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The Impacts of COVID-19 Pandemic on The Volume and Pattern of Public Transport Trips in The Greater Sydney Area

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Abstract

The COVID-19 pandemic and its following restrictions changed the volume and patterns of Public Transport (PT) trips in the Greater Sydney area. This study explores the trip volume changes by applying comparative and statistical analyses on hourly PT fare card (Opal) transactions data for trips in 2019, 2020 and 2021 (up to March). The findings show that total PT trips in 2020 declined by 45% in comparison with 2019, with the maximum decline being in April 2020 at 79.4%. Although there was a sharp decline in PT demand for 6 weeks in March and April 2020, the demand has smoothly recovered by March 2021. Comparing the skewness and kurtosis of PT trip histograms in morning and evening time periods resulted in interesting findings. It is observed that the time PT commuters spend at their workplaces was decreased during COVID-19. The change in spatial patterns of PT trip production and attraction were quite similar, where a yearly drop between 34% to 59% in volumes of both PT trip production and attraction was recorded for every zone in the network. Clustering SA2s based trip distribution patterns in 2019 and 2020 revealed that several parts of the cluster within the CBD core were separated and either joined to other clusters or formed new clusters. Correlation analysis showed that decline in PT use had a direct relationship with income levels, with zones having higher income distributions displayed the highest decline in PT ridership, whereas lower income zones were more likely to continue using PT through COVID-19 outbreak times.

Keywords: COVID-19; Epidemic, Public Transport; Travel Behaviour

1. Introduction

In early 2020, the Australian states of Victoria and New South Wales (NSW) faced big waves of COVID-19 infections leading to severe restrictions on peoples' work, travel and social activities. Australia has been successful in containment of COVID-19 infection cases through the severe restrictions. However, from travel and transport sustainability perspective, Public Transport (PT) systems have experienced significant changes from which many cities have not recovered yet.

In this study, the effects of COVID-19 pandemic and its related restrictions on the volume and pattern of PT trips in the greater Sydney Area are investigated. PT fare card (Opal) transactions data for trips in 2019, 2020 and 2021 (up to March) are queried. Some comparative and statistical analyses are conducted to show the changes in:

- zonal PT trip production, attraction, and distribution in the network,
- changes in patterns of spending time on city activities by PT users, and
- correlation between population of income groups and drop in PT trip production in zonal level.

This paper explores the impact of COVID-19 on the greater Sydney area, since this case has not been studied yet. Also, the patterns of the time spent in city activities are estimated for the first time by analysing skewness and kurtosis of PT trip histograms for trips before, during, and after COVID-19. Moreover, the majority of previous work considers macro level analysis at the country, state, or city level, while this research investigates changes in PT trip production, attraction, and distribution in zonal level. In fact, in presenting the results, five time-aggregation levels (year, month, week, representative day of week, and representative hour of week) and four space-aggregation levels (greater Sydney area, Statistical Areas Level 4 (SA4), Statistical Areas Level 3 (SA3), and Statistical Areas Level 2 (SA2)) are used. Finally, several findings are introduced that can be useful in PT service planning and operations during and after the global pandemic.

The rest of the paper is organized as follows: A review on the literature is presented in Section 2. Section 3 introduces the data. An overview of the changes in PT trips on metropolitan-level based on the entire time-aggregation levels is presented in Section 3. In Section 4, the changes in PT trip production and attraction based two time-aggregation levels (year and month) and the all space-aggregation levels are described. Section 5 presents the changes occurred in PT trip distribution and the conclusions are presented in Section 6.

2. Literature Review

This section reviews the papers published in 2020 and 2021exploring the effects of COVID-19 on travel behaviour for different transport modes including PT. Much research has been done to investigate the changes that occurred in travel behaviour in different parts of the world. Reviewing them showed that they are different in light of several aspects including:

- case study, type and degree of included mobility restrictions,
- considered COVID-19-related time periods (before, during, and after),
- data collection method,
- data analysis type,
- time resolution (e.g. yearly, monthly or weekly),
- space resolution (e.g. state-level or zonal-level), and finally
- reported findings.

In the following, the literature is reviewed in terms of these aspects. De Vos (2020) is one of the first papers that investigated the effects of COVID-19 and social distancing on travel behaviour. The author predicted several serious effects on travel behaviour in PT systems based on his expectations and reviewing the findings of previous publications. The major predication is that the demand in PT is expected to decrease more because not only many people consider it a breeding ground for viruses but also it is difficult to observe social distance in these systems. De Haas et al. (2020) investigated the effect of COVID-19 and Dutch government's 'intelligent lockdown' on travel behaviour in different modes, where they resulted that crisis might result in structural behavioural changes. The authors conducted a survey-based analysis and gathered the responses of people regarding some travel questions, where 2500 respondents were questioned. The findings indicated that 80% of outdoor activities dropped, where the elderly had the highest share in this drop. Moreover, nearly 55% and 68% drop occurred in trip volumes and total travel distances in fall 2020, when it is compared to fall 2020. The demands for walking and cycling are predicted to increase by 20% after COVID-19 but the demand for air travel will decease 20%.

Aloi et al. (2020) explored the effect of COVID-19 restriction measures or quarantine on urban mobility in northern city of Santander, Spain on 15 March 2020. Data was collected from PT ITS, traffic counters, environmental sensors, and recordings from traffic control cameras. Using the data, the authors re-estimated the origin-demand travel matrices for private and PT modes before and during the lockdowns. The findings showed that overall mobility declined by 76%, while the decline in PT was 93%.

Bucsky (2020) explored the effect of COVID-19 restrictions in Budapest during March 2020 on PT mobility. Automatic recorded data provided by Budapest Roads Ltd as well as the Waze application usage by users was used for collecting road data. Daily trips by PT were estimated by physical passenger counting data. The data for the number of cyclists was also extracted from 5 automatic counting stations. By comparing the data of weeks 10 and 11 (before restrictions) with week 12 and 13 (during restrictions), authors reached to the following findings:

- 37% drop in motorways traffic volume,
- 61% drop in Waze application usage,
- 90% drop in PT demand, and
- 50% drop in pedestrian traffic volume.

Abdullah et al. (2020) studied the changes in travel behaviour and the factors attributed to the changes. They did an online questionnaire survey from different countries and collected 1,203 responses. By analysing the data, they presented several findings as follows:

- during COVID-19, the majority of trips were made for shopping purposes,
- there was a significant shift from public to private transport mode,
- some of the most influential factors on transport mode choice during pandemic were car ownership, gender, travel distance, employment status, and primary purpose of traveling.

Jenelius and Cebecauer (2020) studied the impact of COVID-19 during spring 2020 on PT demand in most populated regions of Sweden. A disaggregated data of the usage and sale of PT ticket cards during the pandemic as well as the type of the tickets, seniors or youths, was collected. Exploring the data showed a 40% to 60% decrease in PT demand that is not related to reduction in service level.

Gao et al. (2020) explored the changes in home-stay dwell time and trip mobility caused by stay-at-home and social distancing restrictions (in mid-March 2020) in the US. The authors used the U.S. mobility data released by the Descartes Labs (Warren and Skillman, 2020) and found that the trip mobilities in the US is dropped nearly 26%, where the figure for New York State was 73% due to the imposed lock-down order.

There are also papers in the literature that investigated Australian case studies (Beck et al., 2020; Beck and Hensher, 2020; Hensher et al., 2021; Beck et al., 2021; Munawar et al., 2021). Beck et al. (2020) studied the working from home profiles during COVID-19 restrictions and early days after easing them (i.e. waves 1 and 2 in Australia). Also, the authors develop logit models to identify the factors attributed to the number of working from home. Beck and Hensher (2020) explored the impact of COVID-19 on urban mobility in early days after easing the restrictions in Australia. The authors gathered data through activity surveys, where 1,457 responses were collected. By doing a comparative analysis, the authors found that 55% PT trips returned after restrictions, but total demand is still two-thirds of that occurred before COVID-19. Hensher et al. (2021) estimated the short-term reduction in time and money costs associated with a reduction in private and PT commuting activities in the Greater Sydney area during a period that COVID-19 restrictions in Australia were easing. The authors collected data by surveys where a set of 200 responses from the residents of the area was received. It is observed that $5.58 billion reduction was occurred in private and PT travel time costs, indicating a 54% drop in the Pre-COVID-19 total time costs. Beck et al. (2021) explored the impact of COVID-19 on PT activities by the data collected from survey conducted by Hensher et al. (2021). The authors found that concerns around crowds and hygiene caused a significant drop in PT demand, where even after easing the COVID-19 restrictions in some Australian cities, PT demand has not recovered. Munawar et al. (2021) studied the impact of COVID-19 restrictions on the air, public and freight transport systems. Data was collected through several ways including: Google and Apple mobility trends, the official website of the Australian government, Moovit application, current pertinent research papers, web articles, and results if interviews with the stakeholders of transport sectors in Australia. The authors found that PT demand has dropped 80% causing to a serious financial downfall for this system. Also, 31.5% and 9.5% drops were predicted in revenue of international airlines and maritime freight transport system, respectively.

The majority of previous work has focused on macro-spatial level to explore trip mobilities changes and their correlations with different factors at a large scale. In this paper a zonal level analysis is presented, where PT mobility in 2019, 2020 and 2021 (to March 25th) between 398 different zones in the greater Sydney area. Moreover, the study is the first that investigates changes in trip distribution patterns by applying a clustering method on PT trips in 2019 and 20 and compares the results.

3. Data and Results

An aggregate extract of the Sydney’s Opal transaction data was available by Transport for NSW. This dataset includes zonal distribution counts of tap-ons and tap-offs made on the Opal ticketing system from January 2019 to 25 March 2021. This is an hourly aggregated PT Origin-Destination (OD) trips between 398 SA2s of the total 578 SA2s in New South Wales state (Figure 1).

A review on the chronology of NSW announcements regarding COVID-19 is presented by Table 1. As the table shows, April 2020 is considered as the nominated month during COVID-19 restrictions, February 2019 as the nominated month before COVID-19, and February 2021 as the nominated month after COVID-19 restrictions. It should be noted that within the studied time horizon, December 2020, another COVID-19 cluster emerged in NSW (called Sydney's northern beaches COVID-19 cluster). It was observed the effect of this cluster was very similar to the cluster during May and April 2020; hence, only focused on the first major cluster.

Table 1: The chronology of NSW announcements regarding COVID-19

ID	Date	Announcement
A	25 January 2020	The first case was identified
B	06 February 2020	NSW Health released a statement in response to concerns about COVID-19.
C	27 February 2020	Individuals and businesses advised to take steps to prepare for a possible pandemic
D	03 March 2020	The first death was occurred
E	15 March 2020	Cancellation of major events with more than 500 people
F	17 March 2020	Introducing a $2.3 billion health and economic stimulus package
G	18 March 2020	A ban on non-essential indoor gatherings of 100 people or more
H	23 March 2020	Non-essential activities and businesses were temporarily shut down.
I	02 April 2020	allowing construction sites to operate on weekends and public holidays
J	25 April 2020	Returning to school
K	01 May 2020	Easing restrictions has started.

PostgreSQL and ArcGIS were used to query the data and construct maps of the results, respectively. To investigate the changes in PT trips during days and hours, a representative day for each week that is Thursday and a representative hour of a week that is 8:00 AM to 9:00 AM on Thursdays are presented. Accordingly, it would be possible to compare the changes in production, attraction, and distribution of PT trips before, during, and after COVID-19 by different comparative and statistical analyses.

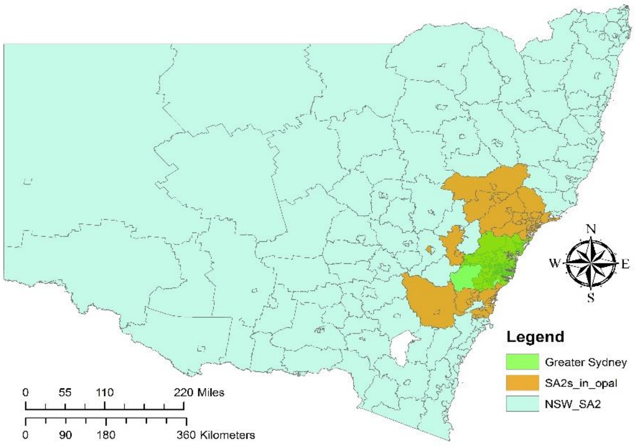

Figure 1: A schematic view of SA2s covered by Opal dataset.

3.1. Trip activities on a macro level

In this subsection, changes in the volume and pattern of PT trips are presented for before and after COVID-19 restrictions. Figure 2 shows the total PT trips made in 2019 and 2020, and Figure 3 shows the monthly changes.

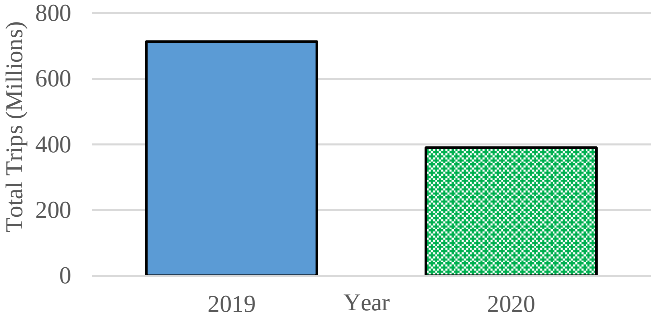

Figure 2: Total PT trips (yearly)

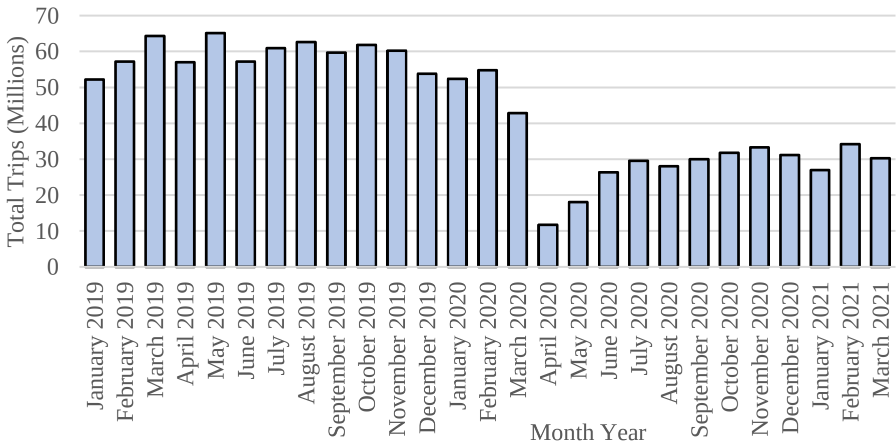

Figure 3: Total PT trips (monthly)

Total PT trips in 2020 declined by 45% in comparison with 2019. The significant drop in the volume of PT trips occurred in April 2020, where April 2020 recorded 30 million trips less than March 2020. After April 2020, by declining the number of COVID-19 cases and lifting the restrictions, a smooth growing trend is observed from 12 million in April 2020 to 30 million trips in July 2020 and then becomes almost constant until March 2021. The percentages of the changes in monthly volume of PT trips in 2020 in comparison to 2019 are shown in Figure 4.

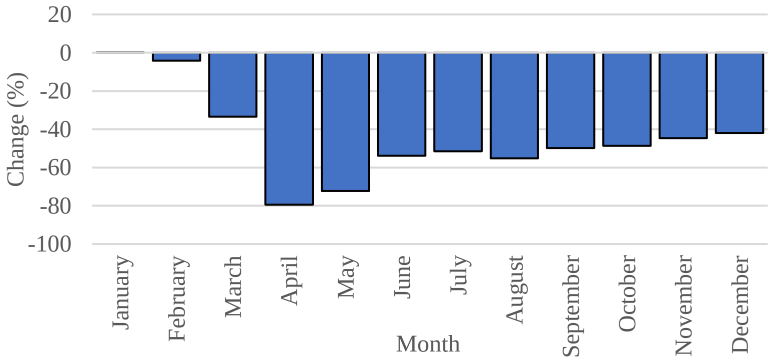

Figure 4: Monthly relative change in PT trip productions in total network

In Figure 4, the patronage decline in February 2020 indicates a decrease (-4.2%) in the number of PT trips that is the initial effect of COVID-19 on PT demand. This figure reached -33.5% and 79.4% in March and April 2020, respectively. After April 2020, by declining the number of COVID-19 infections and lifting the restrictions, gradually the PT demand recovered and reached nearly -50% decrease for July-December 2020. The total weekly volume of PT trips in the network is shown in Figure 5. The highest impact of COVID-19 occurred in between weeks 9 and 15 of year 2020; 84% of PT demand dropped during that period. A slow PT demand recovery is observed afterwards.

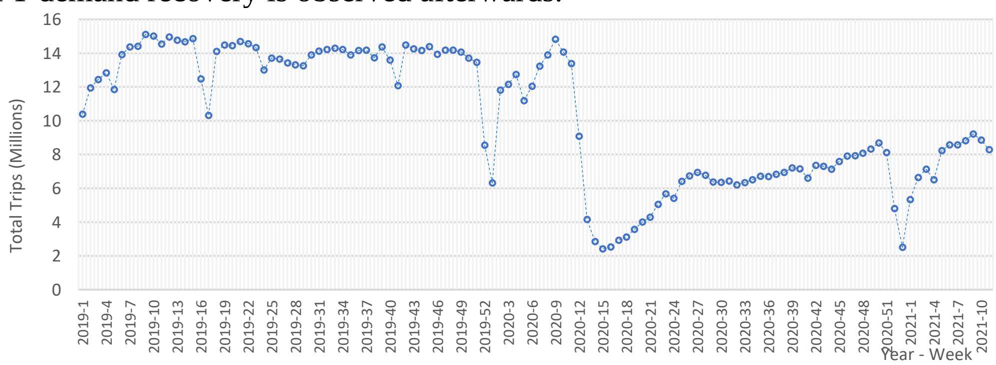

Figure 5: Weekly PT trips

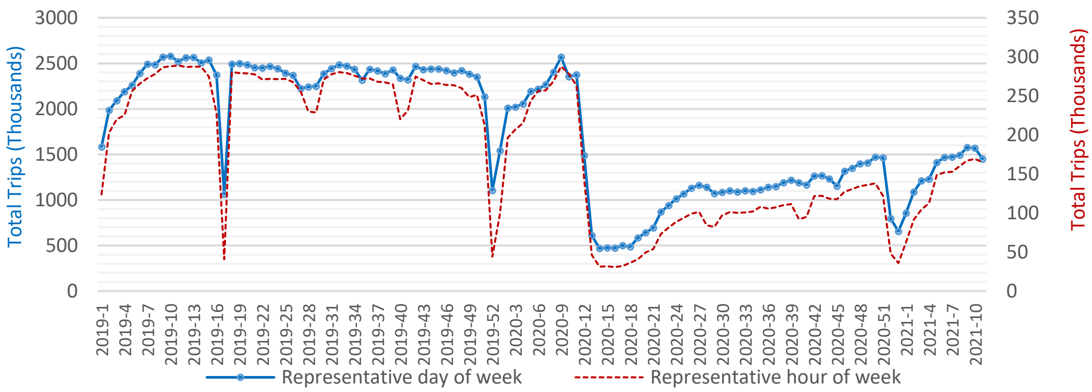

Figure 6: Total PT trips during representative AM peak hour of weeks

The changes in the volume of PT trips during a representative day of week (Thursday) and a representative morning peak hour (Thursday 8am-9am) are shown in Figure 6. Before COVID-19 (week 19 in 2020), a small gap is observed between these two trends; however, during and after COVID-19, this gap seems to have increased. This observation indicates that the PT trips during the AM peak many have decreased with a higher rate than the daily trips.

3.2. Exploring Activity Duration

The hourly distribution of PT trip volumes for each year is shown in Figure 7. Each distribution is divided into two parts: morning (from 0:00 AM to 11:00 AM), and evening (from 12:00 PM to 23:00 PM). The skewness and kurtosis of each part is calculated and reported in Table 1. Skewness is a measure of the symmetry in a distribution and kurtosis measures the tail-heaviness of the distribution. The 2019 or 2020 data is for 12 months, while the 2021 data is only for 3 months, hence the shorter histogram bars in Figure 7, however, that does not affect the analysis of skewness and kurtosis.

Table 1: Skewness and kurtosis for PT trip histograms

Histogram Part	Year	Skewness	Kurtosis
Morning Part (0:00 AM to 11:00 AM)	2019	-0.62	4.82
Morning Part (0:00 AM to 11:00 AM)	2020	-0.61	4.28
Morning Part (0:00 AM to 11:00 AM)	2021	-0.65	4.55
Evening Part (12:00 PM to23:00 PM)	2019	0.35	2.73
Evening Part (12:00 PM to23:00 PM)	2020	0.44	2.76
Evening Part (12:00 PM to23:00 PM)	2021	0.42	2.72

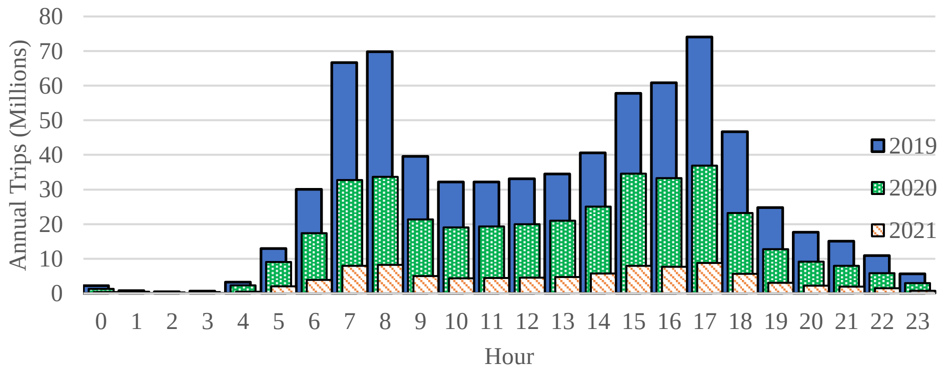

Figure 7: PT trip histograms

The values of skewness for morning periods show no significant difference; however, the kurtosis from 4.82 in 2019 decreased to 4.28 in 2020 and then increased to 4.55 in 2021. This shows that the tail of the morning-part distribution in 2020 is heavier than 2019 and even 2020. This indicates that trips in early morning (4:00 AM to 6:00 AM) in comparison did not decrease as significantly as trips during morning peak hours (7:00 AM to 8:00 AM). Two possible reasons for this observation are:

1- The risk of COVID-19 transmission during the off-peak hours is probably perceived less as compared to morning peak hours. As a result, some commuters may have shifted to earlier or later departure times.
2- Peak hour commuters, who are dominantly 9AM-5PM office workers, may have had more flexibility to work from home, as compared to service and construction site workers who usually start before 7 AM and whose physical presence is usually necessary at work sites.

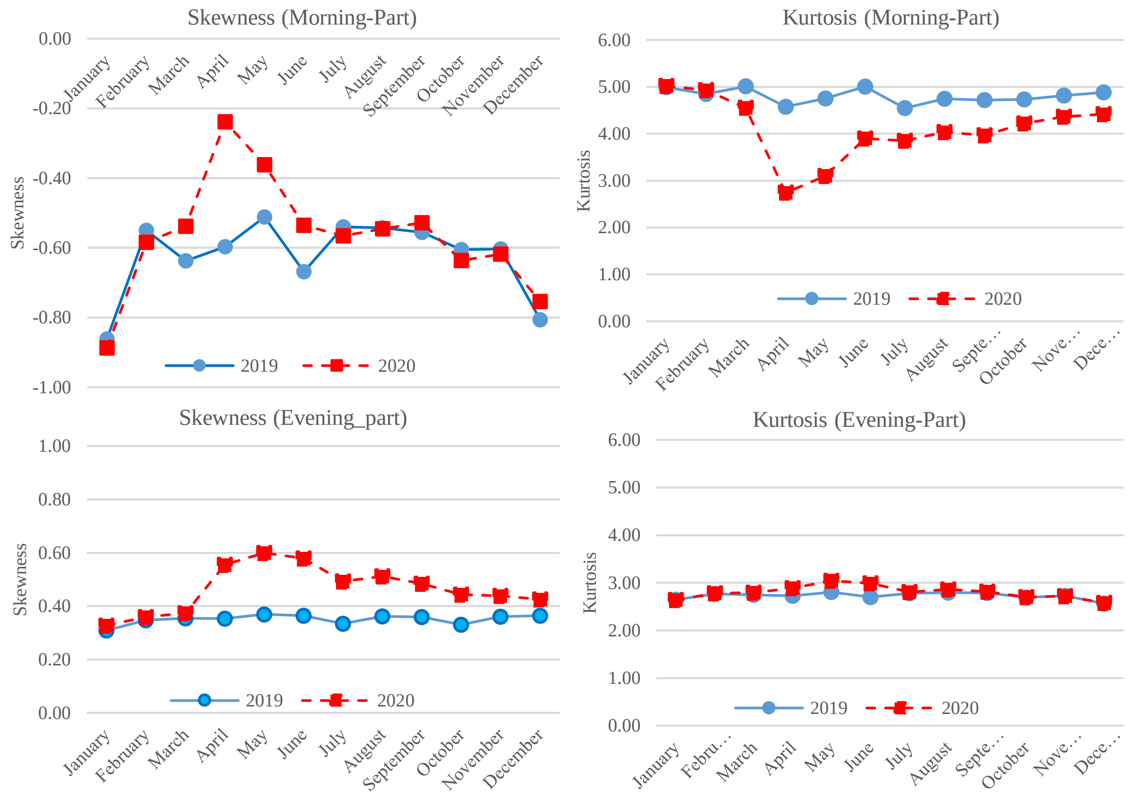

Figure 8: Values of skewness and kurtosis for different months in 2019 and 2020

To increase the resolution of data analyses, the skewness and kurtosis of the hourly distribution of PT trips for each month is calculated. The values of skewness and kurtosis of the PT trip distributions for both morning and evening parts are shown in Figure 8. The results show, in April 2020 the value of skewness for the morning period was -0.20 and the histogram had nearly a symmetrical shape, while, in April 2019, the skewness was -0.60 indicating skew to the right. This observation indicates that a significant portion of trips made during morning peak in April 2019, disappeared or spread into off-peak hours (particularly early hours). However, after July 2020, the pattern of changing skewness in 2019 and 2020 are similar. The values of kurtosis for histograms of PT trips during morning in 2019 and 2020 also show that the heaviest tail belongs to April 2020 and after that the tail heaviness decreases (i.e. kurtosis increases) to return the those of 2019. However, there is still a steady gap between the values of kurtosis in October, November and December. This observation indicates that still a portion of PT users prefer to travel in early morning hours.

In the evening histograms, no significant changes in the values of kurtosis is observed. However, the histogram in 2020 is skewed significantly to the left which shows the peak of PT trips in evening occurred earlier. This observation may indicate that the PT commuters leave their workplaces earlier during COVID-19 and therefore the time PT commuters spend in their workplaces was lower.

3.3. Trip production and attraction

In this section, the changes in PT trip production and attraction in two different time-aggregation levels (year and month) and three space-aggregation levels (SA4, SA3, and SA2) are presented.

3.3.1. Yearly Changes

Figure 9 shows the total number of trips produced from and attracted to SA4 zones in 2019 and 2020.

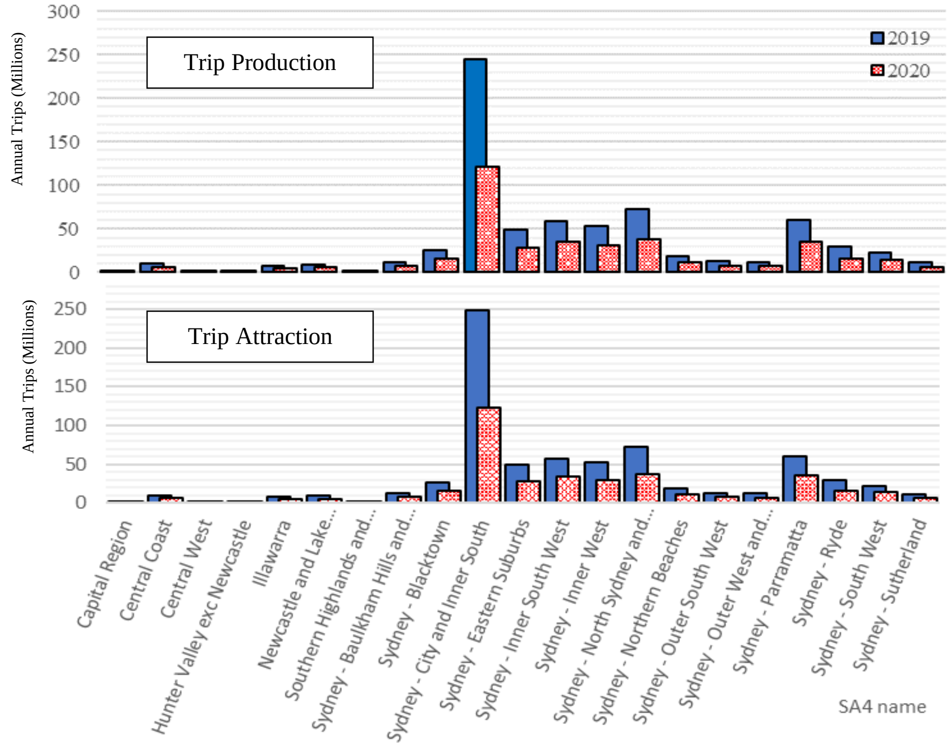

Figure 9: Trip production and attraction from and to SA4s in 2019 and 2020

Sydney - City and Inner South, Sydney - North Sydney and Hornsby, and Sydney – Parramatta generate and attract the first, second, and third highest volume of PT trips in both years. In 2020, Sydney - City and Inner South, experienced nearly 40% decrease (322 million trips). In 2020, all the SA4s experienced nearly 40% to 60% decrease in their PT trip production or attraction volumes, as shown in Figure 10. As shown in Figures 10, the Central West and Capital Region are the SA4s with the highest relative decrease (i.e. nearly 60%) in their PT trip production or attraction volumes. After these two regions, Southern Highlands and Shoalhaven, Sydney - City and Inner South, Sydney - North Sydney and Hornsby, and Sydney – Ryde experienced the greatest declines (i.e. approximately 50% decline). These relative changes in PT trip production and attraction volumes are shown in Figures 11 and 12 based on different area classifications (SA4s, SA3s, and SA2s)

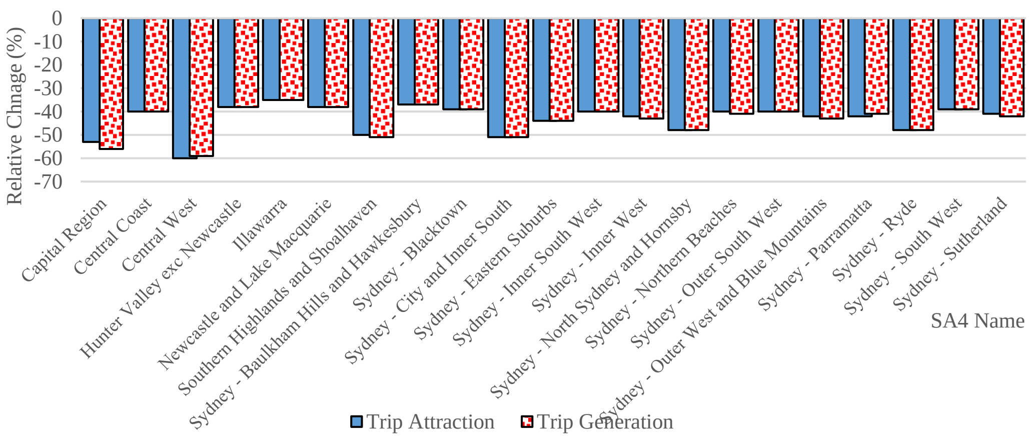

Figure 10: Relative change in volume of PT trip production and attraction in 2019 and 2020.

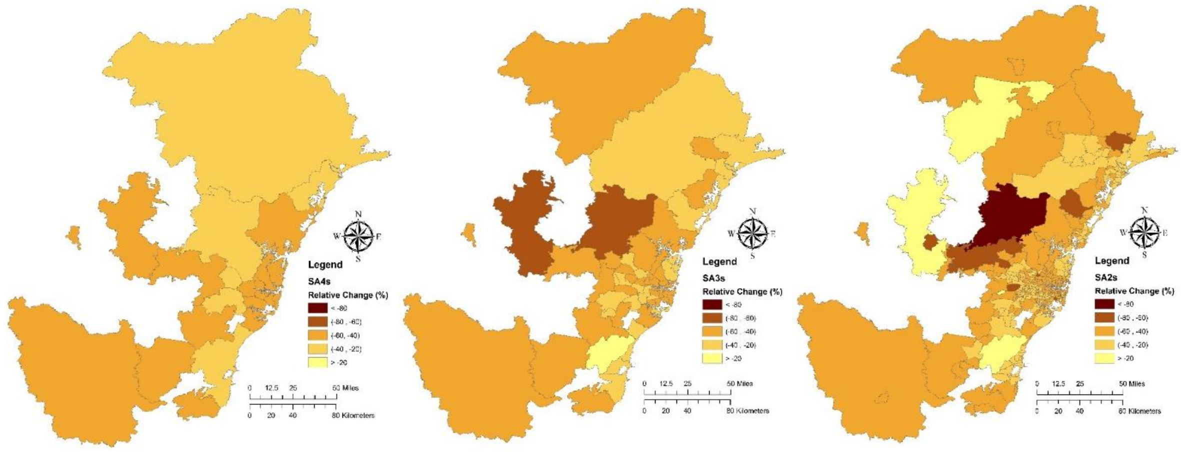

Figure 11: Relative change in volume of PT trip production from SA4s, SA3, and SA2s in 2019 and 2020.

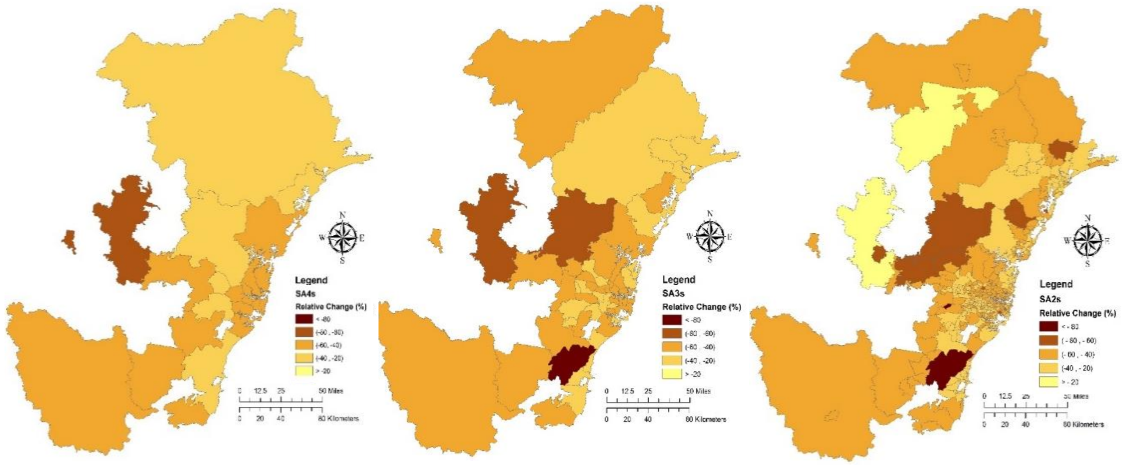

Figure 12: Relative change in volume of PT trip attraction to SA4s, SA3, and SA2s in 2019 and 2020.

3.3.2. Monthly Changes

By changing the aggregation level of time from year to month, the PT trips produced from or attracted to SA4, SA3, and SA2s for months in 2019, 2020, and 2021 are compared. The monthly volumes of PT trip production and attraction in different SA4s are indicated in Figure 13.

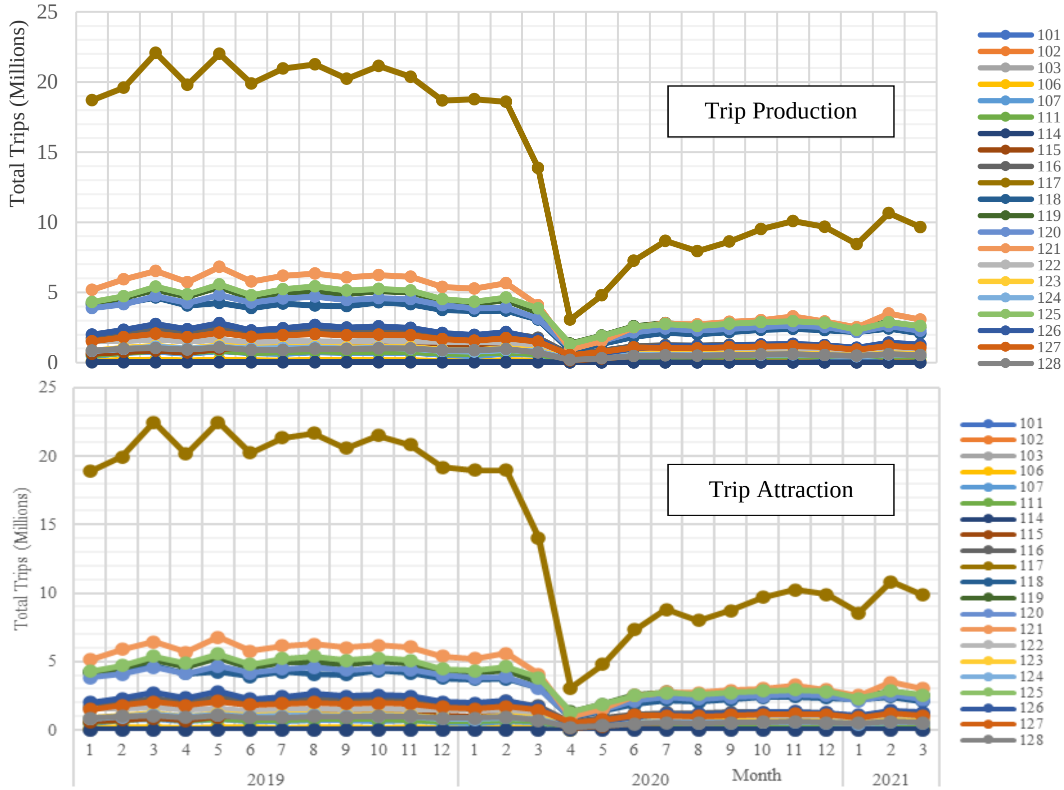

Figure 13. Monthly volumes of PT trip production and attraction in SA4s

These statistics show that zones can be categorized into three groups in terms of PT trip production or attraction volume: high-volume, medium- volume, and low- volume. The high-volume group only contains one SA4 that is Sydney - City and Inner South (SA4 ID=117). The medium-volume group constitutes of four SA4s: Sydney - Eastern Suburbs (SA4 ID=118), Sydney - Inner South West (SA4 ID=119), and Sydney - Inner West (SA4 ID=120), Sydney - North Sydney and Hornsby (SA4 ID=121), and Sydney - Parramatta (SA4 ID=125). Other SA4s belong to the low-volume group.

These groups showed similar reactions to COVID-19 condition in the greater Sydney area, whereby increasing the number of infections and travel restrictions from February 2020, the volumes of PT trip production and attraction declined and after thre decrease in infections and lifting of restrictions from May 2020, users returned and used PT services. The figures indicate that PT trips only sharply dropped for two months (March and April 2020) but with a smooth recovery trend for the next 12 months. However, the trip volumes have not reached the levels before COVID-19 (i.e. 2019), where nearly 10 million trips have not recovered yet.

To increase the spatial and time resolution, the volumes of PT trips produced from and attracted to SA4s during April 2019 and February 2019 are compared with that of April 2020 and February 2021, respectively in Figures 14 and 15. Also, the relative changes occurred in volumes of PT trip production and attraction during April 2020 and February 2021 in comparison to April 2019 and February 2019 are represented in Figures 16 and 17, respectively.

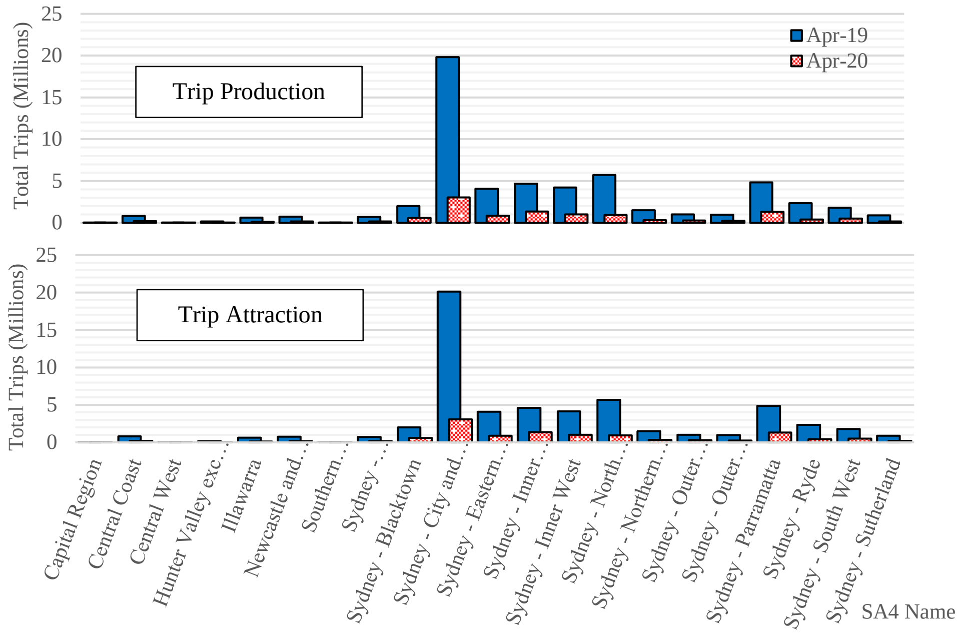

Figure 14: Trip production and attraction from and to SA4s in April 2019 and 2020

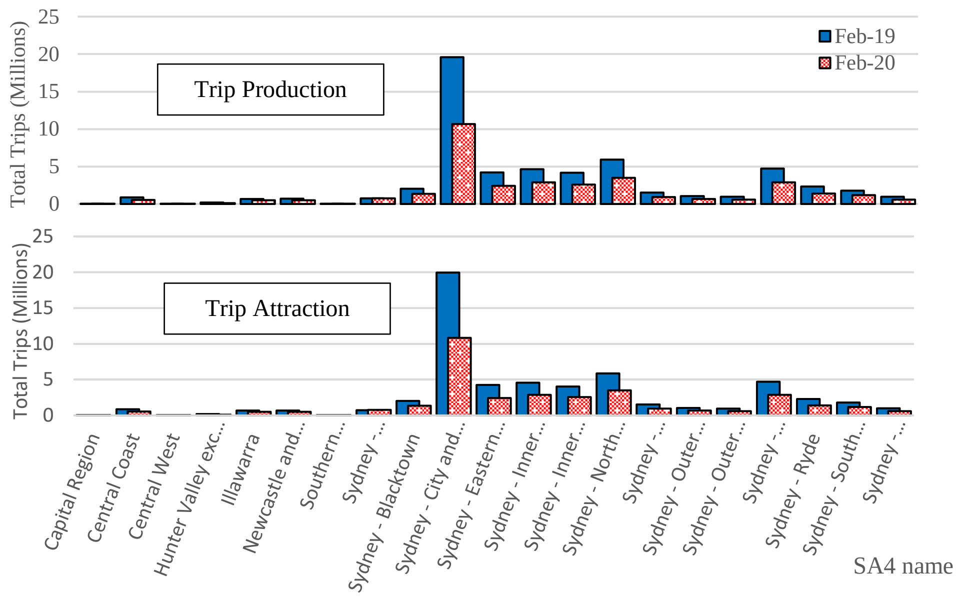

Figure 15: Trip production and attraction from and to SA4s in February 2019 and 2021

As shown in Figures 14 and 16, the SA4s experienced a decrease in range of 71% to 94% in their PT trip production and attraction volumes during COVID-19. Central West is the SA4 with the highest rate of change in both PT trip productions and attraction (i.e. nearly 95%), however, it is in group of SA4s with low PT trip production or attraction volume. Sydney - City and Inner South that is the SA4 with the highest PT trip production and attraction, underwent a 85% decline in its PT trip production and attraction volumes. Also, the figure for Sydney - North Sydney and Hornsby, which is another SA4 with high volume of PT trip production and attraction, had nearly 84% decrease in volumes of both PT trip production and attraction.

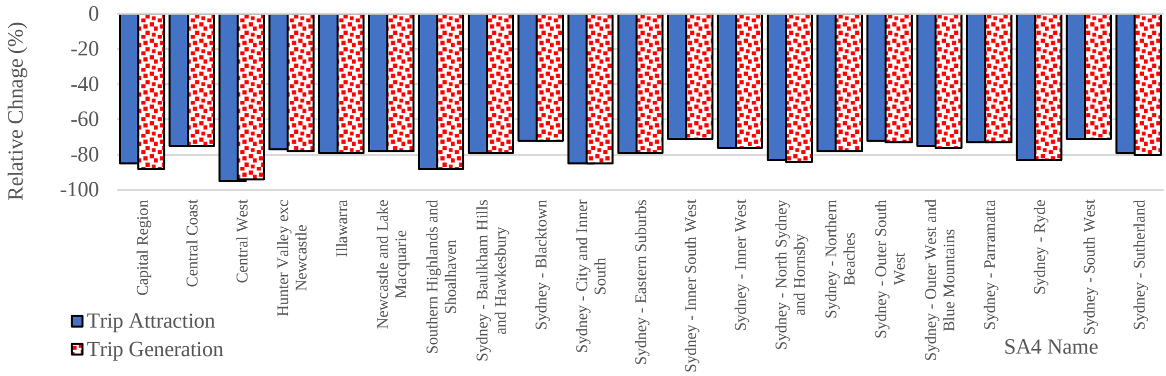

Figure 16: The relative change (%) in volumes of PT trips produced from and attracted to SA4s in April 2020 in comparison to April 2019.

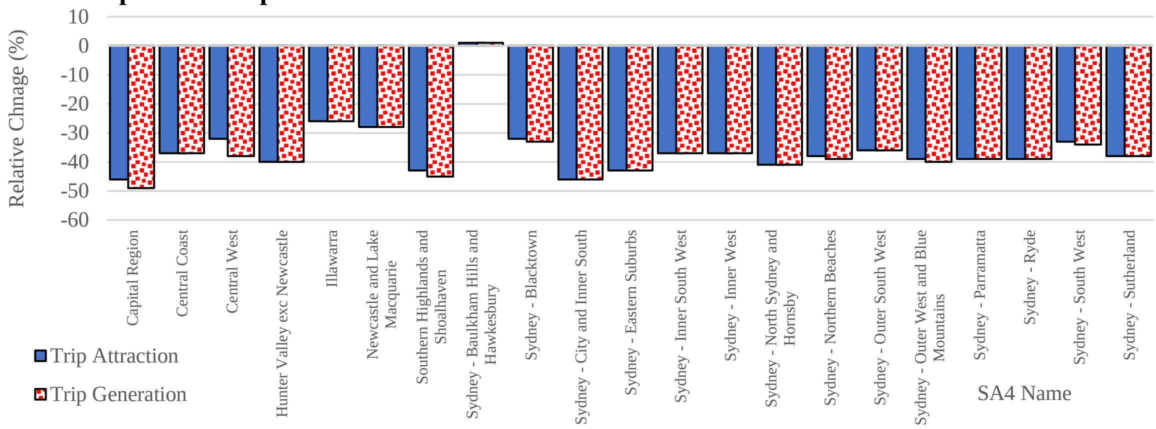

Figure 17: The relative change (%) in volumes of PT trips produced from and attracted to SA4s in February 2020 in comparison to February 2019.

As shown in Figures 15 and 17, the volumes of PT trips produced in and attracted to different SA4s in February 2019 and 2021 are compared. These figures show that apart from Sydney - Baulkham Hills and Hawkesbury, PT trip production from and attraction to all the SA4s in February 2021 (i.e. after COVID-19) still have a declining gap in range of 26% to 41% than the trips in February 2019 (i.e. before COVID-19). Illawarra and Newcastle and Lake Macquarie are the SA4s that their PT trips recovered well, while still a 26% declining gap than their trips in February 2019 is obvious. However, PT users in Capital Region have not considerably returned to use PT service and this region still has a high declining gap (50%) in its demand level in February 2019. Meanwhile, Sydney - Baulkham Hills and Hawkesbury completely recovered and returned to its normal condition before COVID-19. The PT trips produced from or attracted to this region during January and March 2021 and 2019 were also explored, where for these months also no gap between volumes of PT trip production and attraction before and after COVID-19 were observed.

3.4. Trip Distribution

To explore the changes in PT trip distribution in the network, SA2s were clustered through directed clustering in weighted networks. Clustering is a data mining method that simplifies the process of pattern recognition in large datasets. The clustering method proposed by Blondel et al. (2008), which works based on maximizing a modularity index, was employed. The modularity index is a scalar value between -1 and 1 that compares the density of intra-cluster and inter-cluster connections (Mohri et al., 2021; Akbarzadeh et al., 2018). The directed connections between SA2s are weighed by the total PT trips during each year (2019 and 2020) and used as the weights for connections in the clustering method. Hence, the SA2s forming a travel cluster will have high inter-connection with each other and low intra-connection. The results of clustering based on PT trip distribution in 2019 and 2020 are illustrated in Figure 18.

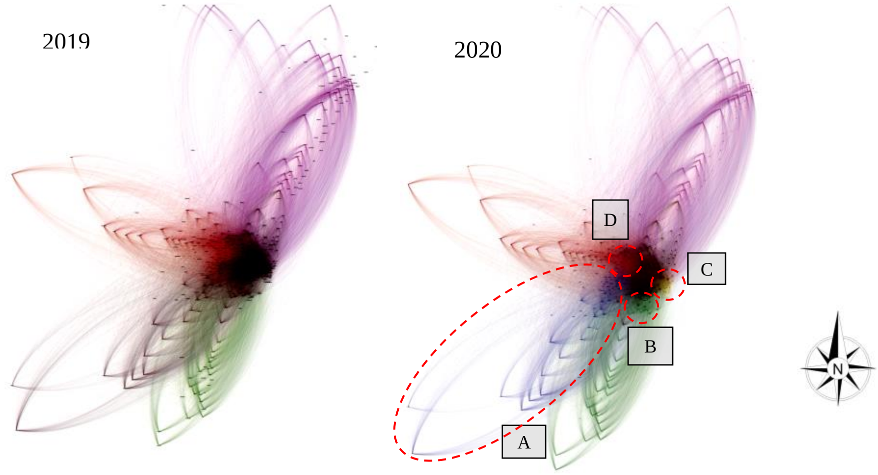

Figure 18: Trip clusters in 2019 and 2020

A comparison between the clusters in 2019 and 2020 shows that there are some differences. The PT network includes four different clusters in 2019, where the black cluster indicates the core of the Sydney CBD. However, in 2020, the number and shape of travel clusters have undergone some changes compared to 2019, shown by A to D in Figure 18 (circled in red). Areas A and C show that some parts of the black cluster in 2019 are separated and formed new clusters in 2020 (Blue and Yellow colours). Areas B and D show that some other parts of the black cluster from 2019 have separated in 2020 and joined other clusters (the Green and Red). These observations indicate that the CBD centralised black cluster decomposed in 2020; i.e. COVID-19 and its following restrictions has affected the patterns of trip distribution to and from CBD.

3.5. Correlation between population of income groups and drop in PT trips

In this subsection, the correlation between relative changes occurred in volume of PT trip productions due to COVID-19 with population of several categories of income on zonal level (i.e. SA2) is explored. For each zone (i), two different relative changes in PT trip volumes are calculated as Equations (1) and (2)

$$R_1^i = \left| \frac{(PT\ Trip\ Production\ from\ i\ in\ Apr\ 2020) - (PT\ Trip\ Production\ from\ i\ in\ Apr\ 2019)}{PT\ Trip\ Production\ from\ i\ in\ Apr\ 2019} \right| \quad (1)$$

$$R_2^i = \left| \frac{(PT\ Trip\ Production\ from\ i\ in\ Feb\ 2021) - (PT\ Trip\ Production\ from\ i\ in\ Feb\ 2019)}{PT\ Trip\ Production\ from\ i\ in\ Feb\ 2019} \right| \quad (2)$$

Equation (1) represents the relative change (in positive value) when PT trip volume in April 2020 is compared with the records of April 2019. This equation is a representative of comparing PT trip volumes during and before COVID-19 restrictions. Equation (2) compares PT trip volume in February 2021 (as a representative for after COVID-19 and its restrictions) with February 2019 (as a representative for before COVID-19). Also, the percentage of population in 12 different categories of income, starting from \$150-\$300 per week, in each zone is estimated based on data from Census 2016, $P_n^i \quad n \in \{1,2,\dots,12\}$ (Australia bureau of Statistics, 2016). A Pearson Correlation technique is employed and the correlations between R_1^i and R_2^i with $P_n^i \quad n \in \{1,2,\dots,12\}$ are calculated. The results are presented in Figure 19.

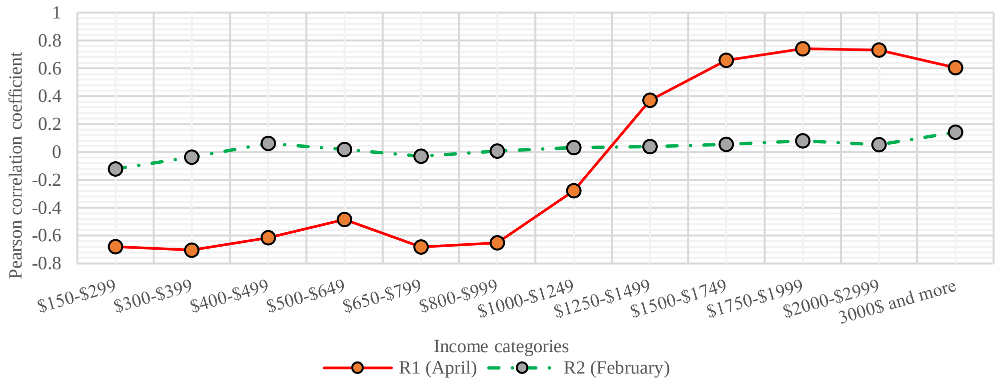

Figure 19: Trip clusters in 2019 and 2020

The correlation coefficients between R_1^i and $P_n^i \quad n \in \{1,2,\dots,12\}$ (Red line) and R_2^i and $P_n^i \quad n \in \{1,2,\dots,12\}$ (Green line) are shown in Figure 19. It reveals that R_1^i has strong correlation with $P_n^i \quad n \in \{1,2,\dots,12\}$ that means the changes occurred in PT trip volume during COVID-19, when it is compared with before COVID-19, have correlation with percentage of population in different categories of income.

An interesting observation is that for those income categories where the total weekly income is less than 1250$ a negative correlation is observed. It means that people in these income categories are probably less likely to show a significant decline in PT trips. Conversely, there is positive correlation between the reduction in PT trip volumes and percentage of population in income categories with a weekly income more than 1250$. It means the zones that have high population of people with an income more than 1250$ (i.e. high income zones) experienced significant drop in PT trip volume.

Interestingly, the correlation analysis also shows that R_2^i values have very slight (if not at all) correlation with $P_n^i \quad n \in \{1,2,\dots,12\}$ that means the changes occurred in PT trip volumes after COVID-19, when compared with before COVID-19, do not continue to show correlation with percentage of population in different categories of income. This observation could indicate that higher income commuters who used PT were more likely to stop using it during the peak of the COVID-19 outbreak in 2020, whereas lower income PT users were more likely to continue using PT throughout the outbreak. This could relate to possible work flexibility to be conducted from home or availability of alternative (less-risky) modes of transport available to higher income individuals, and PT dependency of lower income individuals. After the situation improved in first three months 2021, they all, more or less, returned to using PT across the board.

4. Conclusion

This study investigated the impact of COVID-19 and its following restrictions on the volume and patterns of PT trips in the Greater Sydney area. A database of hourly PT fare card (Opal) transactions for trips in 2019, 2020 and 2021 (up to March) were analyzed by several analytical techniques including correlation and clustering methods and the insights were presented. Several time and space aggregation levels were used to apply the methods and show the changes occurred in the volume or patterns of PT trips over space and time. The most significant findings can be summarised as:

- The number of PT trips in 2020 declined by 45% in comparison with 2019, while the decline for April 2020 was 79.4%. Also, after nearly one year the monthly demand in PT system is 40%-50% of its values in pre-COVID.

- By exploring skewness and kurtosis of PT trip histograms in morning and evening time periods, it was observed that the time PT commuters spent in their workplaces decreased during COVID-19,
- The changes in spatial patterns of trip production and attraction patterns during COVID-19 were quite similar, where regions experienced a yearly 34%-59% drop in volumes of both their PT trip production and attraction,
- By clustering SA2s based trip distribution patterns in 2019 and 2020, it was revealed that several parts of the CBD cluster were separated and either joined other clusters or formed new clusters,
- A strong correlation was observed between the changes in PT trip volumes and the cohorts of the population with a weekly income less than $1250.

The last observation in the above list is probably the most insightful one and may lead to practical decision-making implications. Understanding the relationships between job types/income levels in different zones, and the travel choices of the residents in these zones during pandemic can help planners and PT operators better allocate service capacities for the essential corridors in network and for cohorts of population that are most dependent on PT services and probably highly exposed to COVID-19 contraction risks during their commute.

Future work will investigate the possible substitution of trips from public transport to car based travel from April 2020 as well as how changes in public transport patronage affected goods distribution patterns throughout the Greater Sydney area. Moreover, because of the current emerged COVID-19 clusters in Sydney in 2021, it would be worthwhile to explore the effect of the current COVID-19 restrictions for controlling the growth of the clusters on PT trip volume and mobility and compare their results with those occurred the restrictions during May and April 2020.

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References

Abdullah, M., Dias, C., Muley, D. and Shahin, M., 2020. Exploring the impacts of COVID-19 on travel behaviour and mode preferences. Transportation Research Interdisciplinary Perspectives, 8, p.100255.

Akbarzadeh, M., Mohri, S.S. and Yazdian, E., 2018. Designing bike networks using the concept of network clusters. Applied network science, 3(1), pp.1-21.

Aloi, A., Alonso, B., Benavente, J., Cordera, R., Echániz, E., González, F., Ladisa, C., Lezama-Romanelli, R., López-Parra, Á., Mazzei, V. and Perrucci, L., 2020. Effects of the COVID-19 lockdown on urban mobility: empirical evidence from the city of Santander (Spain). Sustainability, 12(9), p.3870.

Australia bureau of Statistics, 2016, available at https://www.abs.gov.au/, accecced on 20 May 2021.

Beck, M.J. and Hensher, D.A., 2020. Insights into the impact of COVID-19 on household travel and activities in Australia–The early days of easing restrictions. Transport policy, 99, pp.95-119.

Beck, M.J., Hensher, D.A. and Wei, E., 2020. Slowly coming out of COVID-19 restrictions in Australia: Implications for working from home and commuting trips by car and public transport. Journal of Transport Geography, 88, p.102846.

Beck, M.J., Hensher, D.A. and Nelson, J.D., 2021. Public transport trends in Australia during the COVID-19 pandemic: An investigation of the influence of bio-security concerns on trip behaviour. Journal of Transport Geography, 96, p.103167.

Blondel, V.D., Guillaume, J.L., Lambiotte, R. and Lefebvre, E. 2008. Fast unfolding of communities in large networks. Journal of statistical mechanics: theory and experiment, 2008(10), p.P10008.
Bucsky, P., 2020. Modal share changes due to COVID-19: The case of Budapest. Transportation Research Interdisciplinary Perspectives, 8, p.100141.
de Haas, M., Faber, R. and Hamersma, M., 2020. How COVID-19 and the Dutch 'intelligent lockdown'change activities, work and travel behaviour: Evidence from longitudinal data in the Netherlands. Transportation Research Interdisciplinary Perspectives, 6, p.100150.
De Vos, J., 2020. The effect of COVID-19 and subsequent social distancing on travel behavior. Transportation Research Interdisciplinary Perspectives, 5, p.100121.
Gao, S., Rao, J., Kang, Y., Liang, Y. and Kruse, J., 2020. Mapping county-level mobility pattern changes in the United States in response to COVID-19. SIGSpatial Special, 12(1), pp.16-26.
Hensher, D.A., Wei, E., Beck, M. and Balbontin, C., 2021. The impact of COVID-19 on cost outlays for car and public transport commuting-The case of the Greater Sydney Metropolitan Area after three months of restrictions. Transport Policy, 101, pp.71-80.
Jenelius, E. and 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, p.100242.
Mohri, S.S., Mortazavi, S. and Nassir, N., 2021. A clustering method for measuring accessibility and equity in public transportation service: Case study of Melbourne. Sustainable Cities and Society, 74, p.103241.
Munawar, H.S., Khan, S.I., Qadir, Z., Kouzani, A.Z. and Mahmud, M.A., 2021. Insight into the Impact of COVID-19 on Australian Transportation Sector: An Economic and Community-Based Perspective. Sustainability, 13(3), p.1276.
Warren, M.S. and Skillman, S.W., 2020. Mobility changes in response to COVID-19. arXiv preprint arXiv:2003.14228.