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# RP 2021u1 Improving the connection efficiency of existing public transport interchanges

Final Report



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## Acronyms

OD	Origin and Destination
GIS	Geographic Information Systems
ArcGIS	GIS software developed by ESRI (Environmental Systems Research Institute)
LOS	Level of Service
DPTI	Department of Planning Transport and Infrastructure
SQL	Structured Query Language
MAC	Media Access Control
TGSI	Tactile Ground Surface Indicator



## Executive Summary

Public transport interchanges facilitate transfers between a wide range of motorised and non-motorised transport modes, allowing users to move from feeder modes such as walking, cycling, private vehicles and local feeder buses to rapid transit, high volume modes such as heavy rail, light rail and busways. The efficiency of this transfer, and the size of the catchment, impact the effectiveness of the broader transport network.

The increasing importance of public transport interchanges is linked to the limited opportunity for the growth of single-mode trips in low-density Australian cities. Most public transport interchanges in Australia are attracting passengers from large catchment areas around their stations, through 'park and ride', feeder buses, and non-motorised forms. Understanding these catchment areas is important in interchange planning and public transport integration.

There is a dearth of information on the catchment areas of public transport interchanges, especially in the Australian context. One of the key objectives of this study is to develop a method of determining the access distances, and in delineating the service area, using a network approach.

In this study, the service areas of all the 'park and ride' users are delineated using network data analysis, and feeder bus accessibility is assessed. These access distances and catchment area delineation will assist public transport operators in the refinement of existing feeder bus services. This will, in turn, attract an increased segment of the 'park and ride' users to the feeder buses.

This research project also provides an opportunity to trial the innovative use of Bluetooth technology implemented in enter/exit restricted areas to better understand the movement of people within public transport interchanges, and compare the results with traditional methods of monitoring.

The study was undertaken at the Paradise O-Bahn busway interchange in suburban Adelaide, using both face-to-face and Bluetooth surveys. The origins of private cars were retrieved and visualised using GIS. This study also made use of Omnia technology Bluetooth devices and 'Addinsight' to track the vehicles parked in the interchange, to extract travel pattern. Using the geocoded data, the trip distances were calculated for the corresponding networks.

This study extracted Origin and Destination (OD) patterns of passengers arriving at the interchange and compared it with the actual OD pattern obtained from a face-to-face survey. An accurate estimation of public transport OD will significantly aid public agencies involved in route rationalisation, with the potential to lead to higher usage of public transport, and deliver a lower carbon outcome. The geocoded service areas identified in this work will also help to identify the appropriate feeder routes to the interchange and to enhance connectivity.

The study shows there is a spatial mismatch of the bus feeder network and the homes of 'park and ride' users of Adelaide's Paradise O-Bahn busway interchange; that is, only 37% live within 400 metres (walkable areas) of the existing bus feeder service. This finding highlights the need for improving the feeder coverage to increase the usefulness of the interchange and to reduce car parking demand at the interchange.

This study makes several key contributions by identifying different mode catchment areas, using both traditional and new technology tools.

- The analysis shows that 'park and ride' users travel significant distances to reach interchanges where high-frequency public transport is available. As *per* the traditional survey, the average distance and 85<sup>th</sup> percentile distances are 5.1 and 6.9 kilometres, respectively.
- The analysis of Bluetooth probe data, using Addinsight tracking stations, reveals a lower average distance of 3.5 km; however, the 85<sup>th</sup> percentile distance from Bluetooth analysis shows a higher value of 7.75 km.
- This discrepancy can be attributed to the need to ensure complete coverage of Addinsight tracking stations; however, the travel patterns from both studies match closely. It is concluded that to determine the interchange catchment area, Bluetooth technology can be applied to replace traditional face-to-face surveys if adequate Addinsight stations are installed.
- The study also used smartcard (MetroCard) data to determine the catchment area of feeder bus users of the interchange. The analysis shows that, on



average, users are travelling 4 km, and the 85<sup>th</sup> percentile distance is 6.4 km.

- Parking accumulation profiles developed from both traditional and Bluetooth technology methods matched.
- This study shows that 85th percentile of the number of hours parking is nine hours, indicating that the 'park and ride' users in this interchange are long-term parkers.

This research considers various aspects of the role of public transport interchanges in improving public transport patronage, and lowering mobility related greenhouse gas emissions. It also analysed MetroCard data to extract OD pattern of people using the feeder buses and draws conclusions and informs policies regarding effectiveness of the interchange and types of interchange. The results of the research can also inform the design of interfaces to make them more convenient and attractive to users.

## 1.0 Introduction

The level of public transport use is substantially influenced by the quality of walking, cycling, and motorised access to rapid, high-volume transport modes through public transport interchanges. Public transport modal interchanges provide for efficient transfers between motorised and non-motorised feeder transport modes, including cycling, private vehicles, feeder buses and walking, and high-volume modes such as heavy rail, light rail and busways.

Many regional and state governments plan to increase public transport's share of motorised trips, within metropolitan areas to meet multiple policy agendas including the reduction of transport related carbon emissions. Achievement of this target will be influenced by many factors, including the effective use of transport hubs/interchanges. Poor pedestrian connections and inefficient feeder connections for users around modal interchanges are undermining the ability of existing public transport systems to function as truly integrated multi-modal systems.

Studies (Bryniarska & Zakowska 2017; Daudén 2014) show that smart mobility and the proper use of transport infrastructures contribute to a 'smarter city'. Interchanges constitute an important component of the urban public transport system, at various levels of provided connections.

Well-planned interchanges:

- facilitate integration between different modes of transport;
- allow passengers to shorten their overall travelling time; and
- reduce the effort required to change between modes of transport, thereby improving the quality of the experience for users

Accordingly, well-planned interchanges will lead to increased use of the public transport system, and a resulting reduction in mobility related anthropogenic greenhouse gas emissions. This study considers various aspects of the role of public transport interchange in improving public transport usage.

The biggest hurdle in improving the usage of public transport interchanges is in addressing their poor

connections with adjacent suburbs. Transport authorities typically have insufficient knowledge about the effect of catchment areas on these public transport interchanges.

Although there are studies on this topic, they seldom address private car access, especially based on primary surveys. Bluetooth technology may provide a lower cost alternative to data collect and improve the information flow to policy makers.

This study conducted and analysed face-to-face and Bluetooth probe surveys to determine the interchange catchment areas of 'park and ride' users and to understand parking accumulation profile at the interchange. It also analysed MetroCard data to draw some early conclusions and policies regarding interchanges and types of interchanges.

This study investigates issues relating to:

- (1) type of trips at the interchange;
- (2) the distance, and duration of journeys involving interchange;
- (3) who is willing to interchange;
- (4) origin and destination (OD) of passengers using the interchange; and
- (5) parking accumulation, parking volume, and parking load.

This study will enable relevant authorities to understand catchment areas around key public transport interchanges, to:

- guide the management of parking demand;
- rationalise existing feeder services, and
- allow for the proposal of new feeder routes to the interchanges.

Our aim is to make interchanges more convenient and attractive to passengers: interfaces can be designed to achieve this in several ways.

This study used the Paradise O-Bahn interchange in Adelaide as a case study and developed approaches to improve connections to existing public transport interchanges, which can be applied anywhere in Australia.

## 2.0 Significance of this research

The improvement in accessibility and the enhanced integration of other feeding modes with rapid transit systems will boost the ridership of public transport, which is a lower-carbon transport activity (Cervero, 2004). To this end, it is important to determine access distance and service coverage for various feeding modes of public transport interchanges. This research focuses on motorised access and bus feeder service coverage aspects, to improve bus feeder access to the interchanges. This will support transport planners and operators to optimise bus routes, and parking availability for transit users in the catchment range, to increase public transport usage.

A study by Dia et al. (2019) shows that across the whole network in Adelaide, the boardings at interchanges are as high as 18% of total public transport usage during weekends and 17% on weekdays. These results indicate a significant desire by users to access the public transport network at locations where a wide variety of services and high service frequency are available. Over 30% of all public transport boardings took place at interchanges. Another one-third of total boardings took place in the CBD, and about a third at suburban roadside stops.

This also highlights the demand for cross-suburban travel, as one-third of passengers are

not travelling to or from the Adelaide CBD. Another important observation is that up to 59% of interchange boardings (that is, 18% of total boardings) occurs at the three O-Bahn interchanges, with 7.72% of total boardings at Paradise, making it the most attractive public transport access point outside the CBD.

These findings indicate flexibility is significantly higher at interchanges where services intersect, and there is an increased possibility of 'trip-chaining', or using an alternative route if one is missed. Further, increased speed and frequency play a part, with the three interchanges located along with the O-Bahn track recording the highest passenger counts of any bus interchange. This is comparable to Adelaide's rail corridors, which offer fast, direct services at a frequency unmatched across the Adelaide public transport feeder network. As with bus services, the majority of rail boardings occur at designated interchange locations, rather than standard suburban stations.

Previous surveys (Dia et al. 2017; Dia et al. 2019) also find that people were walking 15 to 30 minutes to public transport services, particularly rail. However, these journeys were often made out of necessity, rather than a choice, by those who are reliant on public transport. People are keen to use high-frequency public transport (PT) and are willing to pay an additional amount (~\$2.50) to reach those nearby PT interchanges (Figure 1).

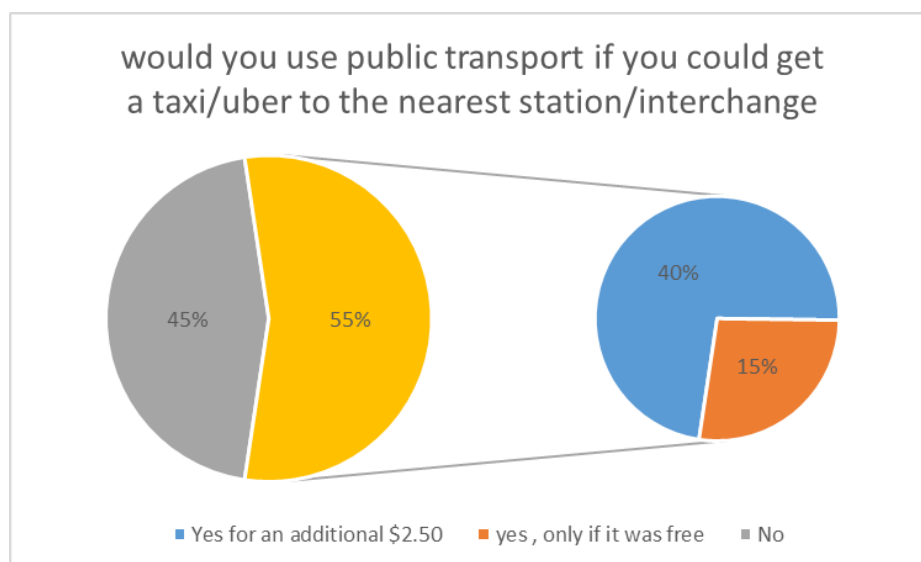


Figure 1 People who are willing to pay an additional amount to reach the nearest high-frequency PT interchange (Source: Dia et al., 2019)

### 3.0 Motivation and organisation of this report

The main motivation for this study is to reduce mobility related carbon emissions by developing an approach to determine the access distance and service area of public transport interchanges for private car and bus feeding modes using:

- Bluetooth technology;
- face-to-face surveys; and
- smartcard (MetroCard) bus data.

The access distances and service areas for different feeding modes (car and bus) are compared. Many studies in North America, for example, demonstrate that walking access distances for bus and rail transports are generally regarded as 400m and 800m, respectively.

A study by Schlossberg et al. (2007) reports a walking distance of 756m from their survey of rail stations in Europe and North America, and a study by Daniels and Mulley (2013) reports a longer walking distance, with a mean of 805m.

In Australian cities, it is demonstrated that people are willing to walk slightly more; that is, the 85<sup>th</sup> percentile is well above the figures for Europe and North America. However, there is little data relating to access distance to interchanges by private cars and buses in the Australian context. This study, therefore, addresses this gap in research.

Moreover, we could identify no published studies which use Bluetooth tracking probes to understand the access distances of the car passengers and this research is perhaps the first attempt to address this issue.

The remainder of the report is structured as follows:

- First, face-to-face survey data collection details and the results of Origin and Destination (OD) of the 'park and ride' users at the Paradise O-Bahn busway interchange in Adelaide are discussed in Section 4.0.
- Section 5.0 outlines the Bluetooth probe data collection method and the OD pattern analysis.
- Section 6.0 reports on the catchment and service area results using MetroCard data.
- Section 7.0 discusses the parking data analysis, using face-to-face and Bluetooth probe data.
- Finally, conclusions, recommendations, and potential applications of the results of this study are discussed.

## 4.0 Catchment areas using Face-to-Face interview survey data

### 4.1 Overview of face-to-face surveys

To determine the access distances and service areas of busway interchange for the 'park and ride' car users, the data was obtained by conducting brief face-to-face surveys during a morning peak period for one day at the Paradise O-Bahn busway interchange in Adelaide.

These face-to-face surveys were conducted with the help of the 'Action Market Research' group. Trained interviewers conducted all interviews. After obtaining the survey data, 'park and ride' users' data was geocoded and, using ArcGIS software Origin and Destination, the desired line diagram was developed.

This OD pattern data analysis also generated the network distance from each of the survey respondent Origin (resolution at the street level) to the Paradise O-Bahn busway interchange. This information was used to estimate the access distance and catchment area.

The surveys were conducted using a pen and paper interviewing method, where the interviewers recruited people to participate in a paper version of the survey. Each interviewer carried a clipboard and was dressed appropriately, with an identifying name tag. A supervisor checked-in with each interviewer during their interviewing period to maintain quality control. Participants selected were users willing to participate in the research and screen, according to whether they had travelled to the interchange by car/bicycle. Interviewers started at the interchange in the first

hour; then fanned out across the car parks and on-street parking in groups of two to three at a time. At least one interviewer stayed at the interchange at all times to interview people at the bus stops, while they were waiting (if they had not already completed the interview).

The Paradise busway interchange (in the North-eastern part of the Adelaide metropolitan area) is one of the three O-Bahn busway stations. It is located mid-way along the O-Bahn Busway, between Klemzig Interchange and Tea Tree Plaza Interchange, and is situated six kilometres from the Adelaide CBD.

There are ten main locations/zones (both on the street and designated zones combined) around the interchange (Figure 2) where cars are parked. The 'park and ride' users were intercepted for the survey closer to the zone where they board the bus and were asked to name or describe the zone where they parked their car.

The other details (see Appendix 1) required of the interviewees were:

- their residential location (suburb and street);
- the number hours they intend to park;
- the second leg trip details (if any);
- the purpose of the trip;
- workplace location (suburb); and
- age and gender.





Figure 2 On-street and off-street parking lots around the paradise interchange

The survey was conducted on 8th May 2019 during the morning peak period from 5.30 am, until 9.30 am. At the end of the survey period, all the car parks were filled to the capacity; that is, in total, there were 637 cars parked in the ten zones shown in the figure.

In total, 412 respondents participated in the survey, which amounts to a highly credible sample size of 65%. Further, the interviewed respondents were well-represented from all zones. Table 1 shows zones 5, 7 and 10 had more short-term parkers.

Table 1 Interviewed vs total cars parked

ZONE	Interviewed	Parked Cars	Sample
<b>Zone 1</b>	34	60	57%
<b>Zone 2</b>	60	97	62%
<b>Zone 3</b>	77	100	77%
<b>Zone 4</b>	52	165	32%
<b>Zone 5</b>	45	40	113%
<b>Zone 6</b>	13	32	41%
<b>Zone 7</b>	23	14	164%
<b>Zone 8</b>	24	30	80%
<b>Zone 9</b>	15	33	45%
<b>Zone 10</b>	69	66	105%

In terms of the response rate of those who volunteered to participate, around 17% refused to participate when they were approached. This low refusal rate could be attributed to the survey approach, in which the interviewer would walk with the respondent, and therefore the respondent didn't need to stop to complete the survey.

As an aside, the interviewers compared their iPhone data at the end of the shift; each had walked between 10,000 and 12,000 steps. This equates to between 110,000 and 120,000 steps, or 66 km and 88 km of walking by the whole team.

Using each respondent's street and suburb data, their location was geocoded at the mid-street point (Google Maps was used, and the location of that displayed by the service was geocoded).

The cleaned geocoded data had 1% (five records) less data, as the interviewees had either not reported a valid street location, or the interviewers failed to document the correct information.

#### 4.2 OD pattern from face-to-face survey

Based on the GIS data of trip origins, the road network, access distances were calculated and

visualised in a map, with the help of OD matrix analysis of the network analysis extension of GIS software ArcGIS. Figure 3 shows the OD pattern of all the car users who parked their cars at the Paradise interchange on the morning period on the surveyed day (Wednesday 8<sup>th</sup> May 2019); that is, from their origin (home location) to the Paradise interchange.

Although the visual map (Figure 3) shows a straight-line desire line OD pattern, the actual network distances (instead of 'airline' distances) are used for all the analysis in this report.

The analysis of the OD pattern of the 'park and ride' users (Figure 3) show that they are travelling 5.1 km, on average, to reach the interchange.

The geocoded locations are spatially joined (and summed) with the suburbs and figure and show the suburb's total of the origin of the 'park and ride' users. This indicates that a significant number of 'park and ride' users originate from the suburbs of Athelstone (73), Paradise (48), Highbury (29) Dernancourt (22), Holden Hill (22), Gilles Plains (17), Campbelltown (16) and Newton (16).

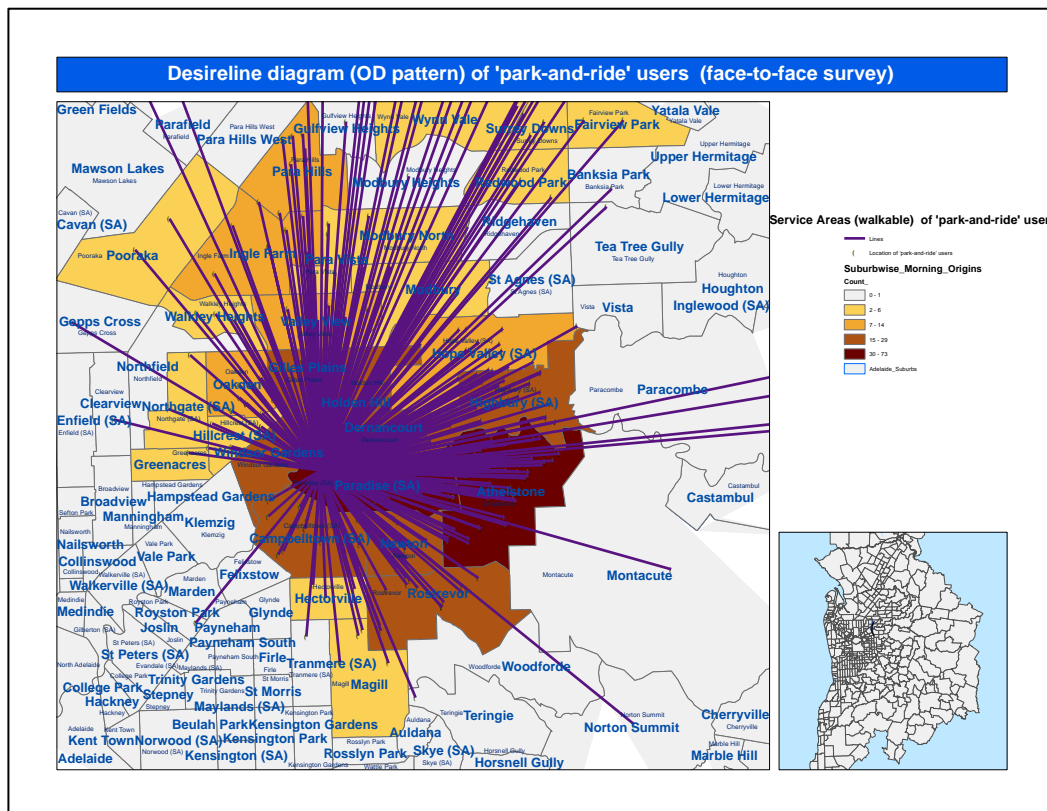


Figure 3 OD pattern of 'park and ride' users (face-to-face survey analysis)



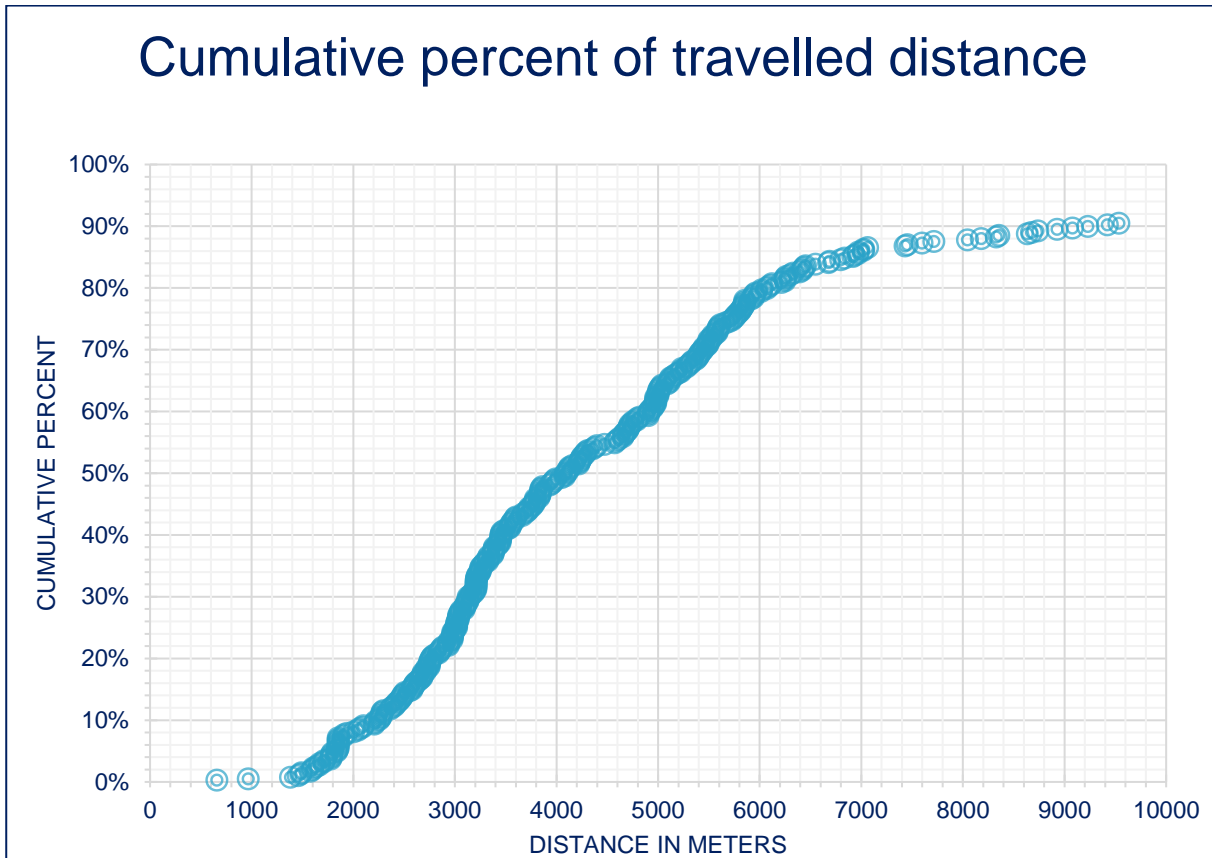


Figure 4 Cumulative percentage of travelled distance in metres (face-to-face survey analysis)

Further analysis of the cumulative percentage of the travelled distance revealed that their 85<sup>th</sup> percentile (Figure 4) travel distance is approximately 6.9 km. This indicates that most of the 'park and ride' users are travelling a relatively long distance to the Paradise interchange.

The next task was to match the location of 'park and ride' users and the existing feeder buses operating to the interchange. In the first step, both the layers are overlapped and then, using the network analysis, 400-metre network service areas were developed around each 'park and rider' location within the transit supportive area (TSA). The Transit Cooperative Research Program Report 165 (Kittelson Associates et al., 2013 ) used minimum density values (household density of 7.5 units per hectare and 10 jobs per hectare) that are capable of supporting hourly fixed-route public transport service to define transit-supportive areas (TSA).

The 400-metre network service areas indicate the acceptable walking distances, along with the

network. There can be a significant difference in service coverage areas defined by air distances from public transport stops, compared to the coverage areas when actual walking distances are used. GIS software (ArcGIS) with a path-tracing functionality to account for street connectivity was used to create accurate service coverage area map.

These walkable service areas were then intersected by the existing feeder bus routes to determine how many of them are within walkable distance from the bus routes, and then the coverage level of service is calculated as explained below:

The public transport level of service (LOS) was calculated based the ratio of those areas that are within walking distance from the feeder service (i.e. those within 400 metres of the existing feeder bus routes) to the total service areas of the 'park and ride' users located within the transit supportive area.

The analysis of the feeder bus coverage level of service (Figure 5) shows that only 37% of the 'park and ride' users resided within 400 metres of the existing feeder bus service; that is, there is a spatial mismatch of bus feeder network and the residential location of 'park and ride' users. The coverage level of service is considered extremely low, which is indicated by the level of service F in Table 2.

This highlights the potential for improvement of the feeder bus coverage in order for a shift from car-usage to public transport to occur.

One way to increase usage at interchanges is to connect them with demand from adjoining suburbs using high quality and high-frequency feeder services. In this scenario, an on-demand bus system may be a useful additional service.

Table 2 Public Transport Coverage Level of Service (Kittelson, Associates, et al.2013)

LOS	% TSA Covered	Comments
A	90.0-100.0%	Virtually all major origins & destinations served
B	80.0-89.9%	Most major origins & destinations served
C	70.0-79.9%	About ¾ of higher-density areas served
D	60.0-69.9%	About two-thirds of higher-density areas served
E	50.0-59.9%	At least ½ of the higher-density areas served
F	<50.0%	Less than ½ of higher-density areas served

**Transit-Supportive Area (TSA):** The portion of the area being analyzed that has a household density of at least 3 units per gross acre (7.5 units per gross hectare) or an employment density of at least 4 jobs per gross acre (10 jobs per gross hectare).

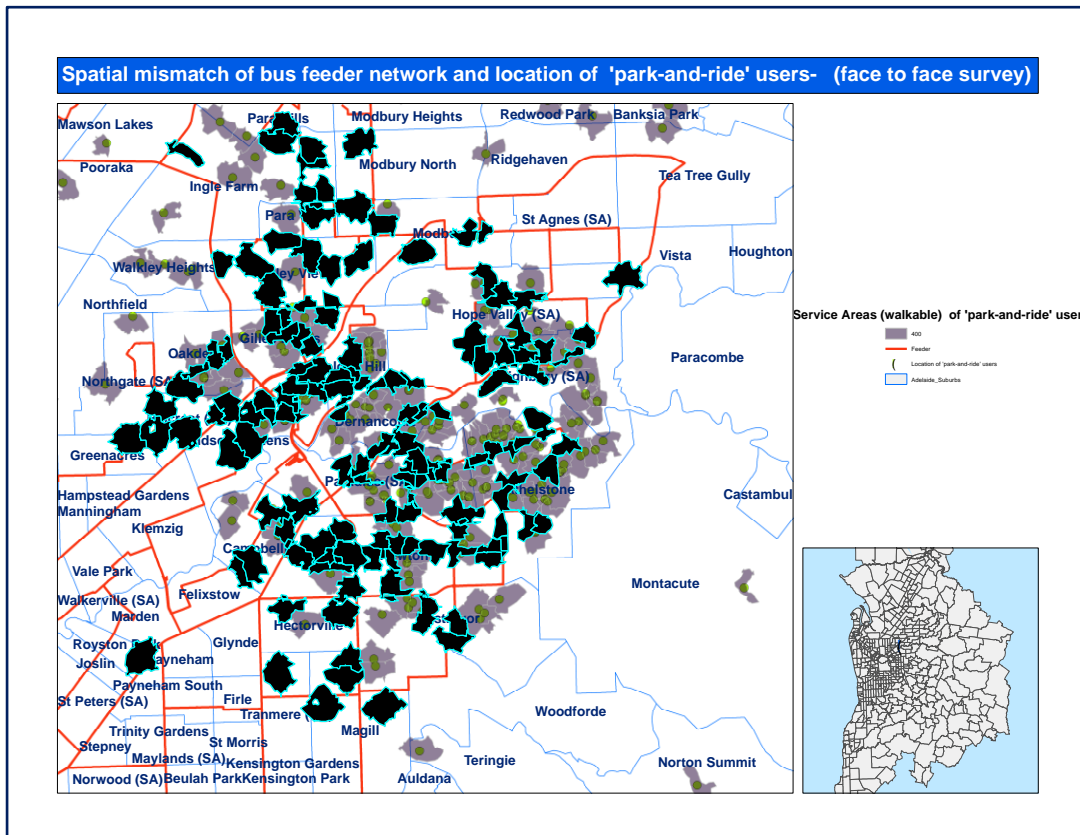


Figure 5 Spatial mismatch between the location of 'park and ride' users and the coverage of feeder bus services

## 5.0 Catchment areas using Bluetooth probe survey data

This section describes the details relating to the Bluetooth probe survey data collection technique.

An Addinsight Omnia detection unit was installed (Appendix 2) within the southern Paradise interchange car park to analyse the trip patterns of car park users.

Addinsight is the traffic intelligence system developed by the South Australian Department of Transport and Infrastructure. It provides real-time road traffic analysis of probe data from Bluetooth, WiFi and other sensor technologies (SAGE Automation, 2019).

SAGE Automation engineers, manufactures and integrates connective data solutions for Addinsight, which is a cost-effective system centred on a network of low-cost receivers that can provide network-wide performance indicators in real time.

The enclosure (see Appendix 2) was temporarily strapped to one of the streetlight poles within the interchange carpark entrance. The unit was installed for 48 hours, and then decommissioned

and was removed. This device was connected to the main Addinsight production system to allow the data to be cross-referenced with data collected from the greater Addinsight network in Adelaide. This unit collects unique IDs using Bluetooth scanning system. Bluetooth Classic is the traditional scanning method used by most Bluetooth systems. This method cannot detect smartphones and is ideal for the reliable, repeatable detection of in-vehicle devices such as GPS, hands-free kits and car entertainment units.

A 3G connection was established to the Department of Planning Transport and Infrastructure (DPTI) network to enable survey unit data collection to pass through to Addinsight. This will then correlate the detections with the wider network of Addinsight capture stations and plot the Origin and Destination data (SAGE Automation, 2019). This unit typically has a range of approximately 100 metres, which is indicated in Figure 6. This unit enabled capture probes to access car parks 2 to 5.



Figure 6 Bluetooth probe Omnia unit location at the Paradise interchange

## 5.1 Hardware details of Omnia Plus Capture Station

The effectiveness of the Addinsight system is dependent on the quality of the input data, which is why DPTI invested in the development of the SAGE Omnia Plus unit. This device can be used to extract an Origin-destination matrix for the entire network or any sub-area using various filtering criteria. In addition to transmitting iBeacon data, the Omnia Plus brings three different scanning technologies into the one device (SAGE Automation, 2019):

- Bluetooth Classic is the traditional scanning method for most Bluetooth systems, and was used by this study to detect vehicles.
- Wi-Fi is ideal for pedestrian detection that can locate smartphones, even when not connected to an access point. The potential sample size is huge due to the ubiquitous nature of smartphones, but detections are not as reliable as Bluetooth detections. Although this data was collected, it was not further analysed as this data was beyond the scope of this particular study.
- Ubertooth is a Bluetooth scanner that can reliably detect Bluetooth devices if they are paired with another Bluetooth device. It generally detects three times more devices than a Bluetooth Classic scanner.

## 5.2 Study Date and Periods

The survey was conducted on two days (7<sup>th</sup> and 8<sup>th</sup> May 2019) and the detailed analysis in this report is restricted to one four-hour peak morning period of data collected on Wednesday 8 May 2019. This is done to coincide with the face-to-face interview date and time; thus, enabling a comparison of the results from both survey methods.

The focus of the results is based on the main direction of travel. In the AM period, the focus is on citybound trips to identify the origin of car park users. The AM period captured from 6 am to 10 am, and included early arrivals to the car park, as well as any 'late starters'. There is a definite peak period between 7 am, and 9 am, but these outer intervals ensured that most trips are included. Site detection rate and parking duration results are reported across the entire day, so temporal changes can be more easily observed.

## 5.3 Bluetooth probe survey data analysis

The data analysis suggested that the actual detection radius was larger than expected, as some portion of Darley Road through-traffic was also detected. However, this data noise was removed using filters with the incorporation of data from other Addinsight stations.

The Select Link Analysis results in Figure 7 demonstrates the amount of noise created by the Darley Road probes.

Select link analysis is a versatile query that can complement an origin-destination matrix assessment. Some potential use cases include:

- a) plotting the routes used by probes travelling between distant locations; and
- b) plotting the trip patterns of probes that pass through an intersection or travel along a road segment to see where they came from and from where they were heading.



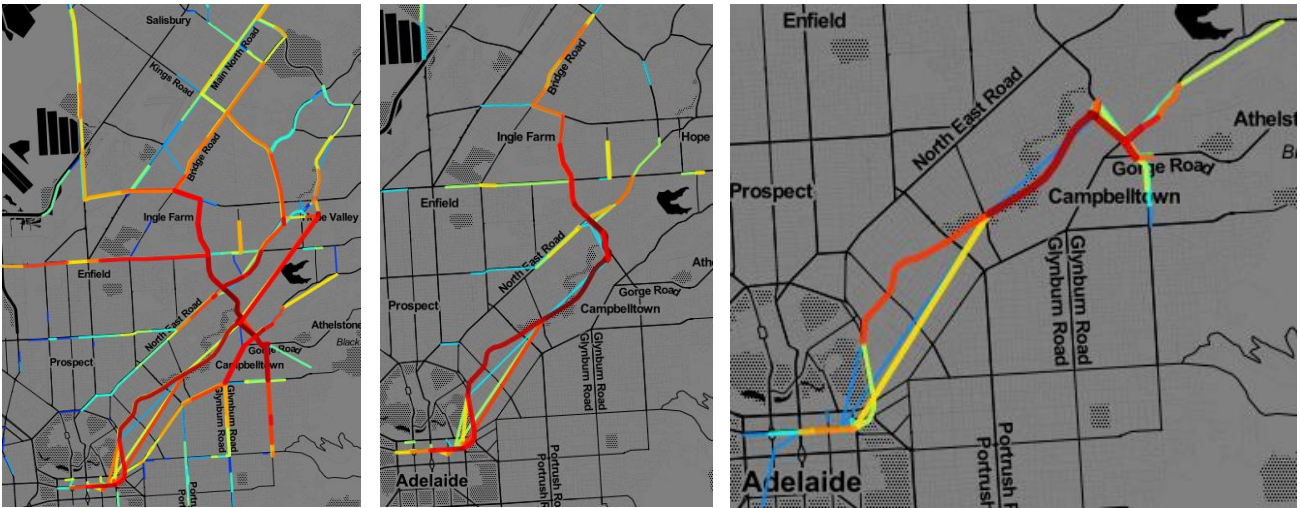


Figure 7 Select Link Analysis results for AM peak: using only the Paradise car park unit as the filter site (left), with additional filters to exclude TPP, Gorge Rd, Lower NE Rd and St Bernards Rd (middle), with additional filters to exclude TPP, North East Rd and Sudholz Rd (right)(Source: SAGE Automation, 2019)

The data cleaning was done at two stages by introducing additional filters. The introduction of the additional probe filter required the analysis to be split into two separate result sets:

- one to the north; and
- one to the south of the interchange.

The results were displayed together on the map, as shown in Figure 8.

The above select link analysis showed only link loads. However, to estimate the extent of influence area of the interchange, the network

distance from the nearest 'Addinsight' station from the location of the 'park and ride' users of Paradise interchange was calculated using Network analysis in ArcMap software.

The desire line (Origin-Destination) diagram was developed from the analysis is shown in Figure 9.

From Figure 9, it is clear that many trips originate from the northeastern suburbs of Paradise and Newton, and the average distance of travel is around 3.5km.

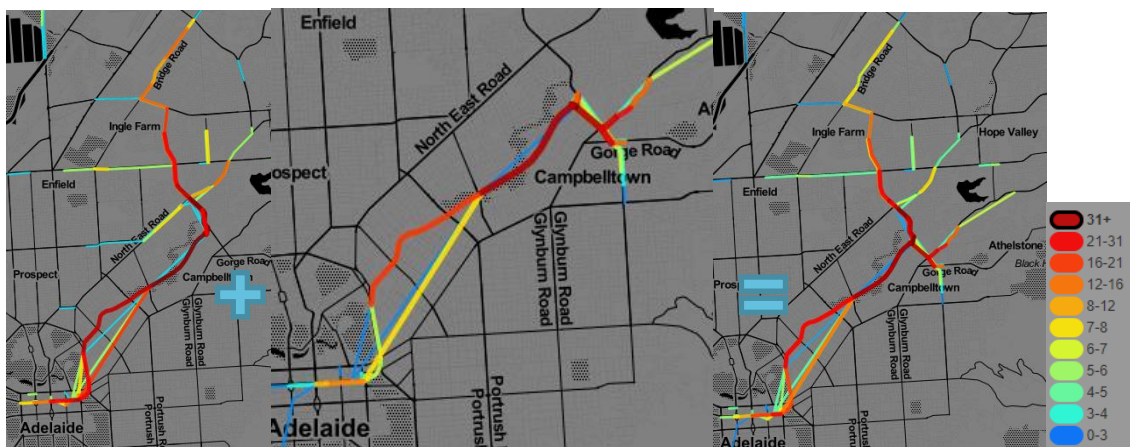


Figure 8 Combining two separate Select Link Analysis results for AM peak to get a general overview of the trip patterns (Source: SAGE Automation, 2019)

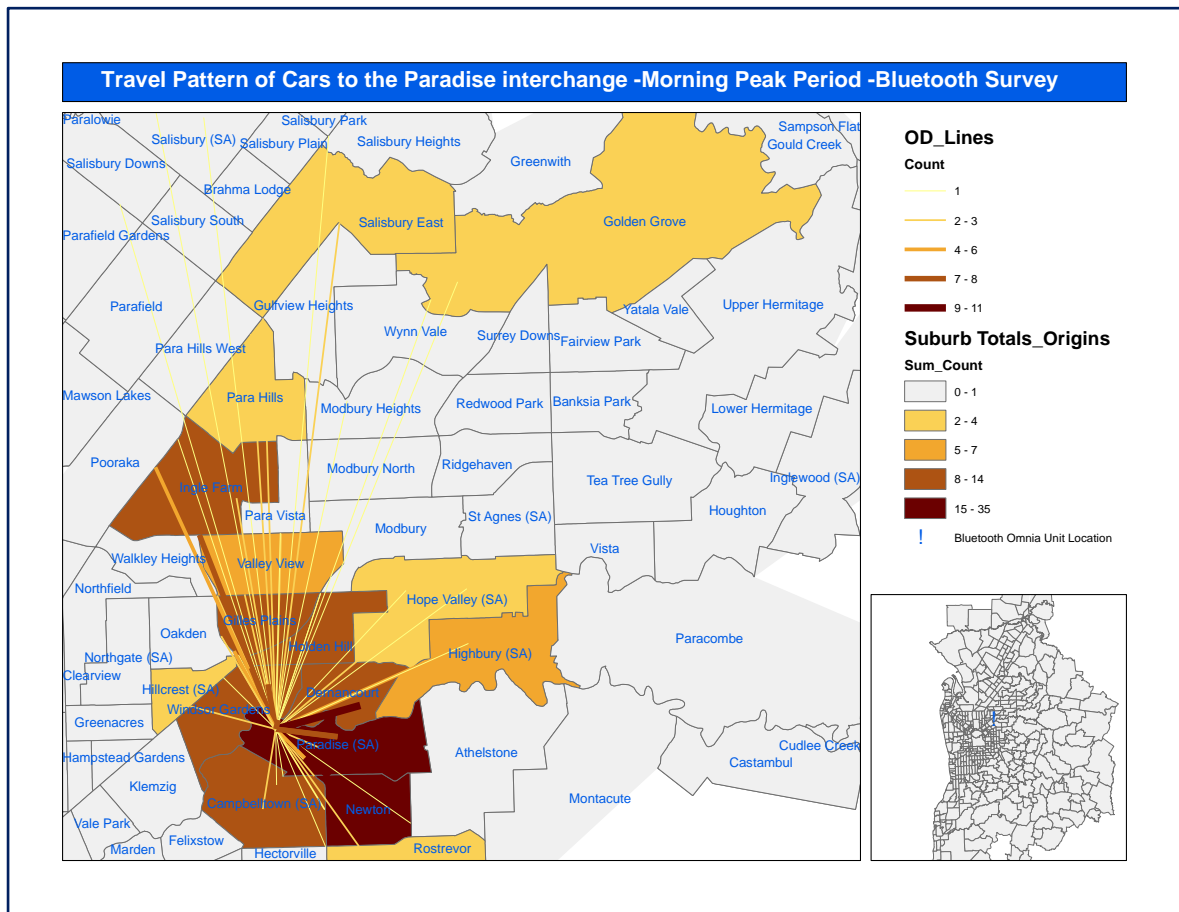


Figure 9 Desire line diagram of 'park and ride' user location to the interchange

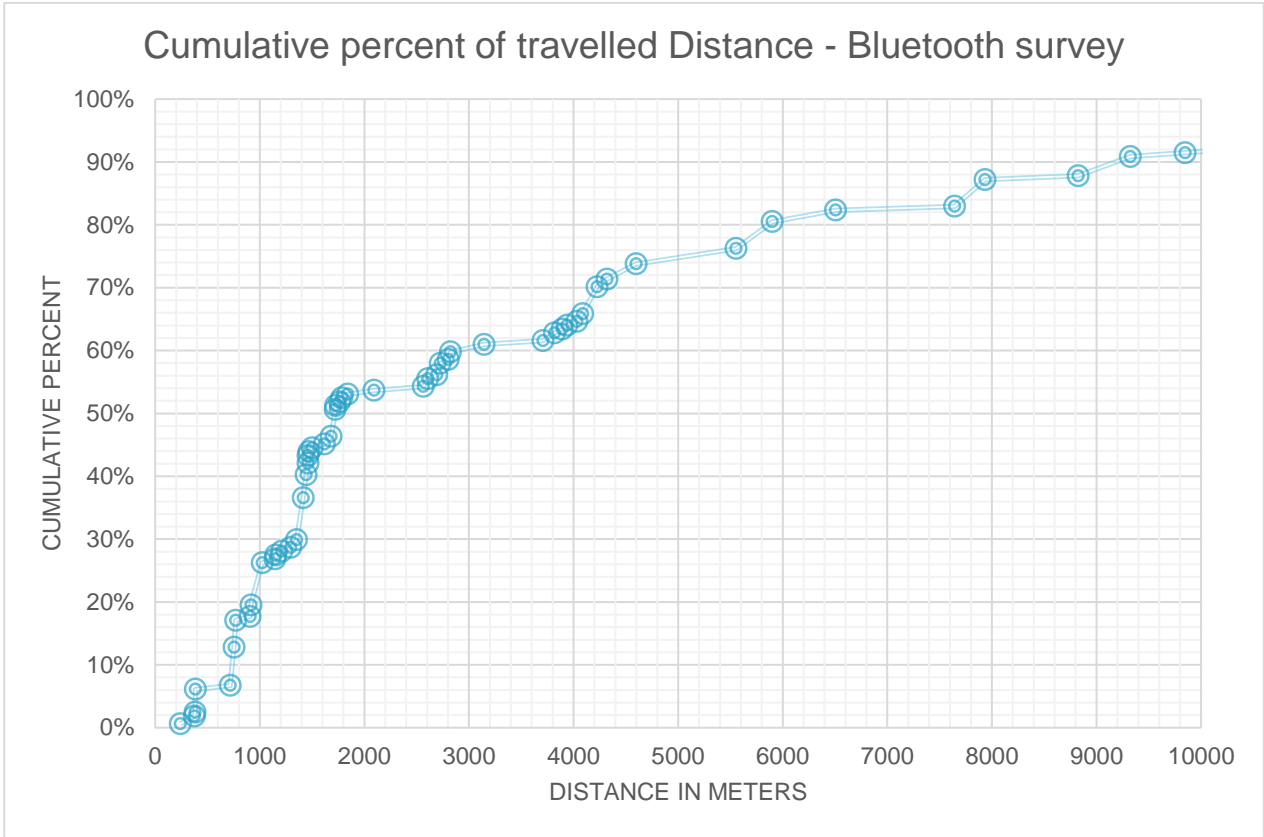


Figure 10 Cumulative per cent of travelled distance to reach the interchange – Bluetooth survey

Using the count of vehicles from each station, 85<sup>th</sup> percentage of travel is 7.75km (Figure 10). However, the main limitation of this analysis is that the accuracy of the analysis depends on the number and location of 'Addinsight' stations.

For example (as in Figure 11), there are no trips that originated from Athelstone, as there is no Addinsight station in that suburb. When the OD

pattern from Bluetooth survey data is compared with the OD pattern of the face-to-face surveys, although the travel patterns match to a large extent, the 85<sup>th</sup> percentile access distances do not tally. This can be explained by the less than perfect coverage of all regions by Addinsight stations.



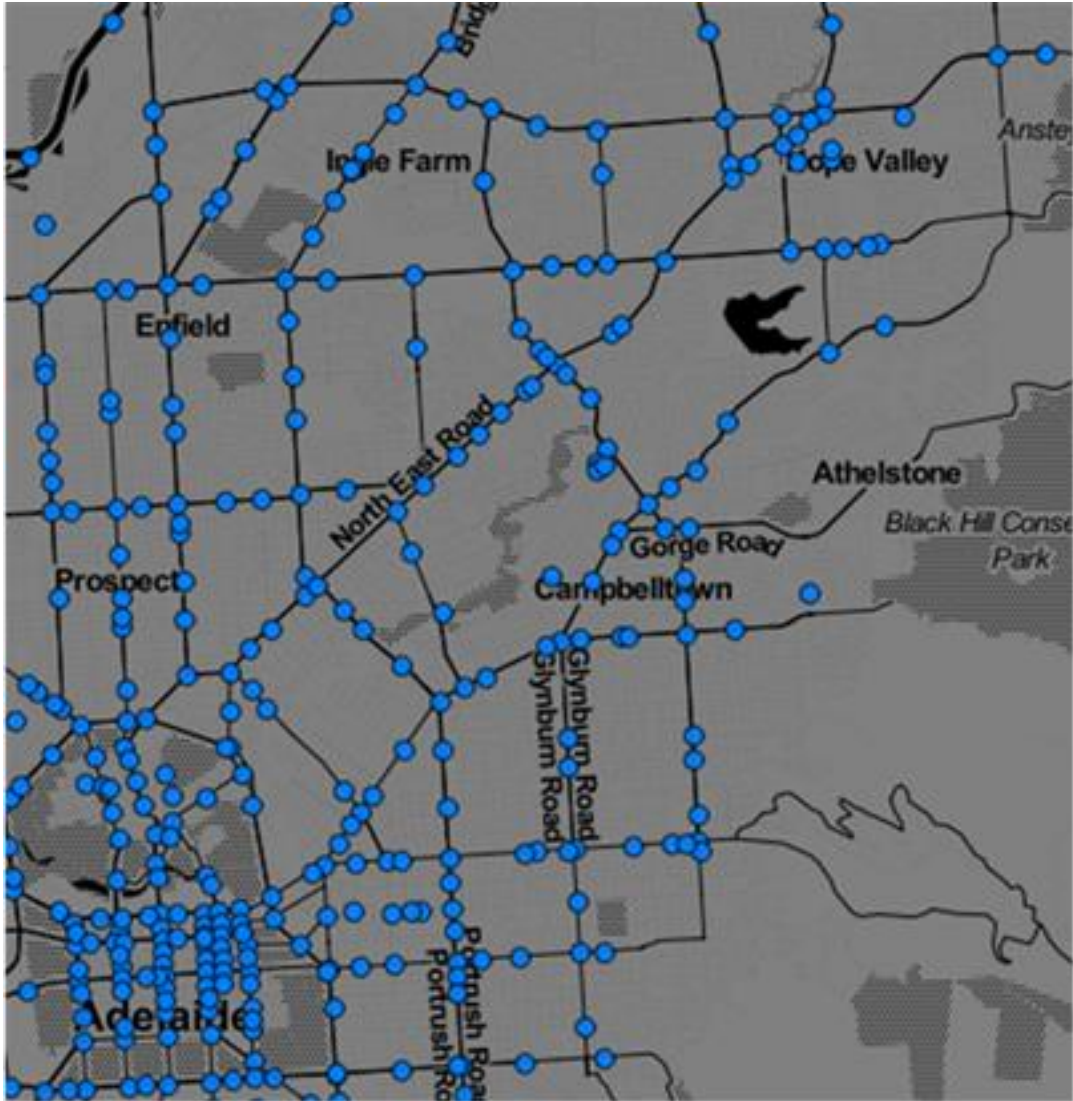


Figure 11 Addinsight Bluetooth coverage within the study area

## 6.0 Catchment areas of feeder buses using Metro Data Analysis

Public transport agencies increasingly adopt automatic data collection systems as a significant amount of boarding data becomes available, which provides an excellent opportunity for transit planners to access spatial-temporal data (Rahbar, Hickman & Tavassoli, 2017; Tao, 2018). This can then be used for a better understanding of human mobility and the performance of a transit system (Mahrsi et al., 2017).

Smartcard data can be used to examine a whole network regularly, and to make practical estimates of OD patterns and is a great asset in understanding issues of public transport reliability (Mosallanejad, 2018).

Reliable knowledge of demand for public transport will facilitate the design of appropriate routes and increase efficiency; this will, in turn, enhance patronage. Although the origin information can be easily obtained from the smart card transactions, it is much more challenging to extract destination information, particularly where users are not required to swipe while alighting.

The data used in this research was provided by the Department of Planning Transport and Infrastructure (DPTI) in Adelaide for May 2017. A methodology was developed using SQL software and based on the trip-chain model to create an OD matrix for feeder bus users to the interchange (Mosallanejad et al. 2019).

## 6.1 Data structure

The primary function of the smartcard is to collect a fare, but it can also be used to understand users' travel patterns. Usually, smartcard data does not directly provide the information required for planners (Kurauchi & Schmöcker 2016) as the flat-fare policy (and some zonal fare policies) require commuters to tap once after boarding, recording only a single transaction.

In comparison, some cities provide an exit reader as well if the fare is based on distance or zones. In such a system, each trip generates records for both boardings and alighting (Kurauchi & Schmöcker 2016).

In Adelaide, where a flat-fare policy is provided, commuters validate their cards when they board but not when they alight. Three modes of transport are available: bus, train and tram. The information for each smartcard transaction includes:

- card identification;
- time and date;
- transport mode used;
- fare type;
- stop code, stop label and route code;
- and validation type (see Table 6.1).

When passengers swipe their card and pay an initial fare, this fare is valid for two hours, and passengers can use any public transport within this time, at a single cost.

Table 3 Individual MetroCard information

Media code	Fare type	Transport mode	Date & time	Stop code	Latitude	Longitude	Route code	Direction
807***CB	SV	4	2017-05-01 09:49:35	8089	-34.979759	138.525912	Tram	1
94E***FB	TICKETS	1	2017-05-01 10:39:15	3351	-34.924343	138.598468	251	1
11C***89	28DAY	1	2017-05-05 10:46:32	3285	-34.920343	138.607313	271	1
707***27	OTHER	1	2017-05-01 11:04:05	2072	-34.870071	138.638452	H22	1
584***97	SV	5	2017-05-08 11:06:36	1852	-34.860916	138.650472	GWC	1

Note: Transport mode: 1 = Bus, 3 = Station, 4 = Tram, 5 = Train

## 6.2 Estimation of origin and destination matrices

Knowledge of transit demand plays a key role when planning to improve the performance of a public transport system. A common method for estimating the destination is the ‘trip chain’ model. As noted in Section 6.1, each smart card can provide the boarding location and time of each bus, trip but not the alighting location. As a result, the trip chain model assumes the alighting stop is located within an acceptable walking distance of the next stop. Some assumptions considered in this algorithm are:

- The initial boarding location of a trip leg is the ‘origin’.
- A user’s alighting point is assumed to be within walking distance of the next boarding stop.
- Users return to the place where they first boarded that day, or to some other nearby station.
- Users take the first available service after arriving at a boarding place.
- Each smartcard is used by a single user, not by multiple users.

- Those who use the public transport system do not use any other mode of transport that day.

## 6.3 Origin and destination analysis

One of the critical considerations when planning transit services is estimating the demand for each route, to determine the frequency and capacity of the vehicles (Tamblay, Muñoz & Ortúzar 2018). An OD matrix provides critical information for transit planners by estimating the number of journeys between different zones and providing meaningful information which can then be used in planning, design and management.

After analysing the data based on the trip chain model, bus users’ origins and destination counts during the morning peak were derived.

The feeder bus OD is then plotted from suburbs where ‘park and ride’ passengers are located (Figure 12).

Further analysis has revealed that 85<sup>th</sup> percentile of distance bus feeder is 6.4 km (Figure) and, on average, people are travelling 4 km to reach the interchange by feeder buses.

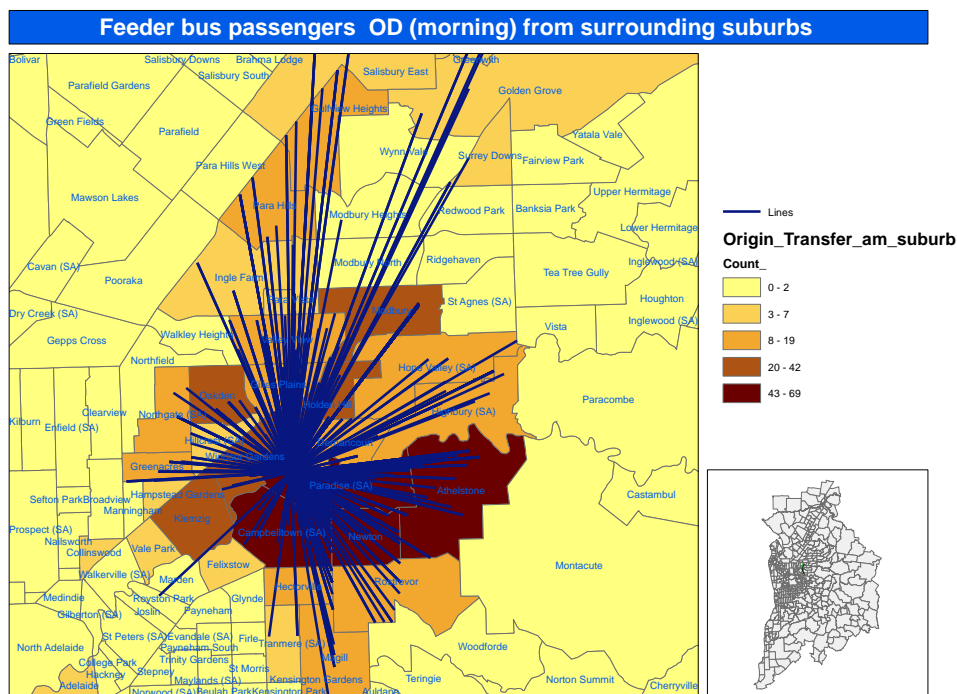


Figure 12 Desire line diagram of the feeder bus passengers from their residence to the interchange

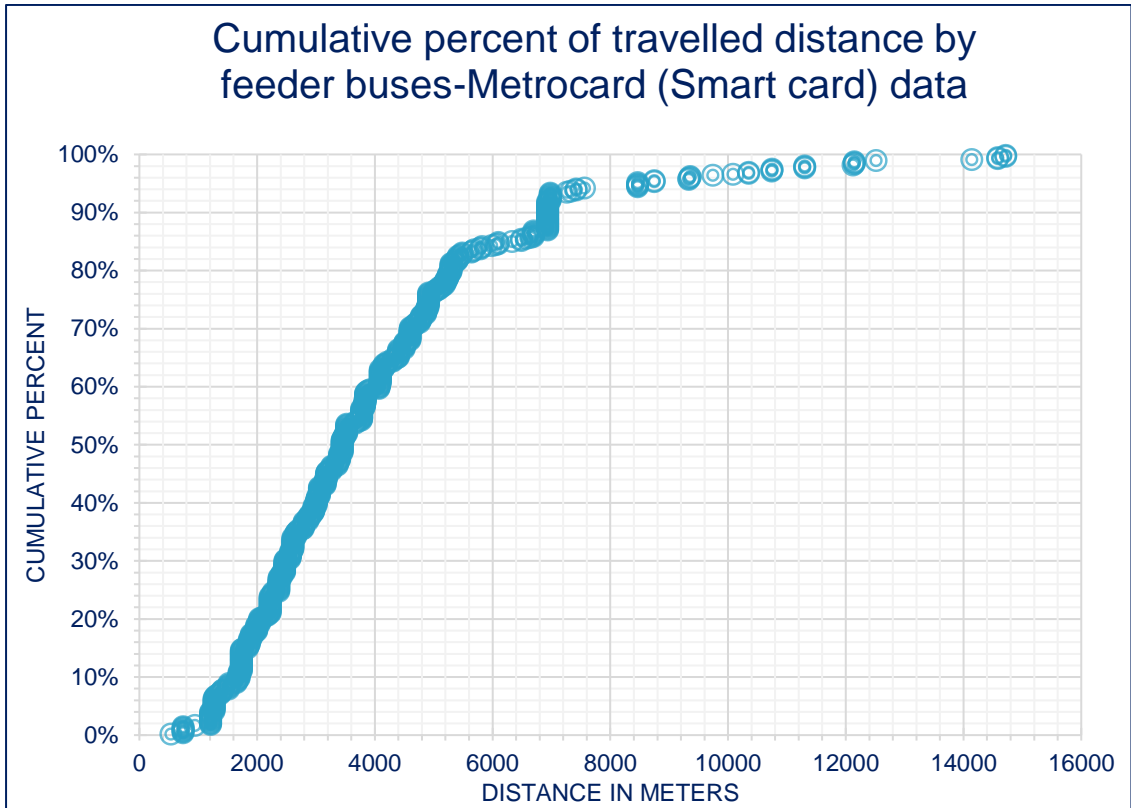


Figure 13 Cumulative per cent of the travelled distance of feeder bus users to the interchange

## 7.0 Parking accumulation

### 7.1 Parking accumulation- Face-to-face surveys

Another objective of this research is to determine the aggregate accumulation profiles of off-street usage-related parking facilities and on-street parking facilities around a public transport interchange.

Parking accumulation is the number of vehicles staying within a parking facility at a specified time. A parking accumulation profile is a graph showing the variation of parking accumulation of a parking facility within a specified period. The capacity of a parking facility is the number of parking spaces provided in a parking facility. The occupancy of a parking facility is the parking accumulation divided by the capacity.

The interviewers collected most of the data required from the 'face-to-face survey. As each car park was surveyed only one day morning

period, the daily or weekly variation of parking accumulation was not discussed.

Parking availability and parking cost are important factors that influence users' behaviour, and detailed and accurate information on parking supply and demand will help transport planners when improving the interchange parking facilities.

Figure 14 shows the parking accumulation profile for all the parking lots in and around paradise interchange during the peak period of parking.

Figure 15 reflects the total number of hours interviewees wanted to park in all the parking lots. From this figure, it is clear that 85<sup>th</sup> percentile of the number of hours parking is nine hours; this indicates that the 'park and ride' users in this interchange are long-term parkers.

It is not surprising to note this trend, as their main trip purpose is either work (89%) or Education (9%) (Figure 16 a), and most (96%) of them are CBD bound trips (Figure 16 b).

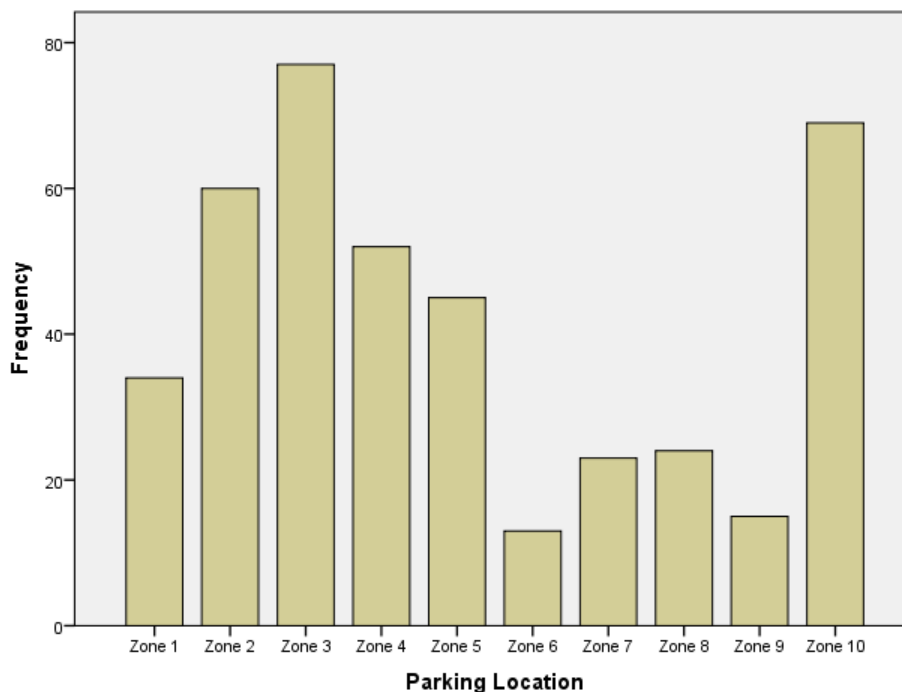


Figure 14 Parking accumulation at the various off-street and on-street parking lots around the interchange

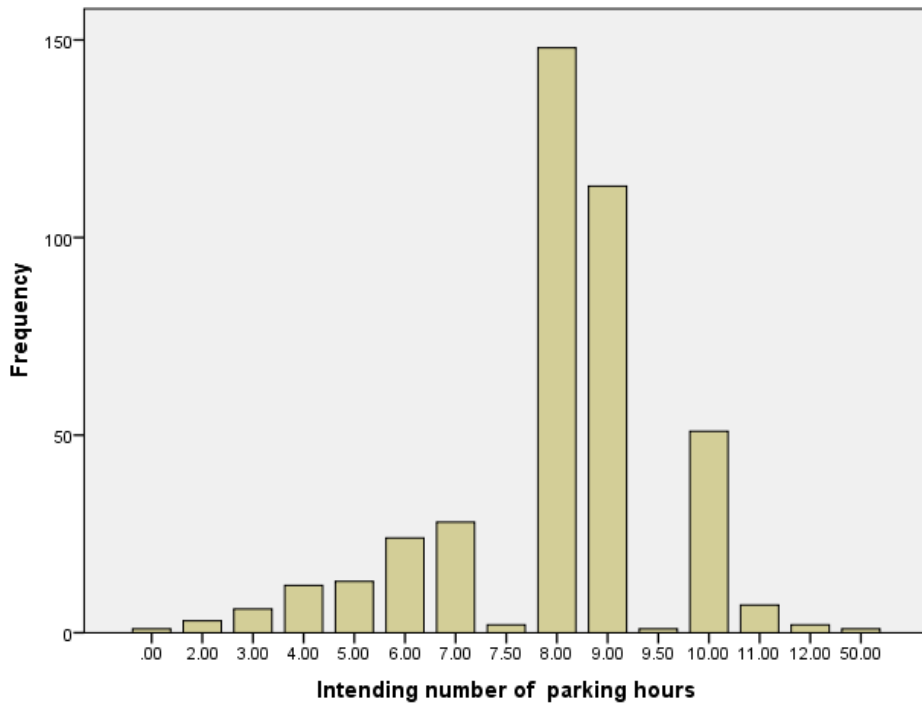


Figure 15 The intended number of parking hours at the interchange-users

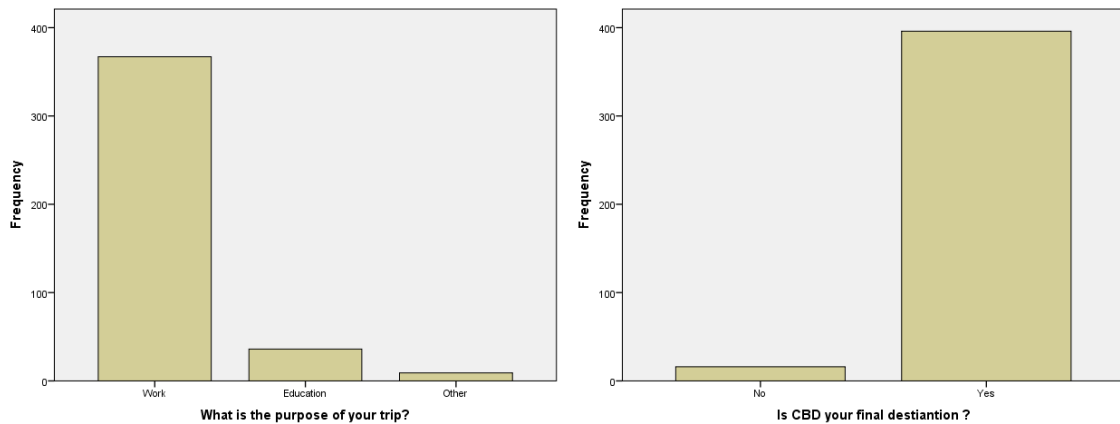


Figure 16 a) Purpose and b) the final destination of the public transport users at the interchange

Most of the trips were recorded as either for work or education. Further, it is noted that the people using this interchange during the peak period are young or working-age adults (Figure 17a).

As in many other studies, the data in this study shows more females (58%) used the public transport interchange (Figure 17b) in the study area.

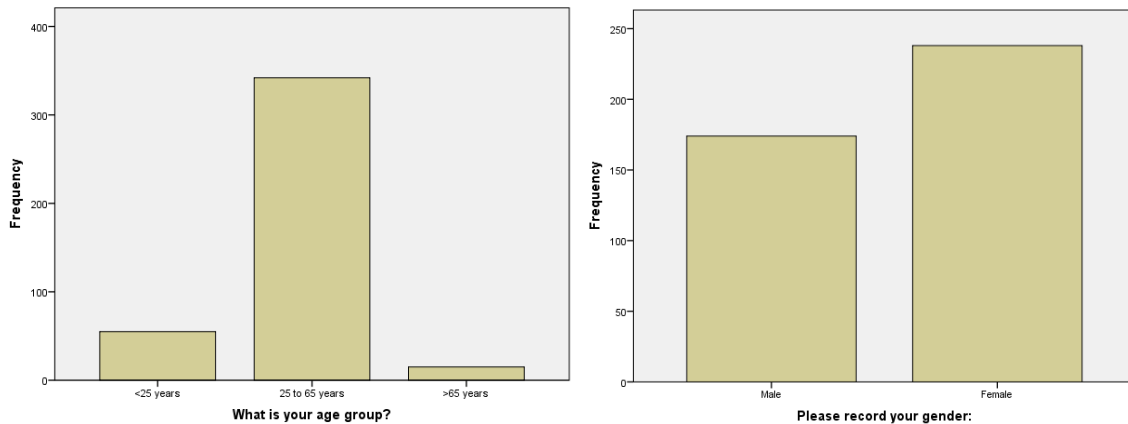


Figure 17 a) Age group and b) the gender of the public transport users at the interchange

## 7.2 Parking accumulation from Bluetooth survey probe data

The detection plot (Figure 18) shows each raw detection as a black dot. The vertical position of each dot corresponds to its media access control (MAC address). The thick blue lines overlaid on the dots indicate chains of detections of the same device, interpreted as visits of a particular device, such as the Bluetooth unit of a vehicle. The horizontal length of a chain represents the dwell time of the device within the

range of the Addinsight unit. At this site, we expected the dwell time to be fairly short; for example, during the morning, it would only be from the time the vehicle enters, until it is parked and turned off. Exceedingly long chains of raw detections are disqualified, as they are likely to be devices that are continuously within the detection range (such as those of employees, and computer equipment). The thick orange lines are parking trips which have been identified by pairing the first incidence of a chain to the last incidence of a chain for the same MAC address.



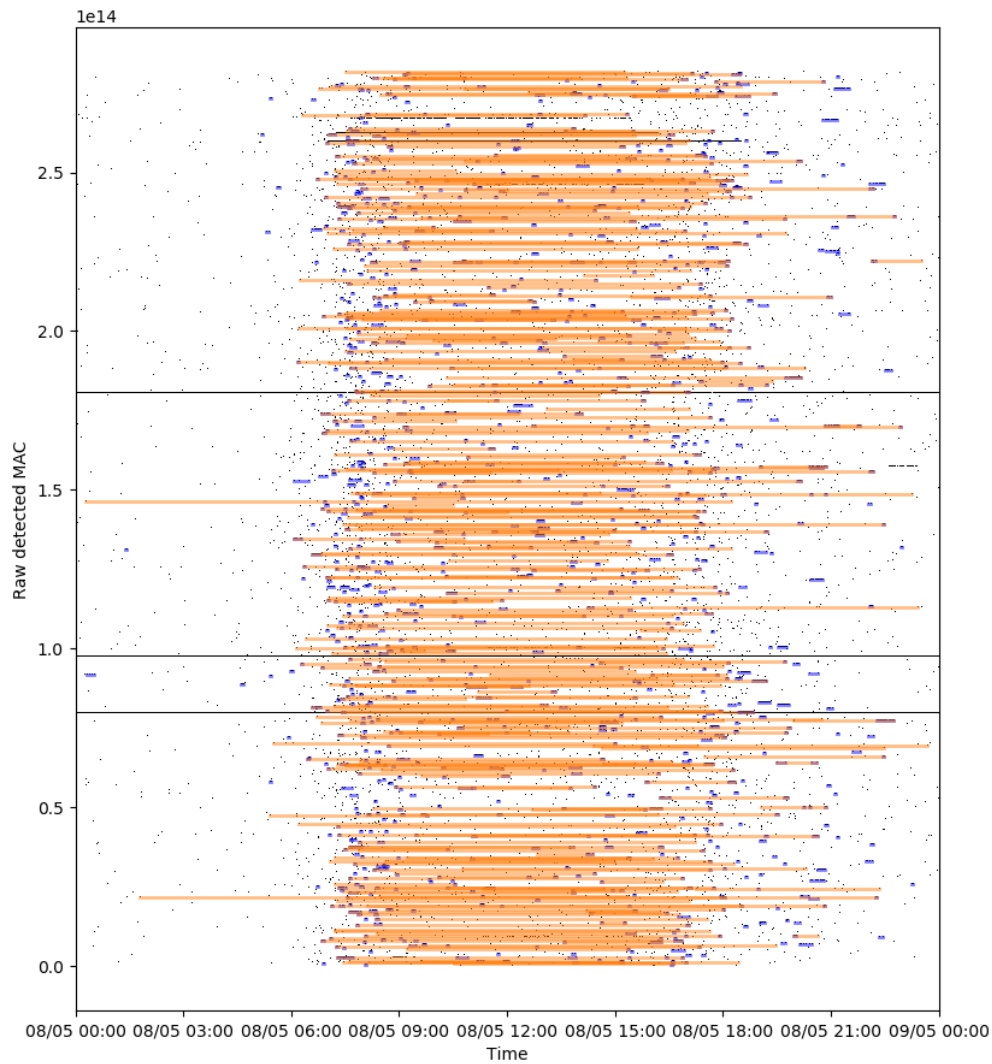


Figure 18 Number of hours parking from Blue tooth probe data analysis (Source: SAGE Automation, 2019)

### 7.2.1 Dwell Time and Park Time histograms

These histograms show the distribution of dwell time (Figure 19a) and parked time (Figure 19b), respectively.

Dwell time corresponds roughly to the time taken for the vehicle to enter the lot and find a park or to leave; however, it is not the focus of this study.

The analysis of parking profile data from both the traditional (face-to-face) and Bluetooth surveys reveal similar trends, and hence, Bluetooth survey methods can be used with confidence to gather parking accumulation data.

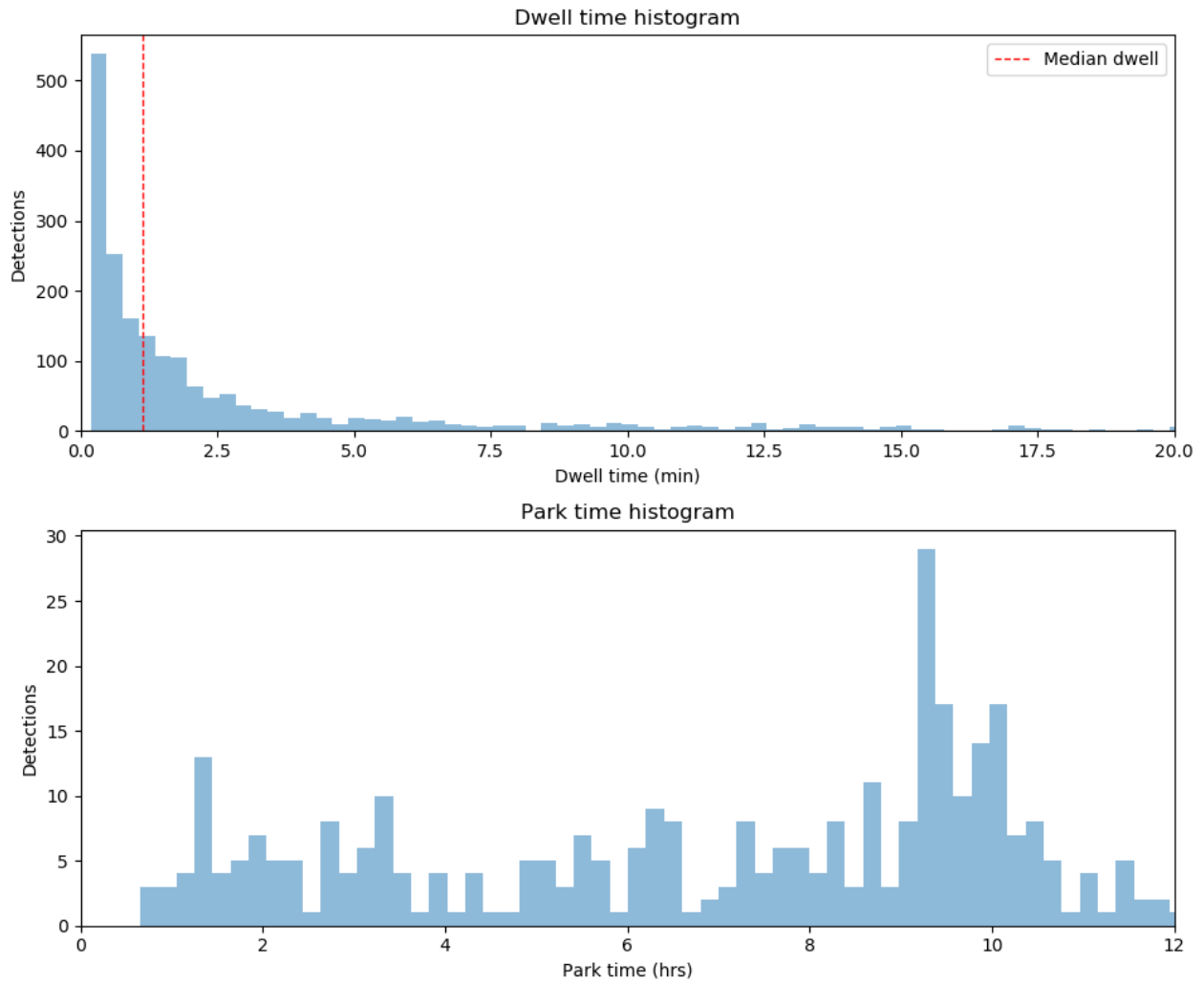


Figure 19 a) Dwell time and b) park time histograms (Source: SAGE Automation, 2019)

## 8.0 Discussion and Recommendations

This study provides significant insights into the strengths and weaknesses of Bluetooth technology used to extract the OD pattern of the 'park and ride' users of one public transport interchange. Public transport operating agencies need a thorough understanding of the origin and destination patterns of the 'park and ride' users at the public transport interchange to refine feeder bus route networks and to avoid a spatial mismatch between the interchange feeder bus coverage and location of people who are currently using the interchange.

To make well-informed operational decisions for transit planning and operations, understanding the origin and destination patterns of riders is crucial. Although studies have been devoted to the catchment area topic, most of them only focus on walking access to the bus stop or interchange.

There are no studies that report the access distance by private mode using the recent data collection method by Bluetooth technology. Vehicle origin-destination (OD) data has traditionally been a resource-intensive and expensive collection process. This study reports on the passive observations of Bluetooth protocol devices embedded in vehicles to collect OD data.

In the last few years, several studies employed Bluetooth media access control to address data to collect speed and travel time data; however, not many studies have reported OD pattern estimation using media access control (MAC) address data for OD surveys (Blogg et al., 2010).

Despite a few current limitations, Bluetooth technology used to track vehicles with Addinsight probe stations is successful in extracting OD patterns effectively. The Bluetooth MAC tracking data compares favourably with traditional face-to-face survey results; however, the accuracy of catchment area depends largely on the coverage of Addinsight stations. Accordingly, more research is needed to improve to reduced data noise by improving filtering techniques.

On the contrary, the Bluetooth MAC data for parking accumulation profiles matched quite closely with the traditional methods, indicating they can be used with great confidence.

The results also show that Bluetooth technology can be successfully applied to derive parking accumulation profiles of the 'park and ride' users.

This study shows there is a spatial mismatch of bus feeder network and location of 'park and ride' users at the Paradise bus interchange; that is, only 37% reside within 400 metres (walkable areas) of the existing bus feeder service. This highlights the potential to improve the feeder coverage to increase public transport usage and reduce the car parking demand at interchanges. This is consistent with the study by Wang et al. (2016) which demonstrated the importance of catchment area determination around the interchanges for the success of an integrated passenger transport system.

This study makes several key contributions by deriving different mode catchment areas, using both traditional and using recent technology tools:

- The analysis shows that 'park and ride' users travel significant distances to reach interchange to connect with high-frequency public transport. As per the traditional survey, the average distance and 85<sup>th</sup> percentile distances are 5.1 and 6.9 kilometres, respectively.
- The analysis of Bluetooth probe data, using Addinsight tracking stations, reveals a lower average distance of 3.5 km. However, the 85<sup>th</sup> percentile distance from Bluetooth analysis reported a higher value of 7.75 km. This discrepancy can be attributed to the current coverage of Addinsight tracking stations;
- The travel patterns from both the studies matched closely.

It can be concluded that to determine the interchange catchment area, Bluetooth technology can be applied to replace traditional face-to-face surveys where sufficient Addinsight stations are available.

This study also used smartcard data to determine the catchment area of feeder bus users to the interchange. The analysis shows that, on average, people are travelling 4 km and the 85<sup>th</sup> percentile distance is 6.4 km.

Parking accumulation profiles developed from both traditional and Bluetooth technology methods matched.

This study shows that 85<sup>th</sup> percentile of the number of hours parking is nine hours, indicating that the 'park and ride' users in this interchange are long-term parkers.

This study also noted that the parking availability at this interchange is below current demand. By 8.30 am, most of the off-street car parks at the interchange are filled, forcing the drivers to use the overflow off-street car park (which is leased by the Department of Transport) or continue their journey by car.

Further, many cars use Darley Road for on-street parking. Darley Road has three lanes each way, and one lane in each way will be taken away by the 'park and ride' users, which may create a traffic flow issues during peak demand.

An alternative to additional car parking infrastructure is the provision of further feeder bus services. New types of feeder services such as bus-on-demand or autonomous mini buses may be viable alternatives to the need for additional car parking.

In conclusion, it is clear that the adoption of new digital user tracking technologies will enable faster and more accurate OD and parking data collection process, provided few technology and coverage issues are addressed.

#### Further research

Whilst this research provides new insights into the effectiveness of transport interchanges, the study was unable to cover all issues. For example, Tong et al. 's. (2004) study demonstrated that people with a disability are less likely to use public transport trips that involve interchanges, as it adds complexity and uncertainty to their trip (DITCR, 2017). This issue could be the focus of future research, and lead to new understanding of how to increase the usability and effectiveness of transport interchanges.

A second area that requires additional research is the effectiveness of 'kiss and ride' (rapid drop off points) and taxi facilities. If mode transfers are designed to be as seamless as possible, then improvements to the usability of those and other transfers will be important. This might also include providing amenities such as sheltered walkways, seats, at interchange services such as kiosks and vending machines, landscaping, attractive design and finishes and improved lighting (Alford and Wild, 2007).

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Appendix 2: Bluetooth probe detection unit (Addinsight Omnia station)



Addinsight Omnia station



Typical installation example of Addinsight Omnia Capture Station  
(SAGE Automation, 2019)