Spatial Analysis of Park and Ride Users' Dynamic Accessibility to Train Station: A Case Study in Perth

Ting (Grace) Lin, Jianhong (Cecilia) Xia, Todd Robinson

Abstract—Accessibility analysis, examining people's ability to access facilities and destinations, is a fundamental assessment for transport planning, policy making, and social exclusion research. Dynamic accessibility which measures accessibility in real-time traffic environment has been an advanced accessibility indicator in transport research. It is also a useful indicator to help travelers to understand travel time daily variability, assists traffic engineers to monitor traffic congestions, and finally develop effective strategies in order to mitigate traffic congestions. This research involved real-time traffic information by collecting travel time data with 15-minute interval via the TomTom® API. A framework for measuring dynamic accessibility was then developed based on the gravity theory and accessibility dichotomy theory through space and time interpolation. Finally, the dynamic accessibility can be derived at any given time and location under dynamic accessibility spatial analysis framework.

Keywords—Dynamic accessibility, space-time continuum, transport research, TomTom® API.

I. INTRODUCTION

ACCESSIBILITY has been of critical importance to physical planning for the last 60 years. Extensive research has been conducted from different kinds of aspects since its first real definition and application by Hansen in 1959 [1]. Meanwhile, accessibility measure has been greatly developed along with development of technologies during these 60 years. Especially in the past two decades, space and time dimensions have increasingly involved in accessibility measures [2]. Kwan [3] suggested that temporal constraints can impact significantly on the ability to participate in activities and it needs to be considered when modelling accessibility. Analysing and modelling accessibility over space and time is pivotal.

Although Time Geography developed by Hägerstrand in 1970s [4], Miller [5] has achieved a great success to integrate time dimension into accessibility measure, it cannot be used in this study because it focuses accessibility on "freedom" measure instead of "ease" measure. This research focuses on modeling accessibility to train stations over space and time from the relative ease of reaching train stations perspective. In the literature, there is limited research examining the accessibility to the valuable destination over space and time from ease perspective and this could be amplified when the research field is narrowed to accessibility to train stations.

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Hence, we developed a new index named dynamic accessibility to measure accessibility over space and time from "ease" perspective.

Dynamic accessibility is developed based on the gravity theory and accessibility dichotomy theory. It focuses on the real-time travel impendence – dynamic travel time, but tried to measure continuous accessibility. The longer of travel time, the less accessible of the facility. The research involved the real-time network through the online network service - TomTom® API. By doing so, we are able to utilize the real-time transportation network data as well the routing algorithm by TomTom® behind the scene and obtain a reliable estimate of O–D travel time matrix with minimal data preparation and GIS software knowledge.

The paper is structured: Section II reviews the related work in the literature. Section III focuses on the framework and methodology of dynamic accessibility. The results are explained based on a case study of Perth, Western Australia in Section IV. A brief summary concludes this article and discusses some limitations of the developed tool in Section V.

II. LITERATURE REVIEW

A. Accessibility

Accessibility is composed of two words: "access" and "ability". Literally, it means the ability to approach or reach some places or something. However, in academic, it is a slippery notion [6]. Burns [7] defined accessibility as "freedom" whist Hanson and Jones noted it as opportunities [1], [8] and Ben-Akiva and Lerman [9] noted it as "benefits". In this research, we are back to the essence and the working definition here is "easy to reach by Park and Ride (PnR) travel mode".

A large literature exists on the accessibility measures since Hansen first introduced the issue to spatial planning in 1959 [10], [11]. Basically, it can be divided into three main categories, which are: attractiveness accessibility measures, utility accessibility measures, and constraint based accessibility measures [12]. The attractiveness accessibility measures are based on the gravity model which describes the accessibility from two main factors: attractiveness and travel cost. It is also called accessibility dichotomy. Attractiveness accessibility based accessibility measures could be very complex to combine all factors together [13], [14]. For example, Lin et al. [14] used Analytic Hierarchy Process (AHP) method to combine all possible factors that affect elderly's accessibility to train station. However, attractiveness accessibility based measure could also be very simple as well which only uses one dominant factor to represent accessibility. For example, Australian Bureau of

Statistics (ABS) utilised Metropolitan Accessibility/ Remoteness Index of Australia (Metro ARIA) as accessibility index [15]. It only uses road distance for the remoteness score generation. Similarly, Bhat et al. [16] only used the physical distance between infrastructure elements as input, and Haugen [17] used the proximity and distance as straightforward representations of the physical spatial separation between locations. In this research, we use travel time as accessibility measure index.

For the other two accessibility measure, the utility based accessibility measures utilize utility model and focus on how much benefit the users could achieve. Multinomial Logit (MNL), Nested Logit (NL), and Mixed Multinomial Logit (MMNL) are the most popular models in accessibility utility measures. Although utility measures are very intuitive to reflect the ease to access a facility or service, this type of measure needs a lot of data (like socio-economic data of trip marker or studied facilities) to formulize, and the data collection is extremely critical to utility measures. Constraints-based measures incorporate the constraints of activities into accessibility measure. The typical and best implementation is Hägerstrand's space-time prism using available time of the commuter as a constraint. A space-time "prism" is the set of all points that can be reached by an individual given a maximum possible speed from a starting and end points. Apart from time constraints, there are only other constraints existing in the literature (for example, financial constraints, congestion, parking capacity) [18], [19]. Genurs and Wee [20] summarized three different approaches to consider the constraints: the first one is dividing the opportunities by potential demand to incorporate the effects of competition; the second one is using the quotient of opportunities; and the last one is using balancing factors.

B. Park and Ride (PnR)

PnR stems from the well-known problems caused by the prevalence of private vehicles in the second half of the 20th century, such as traffic congestion, parking scarcity in central areas and adverse impacts on pedestrians and walkability. It is obvious that the root of the problem is the high number of vehicles trying to enter central areas that are usually quite limited in size. The idea of PnR was developed to decrease the number of vehicles entering central areas. PnR encourages motorists to undertake their journeys in two parts: firstly, driving to a car park adjacent to a transit station and then taking public transport into the central area. It combines the flexibility of the private car for travelling in low density areas with the efficiency of public transport in moving large numbers of people into central urban areas [21].

PnR originated in England with the first services being bus-based. Leicester was the first city to implement PnR in the 1960s, with the aims of reducing car traffic, increasing economic development and as a traffic management measure [22]. Oxford and Nottingham operated similar services from the 1970s onwards and then a few other cities (such as Bath and Chester) followed in the 1980s. The existing Oxford PnR scheme has been running for 43 years and is the oldest continuously operating service in the UK [23], [24]. The prevalence of PnR began in the 1990s, evolving from historic cities to a range of urban areas and from UK to worldwide [25]. The rapid and widespread expansion of PnR was due to the evidence of their success coming from the cities that were operating PnR. The benefits of PnR can be summarised as [22], [24], [26], [27]:

- Reducing the number of motorists using the urban road network which provides local congestion relief and a reduction in energy consumption and air pollution in central areas;
- Increasing the overall supply of available parking spaces (by reducing demand) which increases the accessibility of the city centre for those wishing to drive;
- More economically beneficial land use development in the city centre as less land is required for parking and a lower expenditure on parking as moving car parking outside;
- Improving the suburban development;
- Providing an efficient and less stressful travel mode that encourages public transport ridership.

From the last two decades, a crescendo of PnR research has been originally developed. However, it mainly focuses on bus-based PnR research in UK, Europe and they can be summarized into two groups [27]: (1) Mathematics model based PnR services and facilities analysis and modelling, e.g. Bolger et al. [28] developed planning guidelines for LRT park-and-ride facilities, including location criteria, access and egress considerations and the number and location of parking bays. Spillar [29] focused on the assimilation of reliable methods for selecting optimum locations for park-and-ride facilities in terms of maximising demand and promoting community integration. AASHTO [30] provided a detailed guide for the design and planning of PnR facilities, including how to design the facilities, the planning process and how to operate and maintenance the facilities; (2) Policy implementation and effects of PnR schemes. For example, Horner used a flexible GIS model to determine the potential locations of PnR facilities [31], [32] and Farhan and Murray developed a method for delineating market areas for PnR facilities and a multi-objective spatial model to site PnR facilities [33], [34]. Duncan and Christensen [35] used a logit model to predict the presence of parking at LRT stations in the US. It was found that parking facilities occur much more frequently in lower density environments where the land is cheap and available, and are also related to the characteristic of the municipality where the station is located.

Form the extant PnR literature, there is limited research investigating PnR services from both spatial and temporal perspective simultaneously although some research applied GIS technology to conduct the research. Meantime, geographically, limited research examined the local PnR services in Australia as well. Hence, this research will focus on this research gap.

C. Road Traffic Data Collection

Many organisations and government agencies are interested in live traffic data. Transportation departments (at the local,

state and federal levels), require reliable and timely traffic data to improve the daily management of traffic, (e.g. through variable message signing and interactive traffic signal control), and to manage incidents such as traffic crashes and breakdowns. The general public is also interested in real time travel information as it provides them with advice on where and when to travel, e.g. to avoid a traffic jam due to a crash. There are many ways to obtain the traffic data [36], [37] which can essentially be categorised into one of two types. The first collects traffic data from detectors, e.g. pneumatic tube counters, at fixed locations, although many of these can be moved to other locations if required. The second type is the floating car method that collects data from vehicles equipped with moving sensors such as GPS devices or mobile phones. These data include to location, speed, and direction of travel of each vehicle, recorded at regular and frequent time intervals or set locations on the network. Every vehicle with GPS devices/mobile phones acts as a sensor for the road network for constructing intelligent transportation systems (ITS). It empowers the traffic flow identification, travel times calculation, and rapid traffic reports generation.

Currently, in Western Australia, there are no detectors located along the major roads to provide congestion data although Main Roads WA is considering their installation. At the time of this study, the only available traffic congestion data source from government was the floating car survey by Main Roads WA. The method involves driving a vehicle in the traffic flow along a selected route and measuring the times at known points along the path. The disadvantages of this method are the limited network coverage, (only 11 routes in Perth), limited time periods, and the data are always historic.

There are a number of online APIs providing accesses to historical and live traffic information, such as Google® Maps Direction API, Yahoo® API, Map Quest®, InRIX® and also TomTom® Online Routing API. The main two are Google® Maps Directions API and TomTom® Online Routing API, both of which have very good coverage. Google® Maps Direction API with live traffic information is only available at a cost, while TomTom® Online Routing API is free. Therefore, the live traffic data from TomTom® API have been used in this study.

As one of the world's largest suppliers of GPS navigation devices, TomTom® has a significant floating car database. It uses a wide range of GPS probe data from fleets, portable navigation devices (PNDs), smartphones, in-dash system, and other data sources to generate precise real-time traffic information. Fontaine and Smith [38] suggested that GPS-equipped cell phones will become more attractive and realistic alternatives for traffic monitoring as this technique can provide more accurate locational information, and thus, more accurate traffic data including speeds and travel times. As well as the standard datasets, instantaneous velocity, acceleration, and direction of travel can also be captured. TomTom® has a large database of traffic movements that is utilised for congestion level benchmarking and travel time analysis. It has made over 12 trillion anonymous GPS measurements since 2007 and adds 7 billion new GPS measurements every day.

III. Methodology

D. Study Area

Perth has 70 train stations on 173 kilometres of track, presented in greater detail next [39]. The rail network includes three heritage lines (Midland, Fremantle and Armadale lines built before 1900s) and two new lines crossing the city from the North to the South (Joondalup, 1992 and Mandurah, 2007 lines) [40]. Because Perth has a low population density, the PnR system is well-developed, and the feeder buses - although with a wide coverage - provide reduce service frequencies.

Warwick station is located on the Joondalup line, about 13 kms from Perth station. It is chosen as study station as the floating car survey by Main Roads shows that around there are big travel time variations (congestions) inside station catchment area (see Section IV.A).

Fig. 1 Perth railway network and location of intercept surveys [14]

E. Data Collection

TomTom® provides online routing API to access the abundant real-time traffic network. Online Routing API is a restful API designed for developers to use their latest scalable online routing engine. Through providing the required parameters, TomTom® API returns the response which contains useful real-time and historical travel time information. The

results are returned in XML format and finally interpreted and stored in the ASCII files.

In GIS-T (GIS for Transportation) studies, data can be aggregated into geographic zones because of the data availability and also calculation complexity consideration. In this study, the catchment area of the study station was determined by the minimum bounding geometry approach (Convex Hull) for 90% of the trips [41], [42] . The catchment area of the station is divided into Voronoi polygons where each Voronoi polygon represents a proximity area as Voronoi polygons have been used extensively for conducting the proximity and neighborhood analysis. The centroid of Voronoi polygon is defined as origins. The travel information is collected from 0:00 am to 11:45 pm (every 15min) over five days (workdays).

F. Dynamic Accessibility

Dynamic accessibility was developed based on the gravity theory and accessibility dichotomy. It aims to derive accessibility to train station at any location and time. Therefore, space and time interpolation are required to achieve this.

1) Space Interpolation - Kriging Interpolation

Kriging interpolation is implemented to construct space continuum based on the collected data on the sampled centroid of Voronoi polygons. It was developed in the 1960s by the French mathematician Georges Matheron [43]. A semivariogram graph was developed to model the difference between a value at one location and the value at another location in terms of the distance and direction between them. The basic form of kriging (ordinary kriging) is weighted average of neighbouring samples, which is defined as [44]:

$$\widehat{Y}_0 = \sum_{i=1}^{n} w_i y_i = \begin{bmatrix} w_1 \cdots w_n \end{bmatrix} \begin{bmatrix} y_1 \\ \vdots \\ y_2 \end{bmatrix} = w_1' y \qquad (1)$$

where $\widehat{Y}_0$ is the estimated value; W_i is kriging weights which depends only on locations and covariance function C, Y_i is a known value at location i; i= 1, …, n. over w $w_1, …, w_n$, subject to

$$\sum_{i=1}^{n} w_i = 1 \qquad (2)$$

We will look for the kriging weights w_j that minimize MSE [45]

$$MSE = E\lfloor Y_0 - \widehat{Y}_0 \rfloor = \gamma' \mathbf{T}^{-1} \gamma - (1 - \gamma' \mathbf{T}^{-1} \mathbf{1})(\mathbf{1}' \mathbf{T}^{-1} \mathbf{1})^{-1} \qquad (3)$$

where, **1** is an $n*1$ vector of *1s*; **T** is an $n*n$ matrix whose $(i,j)^{th}$ element is $\gamma(S_i, S_j)$; $\gamma \equiv (\gamma(S_0, S_1), ..., \gamma(S_0, S_n))'$; and

$$2\gamma(S_0, S_n) \equiv C(S_i, S_i) + C(S_j, S_j) - S(S_i, S_j) \qquad (4)$$

where $2\gamma(S_0, S_n)$ is called the variogram, while $\gamma(S_0, S_n)$ is called the semivariogram. We use local semivariogram to determine the weights of kriging using VESPER developed by the Australian Centre for Precision Agriculture (ACPA) [46] .

2) Time Interpolation – Spline Function Interpolation

Time continuum means that continuous time without missing instants. For example, when we measure travel time from location i to location j using travel mode k, the measure should be able to estimate the travel time at any instant t. In order to achieve this calculation, time series models have been developed and applied extensively for predicting the future and understanding the past.

Many techniques have been developed based on these theories to analyse or model the time series. Here, spline function is used to realise the time continuum of travel time from location i to location j using travel mode k at time t. Fig. 2 shows the process which was implemented in MATLAB.

$$\begin{cases} y = mean(x_t) \, t_0 \le t < t_1 \\ y = \sum_{j=1}^{n} a_i Sin(b_i x_{t,} + C_i) \, t_1 \le t < t_2 \\ y = mean(x_t) \, t_2 \le t < t_3 \end{cases} \qquad (5)$$

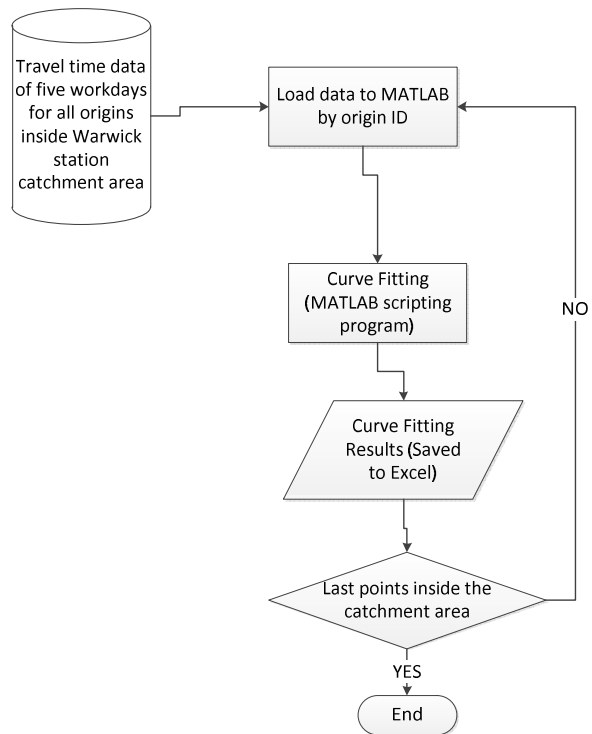where x is known travel time. x is between X_{t1}, X_{t2}. y is unknown travel time.

Fig. 2 The process of curve fitting

G. Hotspot Analysis

By looking at each feature within the context of neighbouring features, the hot spot analysis tells where features with either high or low values cluster spatially. A feature with a high value is interesting but may not be a statistically significant hot spot. A statistically significant hot spot would have a high value and be surrounded by other features with high values. The Getis-Ord Gi* statistic applied by Hot Spot Analysis can be used to identify these.

The Getis-ord local statistic is given as [47]:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\dfrac{[n \sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2]}{n-1}}} \quad (6)$$

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (7)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \quad (8)$$

where: x_j is the attribute value for feature j; w_{ij} is the spatial weight between feature i and j; N is the total number of the feature.

IV. RESULTS

H. Floating Car Survey Analysis

The 2013-2014 floating car survey was used to find out the experiment station. Although the floating car survey covers 11 routes in Perth, only some routes have travel time data for the AM Peak, Off Peak, and PM Peak periods. Main Roads Western Australia's (MRWA) definitions of these three periods are shown in Table I. The variations in the travel times of the 11 routes for the three periods are plotted in Fig. 3 (a). Route 25 inbound and route 49 inbound have the largest variations between AM Peak and Off Peak travel times. For route 49, the largest variations are for segments 7 to 9 (Fig. 3 (b)), which is inside the Warwick station catchment area. Therefore, Warwick station was chosen as the study station.

TABLE I
THE DEFINITION OF AM PEAK, OFF PEAK AND PM PEAK (MRWA)

AM/PM	Time period
AM(Morning) Peak	7:30am – 9:00am
Off Peak	10:00am-12:00 noon
PM (Afternoon) Peak	4:30pm – 6:00pm
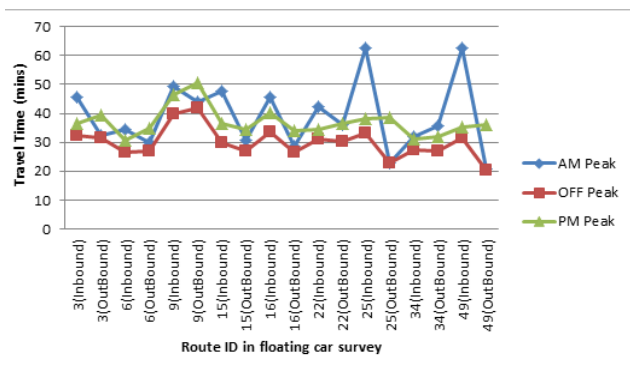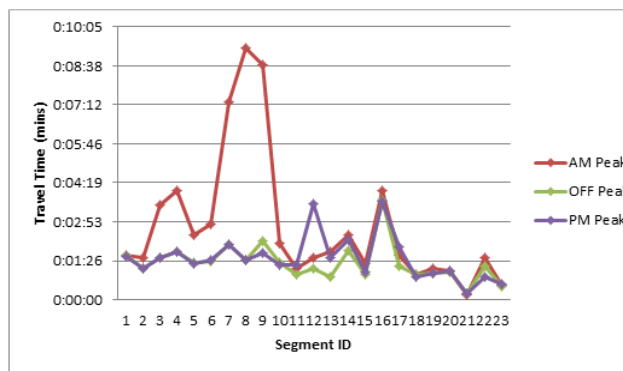
Fig. 3 Floating car survey

İ. Statistical Analysis of Historical Travel Time Using TomTom® GPS Data

There were 401 trip origins within the Warwick train station catchment area from which 401 Voronoi polygons were generated. Each origin had a travel time for 96 times time slices, as data were collected every 15 mins from 0:00 am to 11:45 pm. Therefore, each day 38,496 records were captured. Travel time data were collected for five days, (Monday to Friday), resulting in a total of 192,480 (38496 *5) travel time records.

1) Travel Time Descriptive Statistics

Descriptive statistics summarising the main features of the collected data are presented in Tables II and III. Thursday was the most congested day for travel to Warwick train station as it had the largest mean and median travel times and the largest standard deviation. Kurtosis is a measure of the "peakedness" of the distribution and heaviness of its tail. A high kurtosis distribution has a sharper peak and fatter tails, while a low kurtosis distribution has a more rounded peak and thinner tails. Skewness is a measure of the asymmetry. Thursday also had the lowest kurtosis and skewness values among the five workdays,

which means that the travel time was more evenly distributed over the catchment area compared to the other workdays. When combined with the results for the mean, median and standard deviation, it was concluded that Thursday was the most congested day for Warwick train station. Using the same criteria, Monday seemed to be the least congested day.

Table III presents the maximum and minimum travel times and the range for ten origins for Monday and Thursday. The records are sorted by the Thursday travel time. Only the origins with the five largest and five smallest ranges are listed. ID is the identity number of the trip origin in the system. Min and Max refer to the minimum and maximum travel times from the specific ID to Warwick station in seconds. The range is the differences between the minimum and maximum travel times. ID94 has the largest range in travel times at 217 seconds, or around 4 minutes. This means that travel from Location ID 94 to Warwick station in the peak hour takes nearly 4 minutes longer than travelling in the off-peak. However, for location ID 271, there is no difference in travel times between peak and off-peak.

DayofWeek column indicates the specific day of the week, i.e. 1 means Monday, 2 means Tuesday, etc. The results show that the only significant difference is between Monday and Thursday, which is consistent with the results of the descriptive statistics analysis. Although there were significant differences between these two days, there were no significant differences between Tuesday and Monday, Tuesday and Thursday, Wednesday and Thursday, or Wednesday and Monday. Monday and Thursday were simply the two most extreme scenarios, i.e. the days where travel was the most and least congested respectively. Therefore, it is decided that only one model would be sufficient, rather than a separate model for each day.

TABLE II
DESCRIPTIVE STATISTICS OF TRAVEL TIME TO WARWICK STATION FROM ALL ORIGINS INSIDE WARWICK STATION CATCHMENT AREA BY DAY OF THE WEEK

Monday		Tuesday		Wednesday	
Mean (secs)	882.68	Mean	884.07	Mean	884.61
Median (secs)	893	Median	894	Median	894
Mode (secs)	937	Mode	994	Mode	953
Standard Deviation	181.37	Standard Deviation	182.11	Standard Deviation	182.42
Sample Variance	32892.24	Sample Variance	33165.24	Sample Variance	33276.23
Kurtosis	5.52	Kurtosis	5.42	Kurtosis	5.36
Skewness	0.82	Skewness	0.82	Skewness	0.81
Confidence Level (95.0%)	1.81	Confidence Level (95.0%)	1.82	Confidence Level (95.0%)	1.82
Thursday		Friday			
Mean	887.50	Mean	884.01		
Median	897	Median	894		
Mode	904	Mode	894		
Standard Deviation	184.05	Standard Deviation	181.78		
Sample Variance	33874.84	Sample Variance	33043.24		
Kurtosis	5.05	Kurtosis	5.46		
Skewness	0.77	Skewness	0.81		
Confidence Level (95.0%)	1.84	Confidence Level (95.0%)	1.82		

2) ANOVA Test

The purpose of an ANOVA (Analysis of Variance) test is to determine whether there is a statistically significant difference among several means. One-way ANOVA is the simplest type of ANOVA. It is a technique used to compare means of three or more samples (using the F distribution). ANOVA test lies on the F ratio.

In the study, SPSS was applied to calculate the one-way ANVOVA. It outputs the significant value which helps to determine whether there is a significant difference or not. Table IV shows the results of the ANOVA test. The number in the

TABLE III
DESCRIPTIVE STATISTICS OF TRAVEL TIME FOR 10 ORIGINS (MONDAY AND THURSDAY)

ID	Monday			Thursday			
	Min (s)	Max (s)	Range (s)	Min (s)	Max (s)	Range (s) (↓)	rank
94	945	1026	81	945	1162	217	1
95	953	1035	82	953	1162	209	2
101	994	1082	88	994	1202	208	3
102	1158	1260	102	1158	1334	176	4
92	953	1030	77	953	1125	172	5
…	…	…	…	…	…	…	
277	485	498	13	485	499	14	397
202	493	509	16	493	506	13	398
206	441	456	15	441	454	13	399
201	505	516	11	505	515	10	400
271	436	436	0	436	436	0	401

TABLE IV
RESULTS OF ANOVA TEST

(I) Day of Week	(J) Day of Week	Mean Difference (I-J)	Std. Error	Sig.
	3	-1.9219	1.3143	0.587
	4	-4.8104*	1.3143	0.002
	5	-1.3276	1.3143	0.851
2	1	1.381	1.3143	0.832
	3	-0.5409	1.3143	0.994
	4	-3.4294	1.3143	0.069
	5	0.0534	1.3143	1
3	1	1.9219	1.3143	0.587
	2	0.5409	1.3143	0.994
	4	-2.8885	1.3143	0.18
	5	0.5943	1.3143	0.991
4	1	4.8104*	1.3143	0.002
	2	3.4294	1.3143	0.069
	3	2.8885	1.3143	0.18
	5	3.4828	1.3143	0.062
5	1	1.3276	1.3143	0.851
	2	-0.0534	1.3143	1
	3	-0.5943	1.3143	0.991
	4	-3.4828	1.3143	0.062

3) Travel Time Curve Characterisation

Fig. 4 shows the travel time variation curves for six randomly selected sample origins. As it was decided not to model the temporal information by different days, all collected data have been plotted on the figure to get the generalized

(averaged over five days) distribution. It is found that, overall, they have very similar trends. Travel times from the origin to the train station were stable until around 4 am and then rose sharply to peak at around 8 am, with a second peak around 6 pm. Some origins had longer travel times in the am peak, whilst others were in the pm peak, probably depending upon whether or not the trip to the station was in the peak or non-peak direction for general traffic. After 10 pm, the travel times became stable again, indicating free flow conditions.
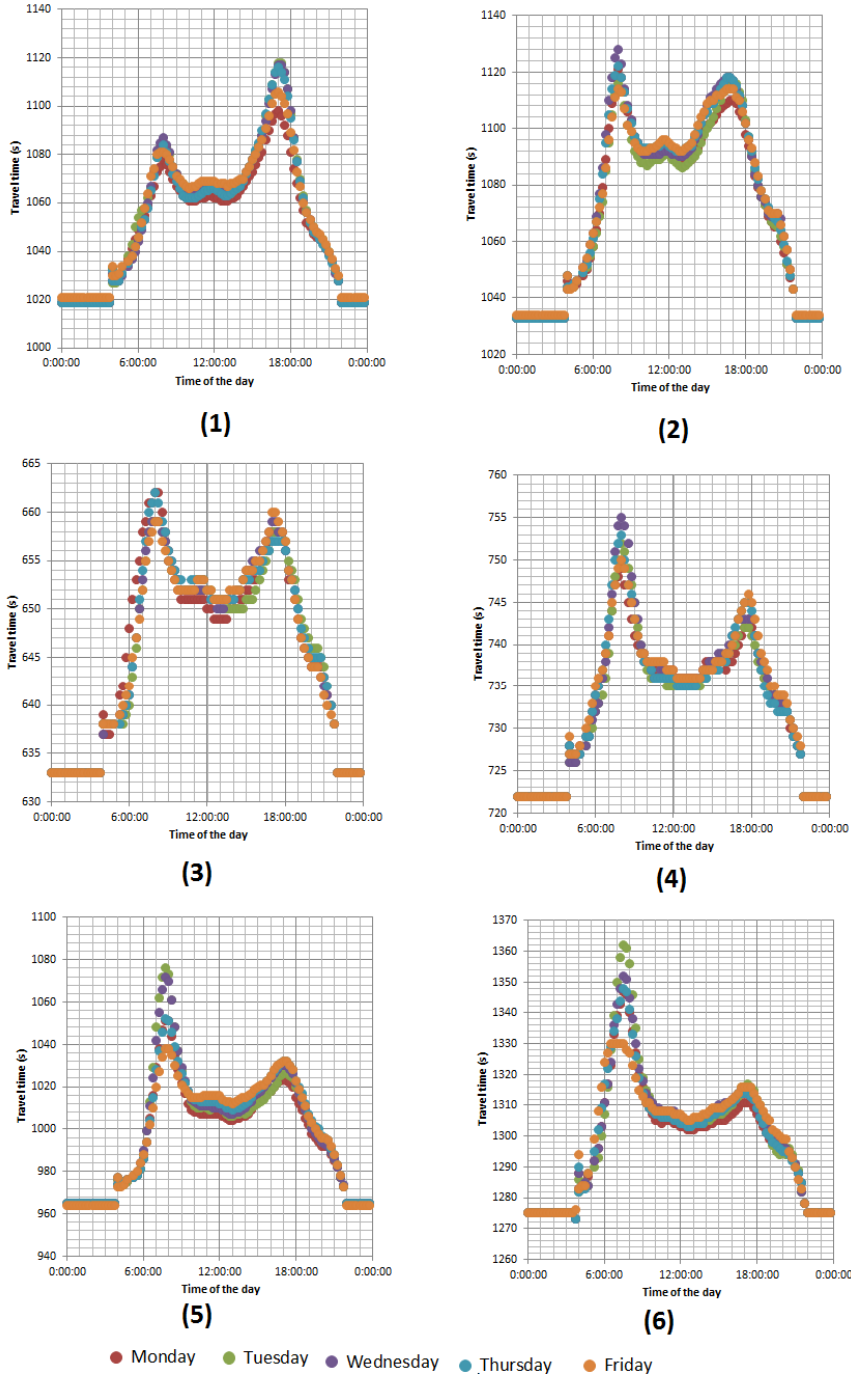
Fig. 4 Travel time curve for six origins

4) Travel Time Hot Spot Analysis

A hot spot analysis indicates where either high or low travel time clusters locate spatially, by comparing travel times for individual origins with neighbouring origin travel times. The range data of Thursday (Table III) were used for the hot spot analysis, and the results are shown in Fig. 5. The hot spots (red dots) were found to cluster at the southwest of Warwick station, which is consistent with the Floating Car Survey results, i.e. a separate analysis using a different data source. The red spots are mainly distributed among those segments.
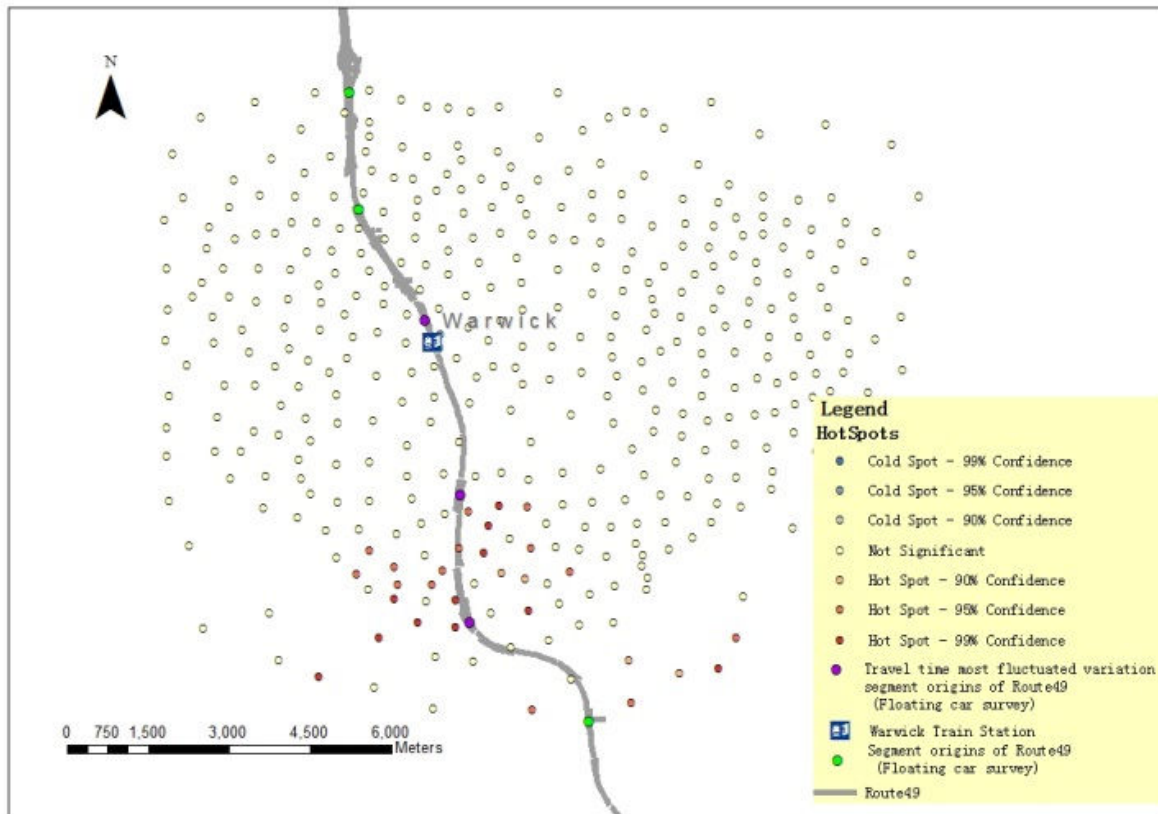
Fig. 5 Results of the hot spot analysis

J. Dynamic Accessibility

The travel data were put in the spatial and time interpolation model, and the result is shown in Fig. 6. Fig. 6 shows the variations in travel times to Warwick Station over 24 hours. The green colours indicate shorter travel times and red colours longer travel times. During the peak hours, e.g. 7:00 am to 8:00 am, the size of green area reduces significantly. The southern central part of map, which was identified as the hot spot in Fig. 6, also changes significantly. In the peak hours, most of the areas are coloured red. However, outside the peak hours, they turn green or yellow. Another interesting finding for the southern central part of map is that the travel times in this area also change during the off-peak hours.

V. DISCUSSION AND CONCLUSION

Through the interrogation of an online live traffic service, this data collection method overcame the deficiencies of a commercial GIS package including extra data support, knowledge and license of the software. Analysis of the collected data has proven that they were robust and consistent with the data obtained from the more traditional floating car survey method.

Another contribution of this research is to develop a new method to measure dynamic accessibility. It is a novel method that can estimate accessibility to a train station from any location at any time. The study used Warwick station as a case study, demonstrating the usefulness of the approach in assessing how accessibility to the train station changed over time, in terms of travel time. The 3D and animation presentations would give the policy maker a more intuitive understanding of the variations in accessibility over time.

In this research, only travel time has been considered when measuring accessibility, in order to reduce the model complexity. In the future, the model could be expanded to include additional factors, including variations in available parking supply at the station over time, and factor weighting. This model could also be adapted to assess the accessibility of other travel modes, such as Bus and Ride (BnR).
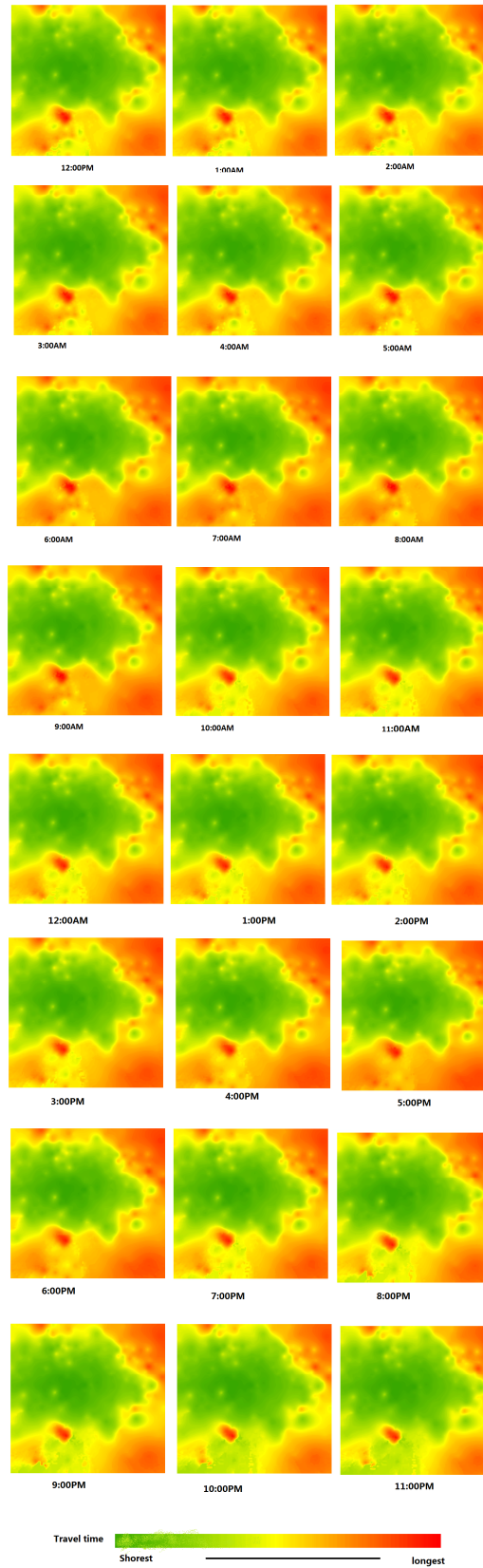
Fig. 6 Dynamic accessibility

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