with rail and tram focussing on CBD radial travel while bus services provide suburban access. Melbourne has a high dependency on the private car for most travel, but particularly in suburban areas.

In early 2020 COVID-19 was detected in the Melbourne population. A relatively strict Government policy response was enacted; an index of global policy responses suggests Australia is ranked 4th in the world out of 36 major countries for effective responses (FP Analytics, 2021). Two large lockdowns occurred in Melbourne; March 23rd to May 13th and 9th July to 2nd August. 2020 saw a total of 20,345 cases of COVID-19 and 820 deaths (Department of Health and Human Services, 2020). Victoria experienced some 306 COVID-19 cases per 100,000 population (Statista, 2020b) which compares to 2,626 in the UK, 4,500 in the USA and 5,189 in Belgium (Statista, 2020a).

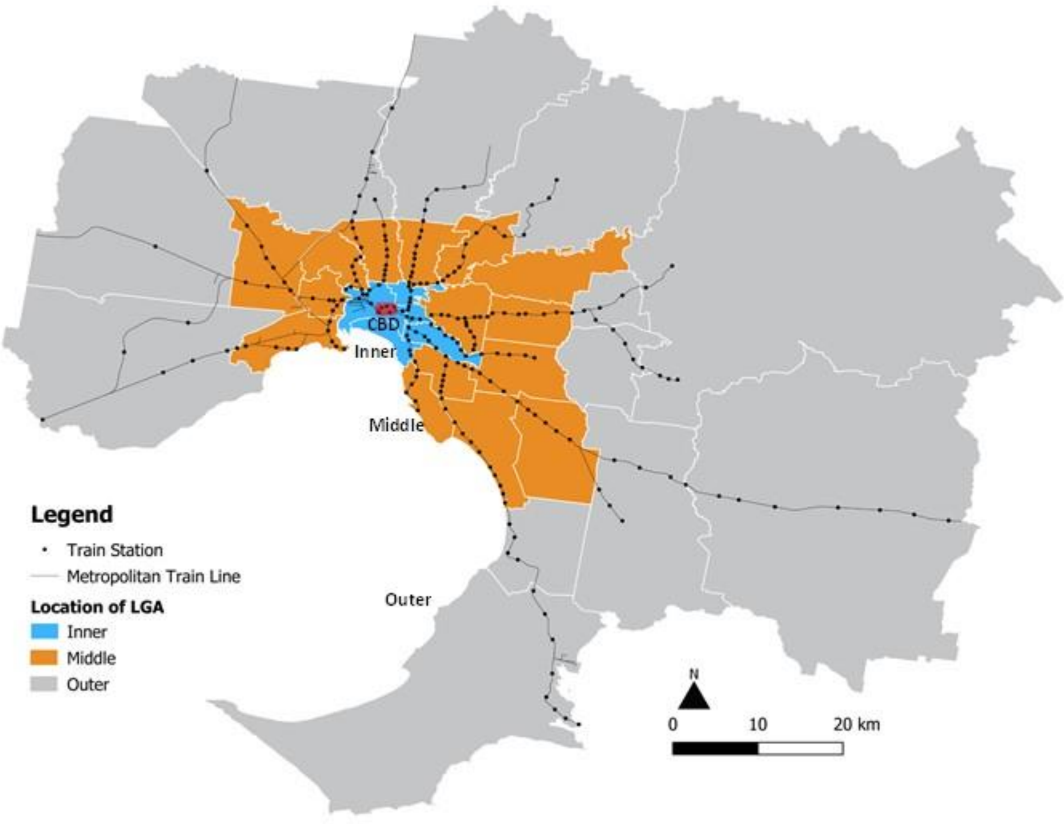


Figure 1: Public transport network in Melbourne.

COVID-19 shutdowns considerably decreased travel in Melbourne. Figure 2 illustrates mode volume effects of the early shutdown sourced from ridership/ traffic count data. Compared to 2019 baseline data, all travel declined with public transport modes and (CBD) walking declining by around 90%. Car travel declined by 29% while cycling declined the least; by 8%.

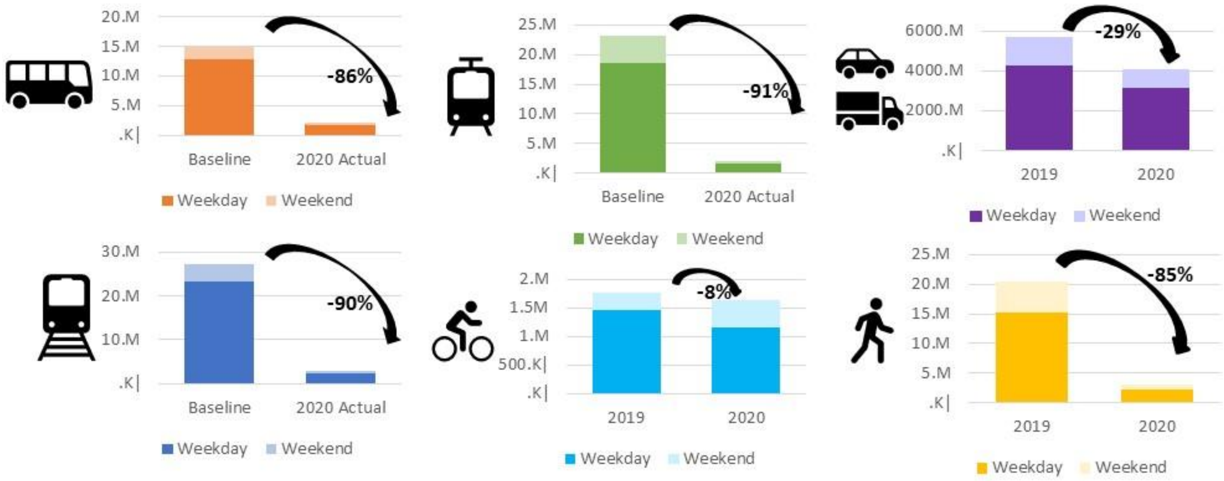


Figure 2: COVID-19 shutdown impacts on travel count data in 2020 (average trips per week)

Source: authors' analysis of (Department of Transport, 2020; Victorian State Government, 2020a; b)

4. Research Approach

The research sought to explore respondent self-reported expectations of travel after the virus had gone (stated intention method) for inner, middle and outer Melbourne. This was compared to travel before COVID-19.

An online questionnaire was adopted, however online surveys have significant 'under-representation bias' issues (Bethlehem J, 2010) including low representations of older age groups or low income groups. To address this a pre-survey stratification sampling approach was adopted using a stratified random sample (Richardson AJ et al, 1995) designed around the cohort dimensions of age and income; the two dimensions most commonly under-represented in web surveys. In addition, we sampled separately in different regions of Melbourne (inner, middle and outer; see Figure 1) to explore spatial variations in behaviours. Sample size requirements were based on standard industry calculators (Calculator.Net, 2020; Levy P.S. & Stanley L. , 2008). A minimum sample of 600 was required to achieve a 4% standard error for each geographic region at 95% confidence levels. This was increased to 700 per region to ensure a more robust sample. For Melbourne as a whole a sample of 2,100 was required. Delivery of the sample was managed by a market research company (Ipsos) using an online panel but with the questionnaire operated using a commercial questionnaire delivery platform owned and hosted by the researchers.

The survey ran between 26 June 2020 and 8 August 2020 and is described in detail in Currie G et al (2021). Quota-based exclusion criteria were used to ensure that the respondent characteristics were in line with the sampling frame. This proved difficult to achieve because it was necessary to fill all cells of the frame to achieve a full diversity of sample representative of the population. On completion of the sample, survey responses were cleaned and screened to remove any skimmers.

The final sample achieved a total of 2,163 valid responses with all sampling for each of the regions above the minimum required and almost all of the individual age/income sampling cell quota in the age/income cohorts by region being achieved.

The questionnaire sought to understand both reported commuting behaviour before and during COVID-19 and self-reported expectations of commuting post-COVID. Related issues such as alternative working practices (including WFH) were also explored including reported and expected changes in employment.

5. Results

The results compare survey findings for reported actual commuting travel pre-COVID and compare them for self-reported expectations of commuting after the virus has gone. Results are reported in four main areas:

- Total Commuting, Working from Home and Employment,
- Travel Mode volume/share,
- Car Ownership and Use; and
- Commute Trip Timing.

5.1. Total Commuting, Working from Home and Employment

Table 2 shows the expected change in commuting, employment and WFH when the virus has gone. This indicates that:

- Total commuting declines in all regions but is notably in inner Melbourne (-12.4%).
- These reductions are not explained by expected changes in employment; small increases are expected in inner/middle Melbourne and no change in outer Melbourne
- WFH is also shown in Table 2; this is expressed as a share of commuting travel to work plus WFH to indicate the scale of people who are actually working on a given morning. Pre-COVID only 2.24%-2.68% of all people working on a given workday actually worked from home. This is expected to increase to 6.52% in inner Melbourne while middle/outer Melbourne increase to 4.68%/4.98%.

Table 2: Commuting, Employment & Work from Home Change – Pre/Post COVID-19

Work/Commuter Related Activity	Pre-COVID	Post-COVID	% Net Change from Pre-COVID
Commuting – Sample trips to work per week			
- inner	4,197	3,678	-12.4%
- middle	3,724	3,530	-5.2%
- outer	3,648	3,451	-5.4%
Employment (share of sample aged above 18 employed FT/PT or Casual)			
- inner	72%	75%	+4%
- middle	66%	68%	+4%
- outer	62%	62%	0%
Work from Home (Share of travel to work plus work from home per week[1])			
- inner	2.24%	6.52%	+4.28%
- middle	2.68%	4.68%	+2.00%
- outer	2.37%	4.98%	+2.31%

Note: [1]Excludes workers who don't go to work that day (sick or vacation leave)

Overall increases in WFH after the COVID-19 pandemic is over seem to match reductions in total commuting travel after the virus has gone. Employment increases in inner/middle Melbourne and does not explain reductions in commuting.

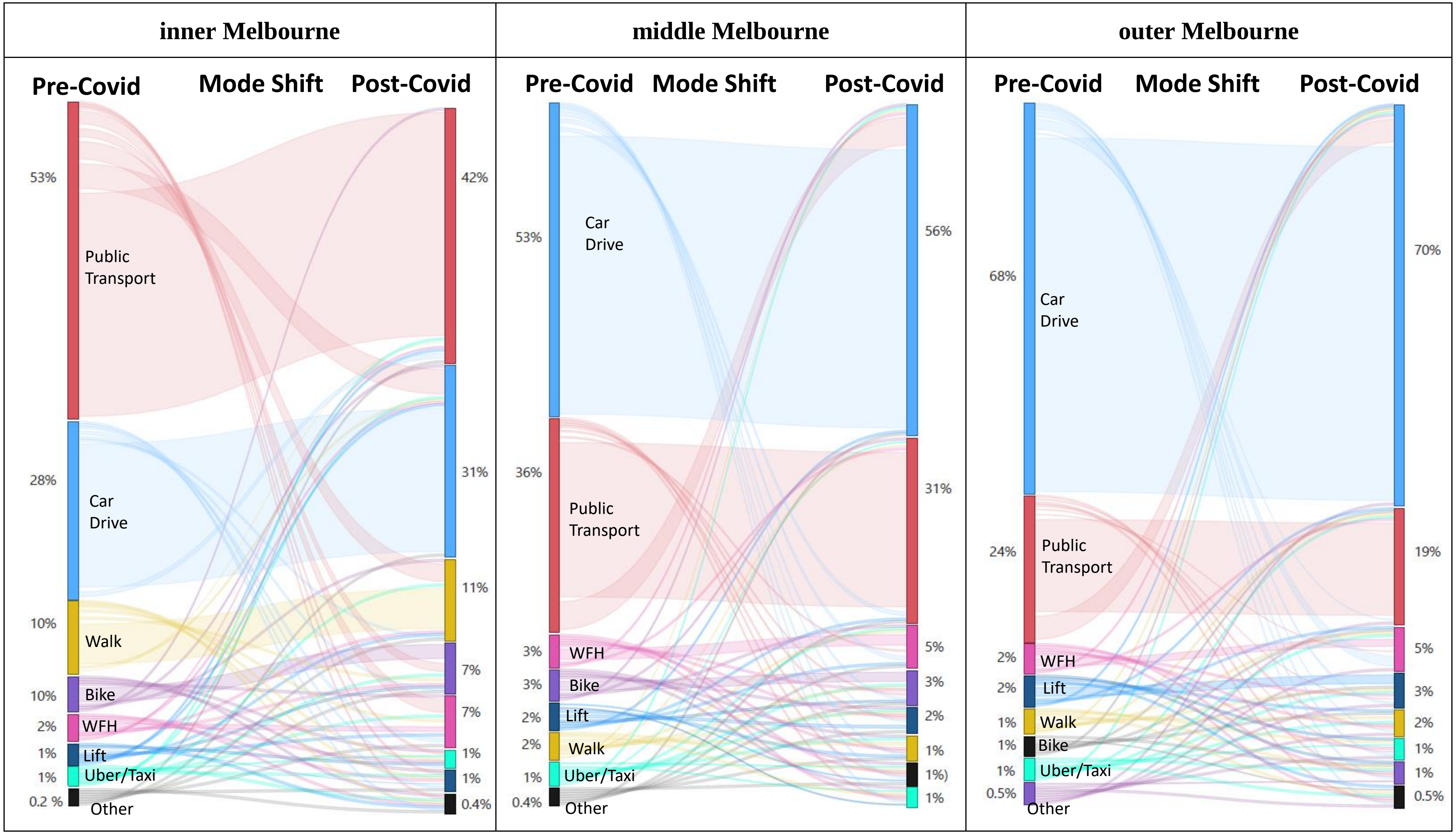
5.2 Travel Mode Volume/Share

Figure 3 illustrates the share of travel measured in terms of weekly trips to work by region (inner/middle/outer) but includes working from home per week to help understand the relative influence of home working on those working in each morning. Shares are illustrated pre-COVID and expectations of travel/WFH after the virus has gone.

This illustrates:

- Much shifting of commuting activity between modes and WFH post-COVID.
- The largest outcomes are:
  - A decline in public transport share from 53% to 42% (inner), 36% to 31% (middle) and 24% to 18% (outer)
  - An increase in car driving from 28% to 31% (inner), 53% to 56% (middle) and 68% to 70% (outer)
  - An increase in WFH from 2% to 7% (inner), 3% to 5% (middle) and 2% to 5% (outer)
- The biggest shift by individual mode is the loss of public transport commuting resulting in a net loss as a share of PT ridership by region of 21% (inner), 15% (middle) and 22% (outer).
- Net losses in PT ridership are balanced by some gains from other modes; these patterns vary by region. The following quotes regional PT shifts as a share of region PT use:
  - For inner Melbourne; 29% of inner PT ridership is lost mainly to car driving (9%) and walking (7%), work from home (5%) and bike (4%). This is offset by a 3% increase in car drivers deciding to shift to public transport use, post-COVID, plus some shifting from walking to PT use.
  - For middle Melbourne; 26% of middle region PT ridership is lost mainly to car driving (15%) and bike/WFH (2%). Car lift and walk also account for 1% of middle PT loss. This is offset by a 4% shift from car drive to middle region PT use and 1% gains from car lift, bike, walk and uber/taxi.
  - For outer Melbourne; 29% of ridership is lost again mainly to car drive (20%), Lift/ WFH (3% each) and User/Taxi are the other modes that PT use is lost to in the outer region. These are offset by a 2% gain from car drive post-COVID and 1% each from WFH/Uber/Taxi and walk.
- The main source of increases in car driving for all regions is mode shift from PT.
- Increases in WFH are mainly sourced from public transport, however for inner Melbourne a shift from car driver and walking to WFH is also important. For middle and outer Melbourne; shift from car driving pre-COVID to WFH is larger than shifts from public transport use.

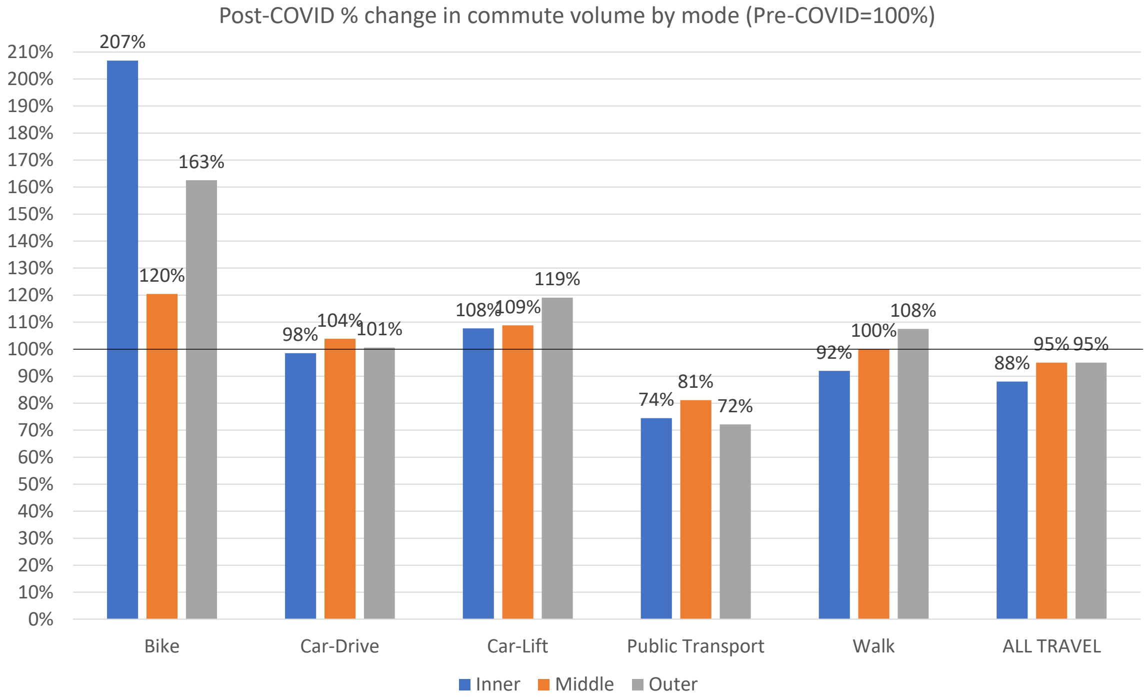
Figure 3 : Commute Mode and Work from Home Shift Between Pre-COVID to Post-COVID Periods



Note: Modes in pre-COVID order of mode share from top to bottom. Shares are computed as the sum of weekly trips to work plus number of work from home days per week.

Figure 4 shows the percentage absolute change in total mode use commuting by region between the pre to post-COVID periods. The largest percentage increases are in cycling which is expected to more than double in inner Melbourne. In travel share terms this is still relatively small (a shift from 3% to 7%) nevertheless there is a clear expectation that bike use is going to grow after the virus has gone. Car driving (the most common mode in Melbourne) is expected to grow a little in middle and outer Melbourne but decline slightly in the inner region. Car lift travel will grow in all regions, but is higher in outer Melbourne. Public transport travel declines in all regions as does total travel. Walking increases by 8% in outer Melbourne but declines by 8% in inner Melbourne.

Figure 4: % Change in Mode Commute Volume by Region - Pre-COVID to Post-COVID



5.3 Car Ownership and Use

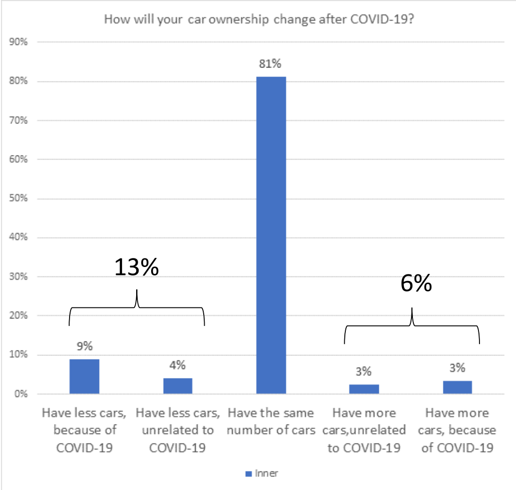
Figure 5 shows the expected change in car ownership and use when the virus has gone for each of the regions. This indicates that:

- In general car ownership is expected to decline for all regions while car use is expected to increase for all regions. Lower ownership may be the result of financial concerns as a result of the pandemic on economic conditions. Higher car use patterns match mode shift expectations.
- By region, inner Melbourne has the largest decline in expected car ownership (13%) compared to middle (7%) and outer Melbourne (7%). In addition, car use is expected to grow most in inner Melbourne (31%) compared to middle (29%) and outer Melbourne (26%). inner Melbourne also has the highest decline in expected car use (16%) compared to middle (13%) and outer Melbourne (14%).

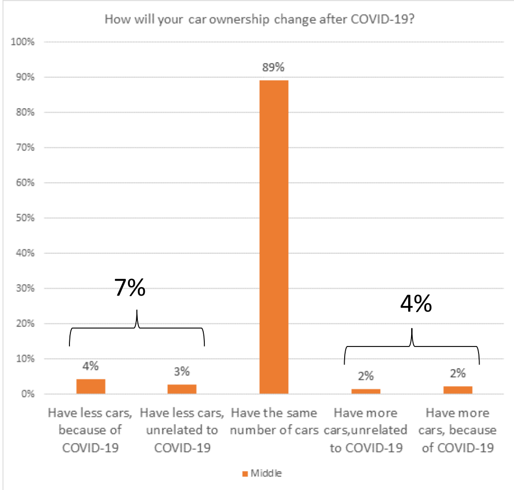
Figure 5: % Change in Expectations of Car Ownership and Use by Region - Post-COVID

Car Ownership

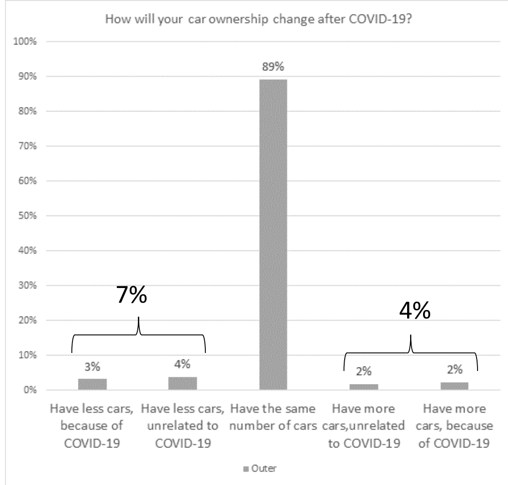
inner



middle

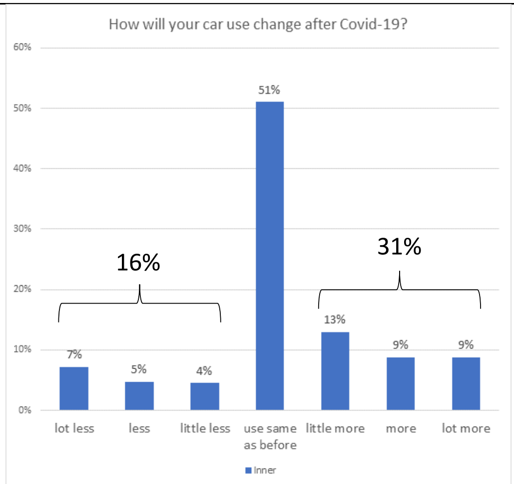


outer

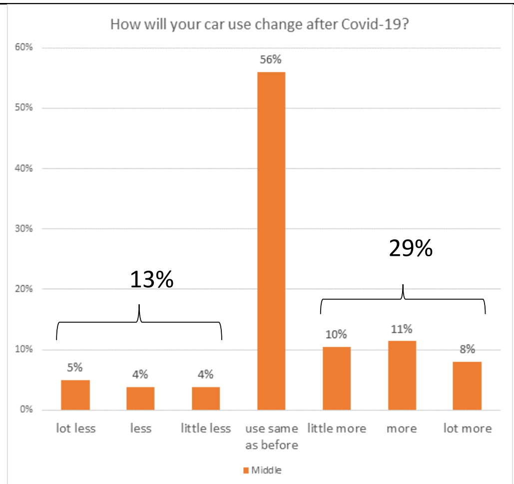


Car Use

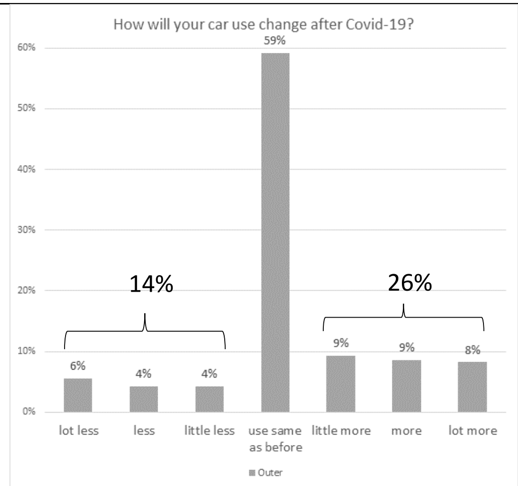
inner



middle



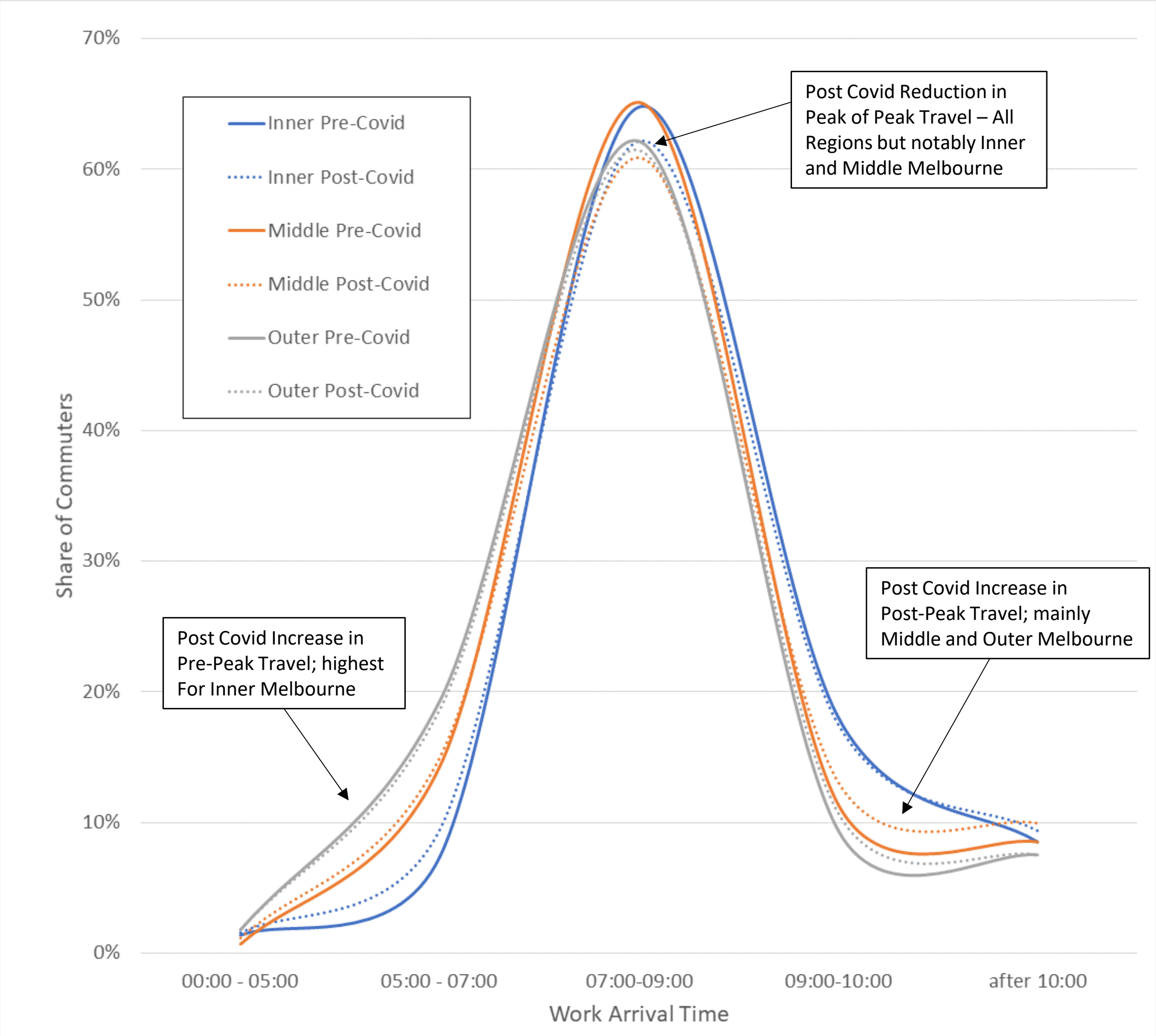
outer



5.4 Commute Trip Timing

Figure 6 shows the expected change in time of commute arrival time when the virus has gone for each of the regions.

Figure 6: Commute Trip Timing – Pre and Post COVID-19



This indicates that:

- Pre-COVID, commuting from all regions was heavily focussed on the 7-9a.m. period.
- Pre-COVID inner Melbourne had significantly less pre-peak travel but interestingly more post peak commuting. This is likely to be associated with the shorter travel distances (and time) involved in inner Melbourne commuting (an average of 9.8km). Also, inner Melbourne is closer to the concentrated Melbourne CBD core of commuting so it takes less time to get to work for inner Melbourne residents
- Pre-COVID outer Melbourne commuting is much more spread across the peak; it has the highest share of pre-peak travel but the lowest share of post-peak travel. This again appears related to travel distances; outer residents travel an average of 22.7kms to work so are taking longer to travel and travel earlier to avoid the peak and ensure they get to work on time.

- Pre-COVID middle area residents commute arrival distribution lies somewhere between the inner and outer Melbourne patterns. Average middle Melbourne travel distance to work is 14.7kms i.e. between the inner/middle Melbourne levels so again travel time seems to explain its distribution of arrival times
- Post -COVID, respondents expected there to be an increase in peak spread of commute arrival times for all regions of Melbourne. The peak (7-9a.m.) share of commuting reduced from 65% to 62% for inner Melbourne, a net change of 4.6% from pre-COVID levels. This effect was larger for middle Melbourne; 65% to 61% a net change of 6.1%. It was a minor reduction for outer Melbourne
- Post-COVID, respondents expected there to be an increase in pre-peak share of commuting for both inner and middle Melbourne while outer Melbourne had no significant change
- Post-COVID, post peak commuting is larger for middle Melbourne and to a lesser extent outer Melbourne.

Overall these findings confirm peak spreading is a key long-term outcome of the pandemic. Spreading is mostly focussed on inner and middle Melbourne with the major impacts resulting in a 4-6% decline in peak of peak travel.

6. Discussion and Conclusions

This paper explores spatial patterns in long-term post-pandemic changes in commuting within a city as a result of the COVID-19 pandemic. The major spatial patterns established were:

- Post-pandemic reductions in commuting as a result of increases in working from home. This is particularly large for inner Melbourne
- Post-pandemic mode shift from public transport to other modes, mainly car driving, as a result of infection fear. Again, this is larger for inner Melbourne where alternatives such as bike and walk are more feasible for commuting.
- In percentage terms, bike use increases considerably in all regions but particularly for inner Melbourne where the volume of cycling to work will more than double.
- Car ownership is overall likely to decline, but car use increases. Inner Melbourne demonstrates the highest expected post-pandemic declines in ownership and increases in expected use.
- Evidence suggests COVID-19 will result in peak spreading. This will be larger for middle and inner Melbourne.

Previous research has already suggested that COVID-19 will result in significant spatial effects related to CBD travel. Overall this paper suggests these patterns will also act to affect inner parts of cities. A good question is why? It seems plausible that commuters living in inner areas might comprise a higher share of white-collar workers who are much more likely to be able to WFH after COVID-19. Inner area residents also live closer to the CBD so more work there and will reflect patterns in CBD commuting activity. Inner area residents are also more likely to use public transport which dominated commuter mode share before COVID-19 (Figure 3 suggests 53% of commuting was by public transport before COVID-19). Residual infection fear acts to cause a long-term mode shift from public transport to other modes; hence it is likely that inner areas will be most affected by this since they use public transport more than other regions. In addition, perceived crowding is a related concern enhanced by the pandemic. Inner area public transport users are more likely to experience crowded public transport more often and are thus more likely to be influenced by crowding concerns.

Long-term reductions in public transport use and increases in car driving do not bode well for traffic congestion, which was a common problem in Melbourne before COVID-19. What is interesting about the spatial patterns of these findings is that we should not expect post-COVID-19 traffic congestion to occur in the same places as it did before COVID. Reductions in CBD/Inner area commuting should offset mode shift effects, suggesting inner city-based traffic congestion is less likely while non-CBD traffic congestion might be more common. Indeed, the combined effect of less traffic in inner areas and a growth in inner city cycling expectations might suggest an opportunity for construction of more inner-city bike paths to lock-in desired changes to cycling.

An obvious question which emerges from this analysis is when exactly is the timing of the long term post pandemic period which respondents in 2020 have reported their travel for. The short answer is we don't know. We are sure respondents didn't know either. Writing this paper in 2022 we can with hindsight say this will easily be more than 2 years after the original survey, however respondents didn't know that then. Indeed the current thinking is that even in 2022, the full end of the pandemic might not be for a few more years yet to come.

For public transport providers, the long-term prospects for ridership are not encouraging, though results do suggest most of the current ridership will return after the virus has gone. Although inner area residents demonstrate higher shares of mode shift away from transit, overall it is middle and outer regions where the bulk of riders are lost since overall these represent a higher share of the city's commuters. Residual infection fear and perceived crowding problems are the two new concerns which need to be addressed by public transport authorities to encourage a return to public transport use. For the Melbourne case, a post-COVID return to long term urban population growth will also assist; we estimate it will take only 7 years for ridership to return to pre-COVID levels if population growth returns to pre-COVID levels of growth.

A good question is; how transferable are the findings from this study to other cities. The obvious answer is that "it depends"; mainly on how comparable the circumstances in Melbourne are to other cities. In practice all cities are unique and COVID-19 and its impact on cities varies widely particularly in relation to rates of infection and also in the degree to which this has been managed by authorities. The time frame/longevity or infection may also be influential. Nevertheless, Melbourne might be classified as a low infection rate case with strong management of the virus. It is also a car based single CBD focussed city with low density urban sprawl and a medium density inner core. Cities with similar conditions to these might be able to transfer findings in Melbourne to their context. We are yet to understand how variations in virus infection rates and virus management act to effect travel in cities of different types. However the literature review results shown in Table 1 demonstrate a remarkable degree of consistency on findings on inner city trip reduction, public transport mode shift and working from home increases. This is despite quite diverse differences in the few cities studied.

In terms of future research, there is a clear need for more city-based studies of the travel impacts of COVID-19, including more evidence of spatial patterns and effects. Research also needs to monitor the strength and longevity of 'residual infection fear'. It was considered to almost entirely disappear after the SARS outbreak in Taiwan (Wang, 2014), however its impact as a result of the much more significant COVID-19 pandemic is less clear. Trends in perceptions of infection fear might be a useful way to understand the how enduring infection fear impacts on travel will be. We should also be monitoring for 'secondary effects'; for example, new instances of traffic congestion might encourage a return to public transport whose occupancy levels compared to pre-COVID crowding are now relatively attractive.

Although COVID-19 has caused some of the most significant changes to urban travel experienced by today's transport professionals; research such as the investigations outlined in this paper provide insights to help us understand these changes. We need to maximise the opportunities which COVID-19 has presented while mitigating the problems it has caused to succeed in a post-CIVID-19 recovery.

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8. References.

Anke, J., Francke, A., Schaefer, L.-M. & Petzoldt, T. (2021) Impact of SARS-CoV-2 on the mobility behaviour in Germany. *European Transport Research Review*, 13(1).

Arimura, M., Ha, T. V., Okumura, K. & Asada, T. (2020) Changes in urban mobility in Sapporo city, Japan due to the Covid-19 emergency declarations. *Transportation Research Interdisciplinary Perspectives*, 7, 100212.

Astroza, S., Tirachini, A., Hurtubia, R., Carrasco, J. A., Guevara, A., Munizaga, M., Figueroa, M. & Torres, V. (2020) Mobility Changes, Teleworking, and Remote Communication during the COVID-19 Pandemic in Chile. *Transport Findings*.

Baert, S., Lippens, L., Moens, E., Weytjens, J. & Sterkens, P. (2020) The COVID-19 crisis and telework: A research survey on experiences, expectations and hopes.

Bethlehem J (2010) 'Selection Bias in Web Surveys'. *International Statistical Review / Revue Internationale de Statistique*, Vol. 78, No. 2 (August 2010), pp. 161-188

Brinchi, S., Carrese, S., Cipriani, E., Colombaroni, C., Crisalli, U., Fusco, G., Gemma, A., Isaenko, N., Mannini, L. & Petrelli, M. (2020) Covid-19 Transport Analytics: Analysis of Rome Mobility During Coronavirus Pandemic Era, *Conference on Sustainable Urban Mobility*. Springer.

Bucsky, P. (2020) Modal share changes due to COVID-19: The case of Budapest. *Transportation Research Interdisciplinary Perspectives*, 8, 100141.

Calculator.Net (2020) *Sample Size Calculator*, 2020. Available online: https://www.calculator.net/sample-size-calculator.html [Accessed.

Chang, H.-H., Lee, B., Yang, F.-A. & Liou, Y.-Y. (2021) Does COVID-19 affect metro use in Taipei? *Journal of Transport Geography*, 91.

Currie G, Jain T & Aston L (2021) Evidence of a Post-COVID Change in Travel behaviour - Self-Reported Expectations of Commuting in Melbourne. *Transportation Research Part A*, Volume 153, November 2021, Pages 218-234.

Dantsuji, T., Sugishita, K. & Fukuda, D. (2020) Understanding Changes in Travel Patterns during the COVID-19 Outbreak in the Three Major Metropolitan Areas of Japan. *arXiv preprint arXiv:2012.13139*.

de Palma, A. & Vosough, S. (2021) *Long, medium, and short-term effects of COVID-19 on mobility and lifestyle*.

Department of Health and Human Services (2020) *Victorian coronavirus (COVID-19) data*, 2020. Available online: https://www.dhhs.vic.gov.au/victorian-coronavirus-covid-19-data last accessed December 2020 [Accessed.

Department of Transport (2020) *Patronage Summary for Reporting*.

Dianat, A., Hawkins, J., Habib, K. N. & Transportation Research, B. (2021) Assessing the Impacts of COVID-19 on Activity-Travel Scheduling: A Survey in the Greater Toronto Area.

FP Analytics (2021) *The Covid-19 Global Response Index*, 2021. Available online: https://globalresponseindex.foreignpolicy.com/ [Accessed.

Gramsch, B., Guevara, A., Munizaga, M., Schwartz, D. & Tirachini, A. (2020) The Effect of Dynamic Lockdowns on Public Transport Demand in Times of COVID-19: Evidence from Smartcard Data. *Available at SSRN 3768561*.

Hossain, M. S., Haque, K., Fatmi, M. & Transportation Research, B. (2021) COVID – 19: Modeling Out-Of-Home and In-home Activity Participation during the Pandemic.

Jain T, Currie G & L, A. (2022) COVID and Working from Home: Long-term Impacts and Psycho-social Determinants. *TRANSPORTATION RESEARCH PART A* Volume 156, February 2022, Pages 52-68.

Jenelius, E. & Cebecauer, M. (2020) Impacts of COVID-19 on public transport ridership in Sweden: Analysis of ticket validations, sales and passenger counts. *Transportation Research Interdisciplinary Perspectives*, 8, 100242.

Lennox, J. (2020) *More working from home will change the shape and size of cities*.

Levy P.S. & Stanley L. (2008) *Sampling of populations: methods and applications.* John Wiley & Sons.

Medimorec, N., Enriquez, A., Hosek, E., Peet, K. & Cortez, A. (2020) *Impacts of COVID-19 on mobility*.

Molloy, J., Tchervenkov, C., Hintermann, B. & Axhausen, K. W. (2020) Tracing the Sars-CoV-2 Impact: The First Month in Switzerland. *Findings*, May.

Musselwhite, C., Avineri, E. & Susilo, Y. (2021) Restrictions on mobility due to the coronavirus Covid19: Threats and opportunities for transport and health. *Journal of Transport & Health*.

Nguyen, M. H. (2021) Factors influencing home-based telework in Hanoi (Vietnam) during and after the COVID-19 era. *Transportation*, 1-32.

Przybylowski, A., Stelmak, S. & Suchanek, M. (2021) Mobility behaviour in view of the impact of the COVID-19 pandemic—public transport users in Gdansk case study. *Sustainability*, 13(1), 364.

Richardson AJ, Ampt ES & AH, M. (1995) *Survey Methods for Transport Planning*. Melbourne, Australia: Eucalyptus Press.

Rubin, O., Nikolaeva, A., Nello-Deakin, S. & te Brömmelstroet, M. (2020) What can we learn from the COVID-19 pandemic about how people experience working from home and commuting? *Centre for Urban Studies, University of Amsterdam*.

Shamshiripour, A., Rahimi, E., Shabanpour, R. & Mohammadian, A. (2020) How is COVID-19 reshaping activity-travel behavior? Evidence from a comprehensive survey in Chicago. *Transportation Research Interdisciplinary Perspectives*, 7, 100216.

Statista (2020a) *Incidence of coronavirus (COVID-19) cases in Europe as of December 9, 2020, by country*, 2020a. Available online: https://www.statista.com/statistics/1110187/coronavirus-incidence-europe-by-country/ last accessed December 2020 [Accessed.

Statista (2020b) *Number of COVID-19 cases per 100,000 population in Australia as of November 17, 2020, by state and territory*, 2020b. Available online: https://www.statista.com/statistics/1103944/australia-coronavirus-cases-per-100-000-population-by-state/ [Accessed.

Victorian State Government (2020a) *Bicycle volume and speed*. 2016, 2017, 2018, 2019, 2020 (-May). Created online: https://discover.data.vic.gov.au/dataset/bicycle-volume-and-speed [Created 1/6/2020]

Victorian State Government (2020b) *Traffic Signal Volume Data*. 2019, 2020 (- May). Created online: https://discover.data.vic.gov.au/dataset/traffic-signal-volume-data [Created 15/5/2020]

Wang, K.-Y. (2014) How Change of Public Transportation Usage Reveals Fear of the SARS Virus in a City: e89405. *PLoS ONE*, 9(3).