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Research Article

Development of Fuzzy Logic Forecast Models for Location-Based Parking Finding Services

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Park-and-ride (PnR) facilities provided by Australian transport authorities have been an effective way to encourage car drivers to use public transport such as trains and buses. However, as populations grow and vehicle running costs increase, the demand for more parking spaces has escalated. Often, PnR facilities are filled to capacity by early morning and commuters resort to parking illegally in streets surrounding stations. This paper reports on the development of a location-based parking finding service for PnR users. Based on their current location, the system can inform users which is the best station to park their cars during peak period. Two criteria—parking availability and the shortest travel time—were used to evaluate the best station. Fuzzy logic forecast models were used to estimate the uncertainty of parking availability during the peak parking demand period. A prototype using these methods has been developed based on a case study of the Oats Street and Carlisle PnR facilities in Perth, Western Australia. The system has proved to be efficacious and has the potential to be applied to other parking systems.

1. Introduction

Parking problems are ubiquitous in almost every major city in the worldwide. Parking supply is always behind ever increasing demand. Many solutions to this problem have been proposed in the literature. Off-street parking supply such as multistorey parking has been broadly accepted as a solution for on-street parking problems, especially in central business areas [1]. Shoup [2] suggested that free parking is the major cause of this problem and pricing parking appropriately can achieve balance between supply and demand. On the other hand, parking-assist systems, such as the parking guidance and information (PGI) system [3–5], have been developed to help drivers find parking easily. These systems use monitoring systems, parking charging data, laser scan detectors, and loop detectors to monitor available parking spaces in real time and then send parking availability messages to drivers via variable message signs (VMSs) [6–9]. This type of real-time information is seemingly a great convenience to drivers, but its accuracy and reliability have been questioned in the literature [10, 11]. For example, if the parking availability information is not updated constantly and immediately, drivers may be frustrated to find they cannot park where indicated. In addition, due to the uncertainty of parking availability during certain time periods, especially during peak hours, a parking finding system should provide some measure of the confidence in the accuracy of the parking information. Various studies have been conducted to forecast parking availability in parking lots. Yang and Chen [12] have used neural networks to forecast the "empty/full" state of a parking lot instead of the number of parking spaces available. Based on this work, the Elman neural network and weighted Markov chain models were proposed to predict available parking spaces [13, 14]. However, very little research has been done to measure uncertainty of parking availability during peak parking demand periods.

The aim of the paper is to apply a fuzzy logic model to capture the uncertainty of parking availability and reflect it in a parking finding system. With this, users can be informed about this uncertainty and can make a better choice of their departure station. In addition, this paper reports on the development of a location-based parking finding system that implements this modelling method. This parking finding and trip planning system have been developed using the Android

Table 1: The Oats Street station and Carlisle Station car-park.

Parking lot	Distance	Travel time	Parking capacity
Oats Street station carpark	1.2 km	3 min	73
Carlisle station carpark	1.6 km	4 min	32

SDK 4.0 and Google API 16 and can be deployed on different mobile devices such as mobile phones and tablets.

2. Method

2.1. Framework of Parking Finder Service. This paper proposes a location-based service for a parking finding (PFLBS) framework designed to help park-and-ride (PnR) users identify the best train station parking lot to park their car based on their current location, planned departure time, parking availability, and shortest travel time. PnR users are car drivers who park their car at train station parking lots and then take a train to reach their destination. PnR services are widely believed to be an efficient alternative to private car use [15–17]. The PFLBS was primarily developed to help PnR users find parking easily during peak times. The basic functions of the system are as follows:

(i) estimating the travel time from the user's current location to PnR facilities in the local area;

(ii) predicting the parking availability of these parking lots at the user's estimated arrival time using fuzzy logic forecast models;

(iii) selecting the best PnR facility based on parking availability and shortest travel time;

(iv) calculating an optimal travel route (shortest travel time) to guide users to reach this parking lot.

The workflow of the PFLBS system was illustrated in Figure 1.

The best PnR facility can be determined using two major criteria: travel time and parking availability. Usually, people would prefer the shortest travel time and the highest probability of finding a parking spot. The PnR selection model can be defined as

$$R = \min \left\{ \frac{T_i}{F_i(t_0 + T_i)} \right\} \quad F_i(t_0 + T_i) \neq 0, \ i = 1, 2, \ldots, n, \tag{1}$$

where t_0 is the planned departure time, T_i is the travel time from origin to each PnR facility, and $F_i(t_0 + T_i)$ is the probability to get a parking space at the expected arrival time.

2.2. Fuzzy Logic Forecast Model. Fuzzy Logic (FL) is a "multivalued logic that allows intermediate values to be defined between conventional evaluations like yes/no, true/false, black/white, and so forth." [18]. It provides reasoning for vague terms using graded or qualified statements rather than those that are strictly true or false and applies fuzzy membership functions to define vagueness or uncertainty of the data [19]. For example, parking availability in a PnR facility could be uncertain. Parking could be available at 7:30 am on Friday but may be unavailable at the same time on Monday due to different demands or social events, and so forth. Figure 2 illustrates the fuzzy principle of the parking availability function.

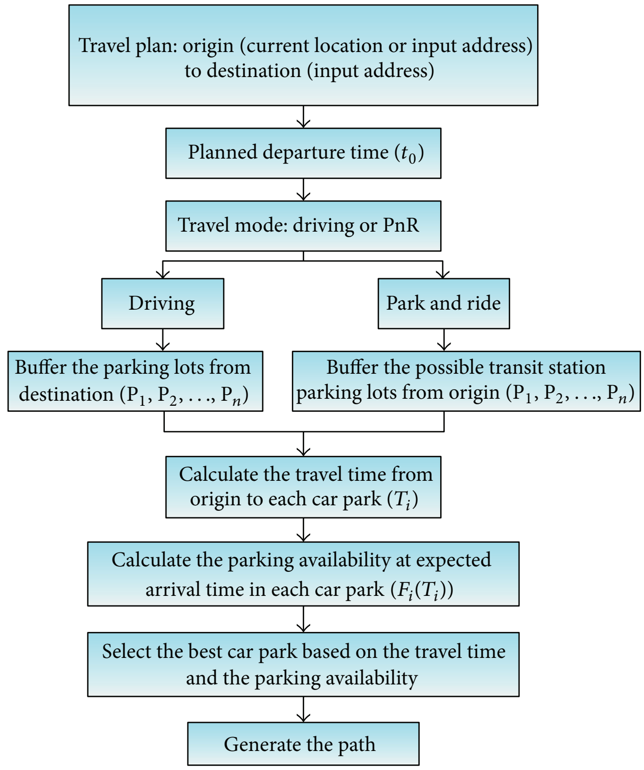

Figure 1: Parking finder decision framework.

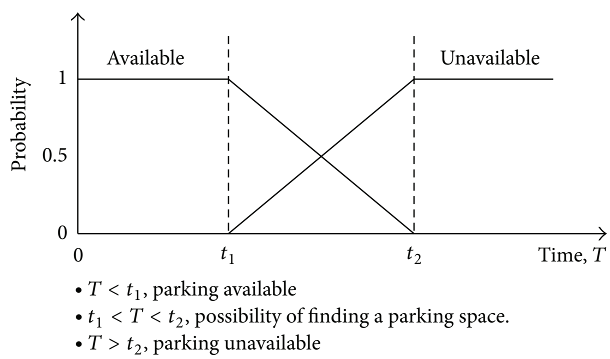

Figure 2: The input fuzzy membership function of parking availability in one day.

The fuzzy set can be defined mathematically as follows: let T be a space of time, with a generic element of T denoted by t; thus a fuzzy set A in T is defined as a set of ordered pairs [20]:

$$A = \{t, \mu_A(t)\} \quad t \in T, \tag{2}$$

Table 2: The last three parking spaces remaining time and the full parked time in Oats Street station carpark and Carlisle station carpark.

Parking lot	Oats Street station carpark		Carlisle station carpark	
	3 spaces remain (t_{1j})	None (t_{2j})	3 spaces remain (t_{1j})	None (t_{2j})
Monday	7:22	7:27	8:23	8:30
Tuesday	7:07	7:11	8:28	8:34
Wednesday	7:25	7:30	8:33	8:45
Thursday	7:22	7:28	8:22	8:36
Friday	7:26	7:31	8:31	8:38

where A is the fuzzy set, which is characterised by a membership function $\mu_A(t)$. It associates with time between t_1 and t_2. The value of $\mu_A(t)$ represents the grade of membership of t in A, which is probability of finding a parking spot in a PnR facility between t_1 and t_2.

The fuzzy membership function adopted in this paper is the trapezoidal curve, which can be specified as follows:

$$f(x, t_1, t_2) = 1, \begin{cases} 1, & x \leq t_1 \\ \dfrac{t_2 - x}{t_2 - t_1}, & t_1 \leq x \leq t_2 \\ 0, & t_2 \leq x. \end{cases} \quad (3)$$

The developed model for forecasting the probability of finding a parking space at an expected arrival time was implemented using MATLAB version 7.11 [21]. The Fuzzy Logic Toolbox was used to model complex system behaviours using simple logic rules and then implement these rules in a fuzzy inference system. The trapezoidal membership function is a relative simple method. However, our survey data distribution is almost linear (see Figure 4). Therefore, this function can have the best fit to the data.

2.3. Data Collection. The Carlisle and Oats Street station PnR facilities in Perth, Western Australia (WA), were chosen as our two case study areas (see Figure 3). These are busy stations on the high-traffic southern line and at which parking is always in high demand. Field surveys were conducted to collect traffic flow data during weekdays from 3 to 17 August, 2012. Researchers stood in the entrance of the car park lot from 6:00 to 8:30 am and recorded the time at which each car entered or exited the car park. Five-day traffic flow data were collected from these two stations.

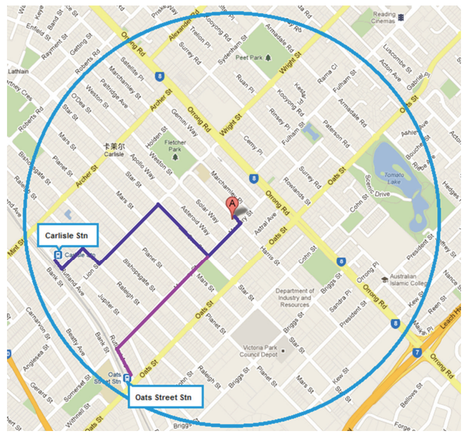

Figure 3: The study area (A is the origin, such as home).

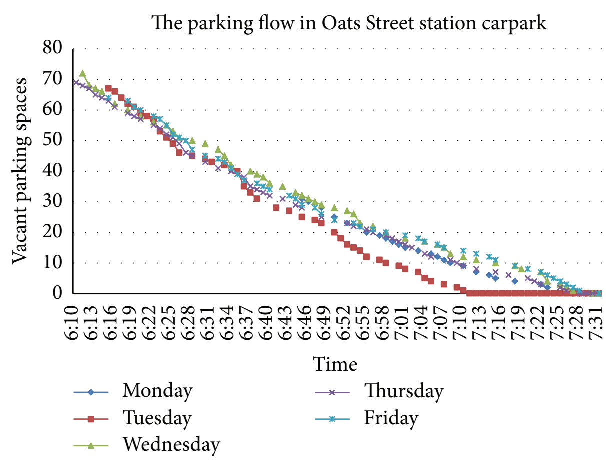

Figure 4: Traffic flow of Oats Street station parking lot.

3. Case Study

3.1. Observed Data. The Oats Street Station is 0.81 km away from the Carlisle Station. The shortest distances from Location A to these two stations and parking capacities are described in Table 1.

Figure 4 shows how parking availability at the Oats Street station car park changes over time at peak times for five days. Generally, the parking bays in this carpark were fully occupied by 7:30 am for all five weekdays, although they tended to be filled more quickly on Tuesdays. These data demonstrate the uncertainty of parking availability. Based on the data, this uncertainty started at 7:11 am until 7:31 am when no more parking was available. Because we only have five-day data, it is safer to set up a three-parking-bay buffer to ensure 100% parking availability. Therefore, the inflection points for fuzzy membership function were chosen for "t_1" as the time at which there were still three parking bays available (before t_1, there is 100% parking available) and for "t_2" as the time when it is fully occupied (see Table 2). Therefore, 100% parking availability will end at t_1 and 100% parking unavailability will start at t_2. We used the fuzzy membership function to estimate the uncertainty associated with parking availability.

Table 3: The rules of parking forecast model.

No.	Descriptions of rules	Parking probability	Number of rules
1	5 days are available	100%	$C_5^0 = 1$
2	4 days are available	75%–100%	$C_5^1 = 5$
3	3 days are available	50%–75%	$C_5^2 = 10$
4	2 days are available	25%–50%	$C_5^3 = 10$
5	1 day is available	0%–25%	$C_5^4 = 5$
6	5 days are unavailable	0%	$C_5^5 = 1$
	Total		32

Table 4: The forecast parking probability in Oats Street station carpark and Carlisle station carpark.

Time	<7:07	7:08	7:09	7:10	7:11–7:22	7:23	7:24	7:25	7:26	7:27	7:28	7:29	7:30	7:31–8:22	8:23	8:24
Oats	100	89	88.1	87.8	87.5	72.6	66	61.2	48.1	32.5	22.8	20.5	10.6		0	
Carlisle								100							91.9	77.9
Time	8:25	8:26	8:27	8:28	8:29	8:30	8:31	8:32	8:33	8:34	8:35	8:36	8:37	8:38	⋯	>8:45
Oats									0							
Carlisle	78	77.9	77.6	76.6	68.9	63.9	60.5	51.9	43.5	31.6	26.8	20.9	17.8	12	⋯	0

Unit: Percent (%).

3.2. Parking Availability Calculation. The fuzzy membership function was illustrated in Figure 5. The fuzzy rules were defined in Table 3.

Table 4 shows an estimate of the degree of parking availability during the period of peak parking demand in these two station carparks.

3.3. Results. As shown in Figure 3, we set up a hypothetical case. A is the home location of a PnR rider, and the planned departure time is $t_0 = 7:19$ am. Then the expected arrival time from Location A to Oats Street station based on the shortest travel time is 7:22 am, and for Carlisle station, it is 7:23 am (see Table 1). According to Table 4, the degrees of parking availability at 7:22 am for Oats Street station and 7:23 am for Carlisle station are 87.5% and 100%, respectively. By substituting these numbers into equation (1), the Oats Street station ($R = 3/87.5\% = 3.43$) sounds a better choice than Carlisle station ($R = 4/100\% = 4$). Furthermore, if a PnR user's planned departure time is $t_0 = 7:20$ am, the Carlisle station ($R = 4/100\% = 4$) would be a better choice than Oats Street station ($R = 3/72.6\% = 4.13$). The departure time of 7:23 am is the dividing decision point. Before this point, Oats Street station is better, while after this point, it would be Carlisle station. However, after 8:45 am, parking is unavailable at both stations.

4. Prototype of the PFLBS

Using location-based service technology, a prototype PFLBS system was designed and developed to implement the fuzzy logic forecast model described previously. After PnR users entered their departure time and travel mode, as shown in Figure 6, the system can automatically identify user's current location, suggest the best station, and calculate and display an optimal travel route from the user's current location to the suggested station using geographic information system (GIS) technologies. The system was developed using the Android SDK 4.0 and Google API 16.

5. Conclusion

This paper developed a fuzzy logic forecast model to measure uncertainty of parking availability at train stations for PnR users. The results were integrated into an PFLBS system, which can help PnR users choose the best departure train station to reach their destinations. A case study at Oats Street and Carlisle train stations in Perth, Western Australia, was designed to evaluate this method. A prototype PFLBS system was designed and developed to implement the fuzzy logic forecast model using the Android SDK 4.0 and Google API 16. The models and PFLBS system have proved to be robust in predicting the uncertainty of parking availability at the two stations.

However, there are still some limitations. For example, the fuzzy membership function we chose is only a simple linear function. More advanced membership functions will be applied to our research problem to further explore the advantages and disadvantages of these functions. In addition, the station choice criteria for parking are relatively simple: only two criteria, park availability and the shortest travel time, were used. In the future, more criteria, such as train frequency, service quality, and parking-and-riding price will be considered. In addition, different criteria could contribute more or less to PnR users' decision making. Therefore, we will develop a weighting set for these criteria.

Conflict of Interests

There is no conflict of interests in this paper.

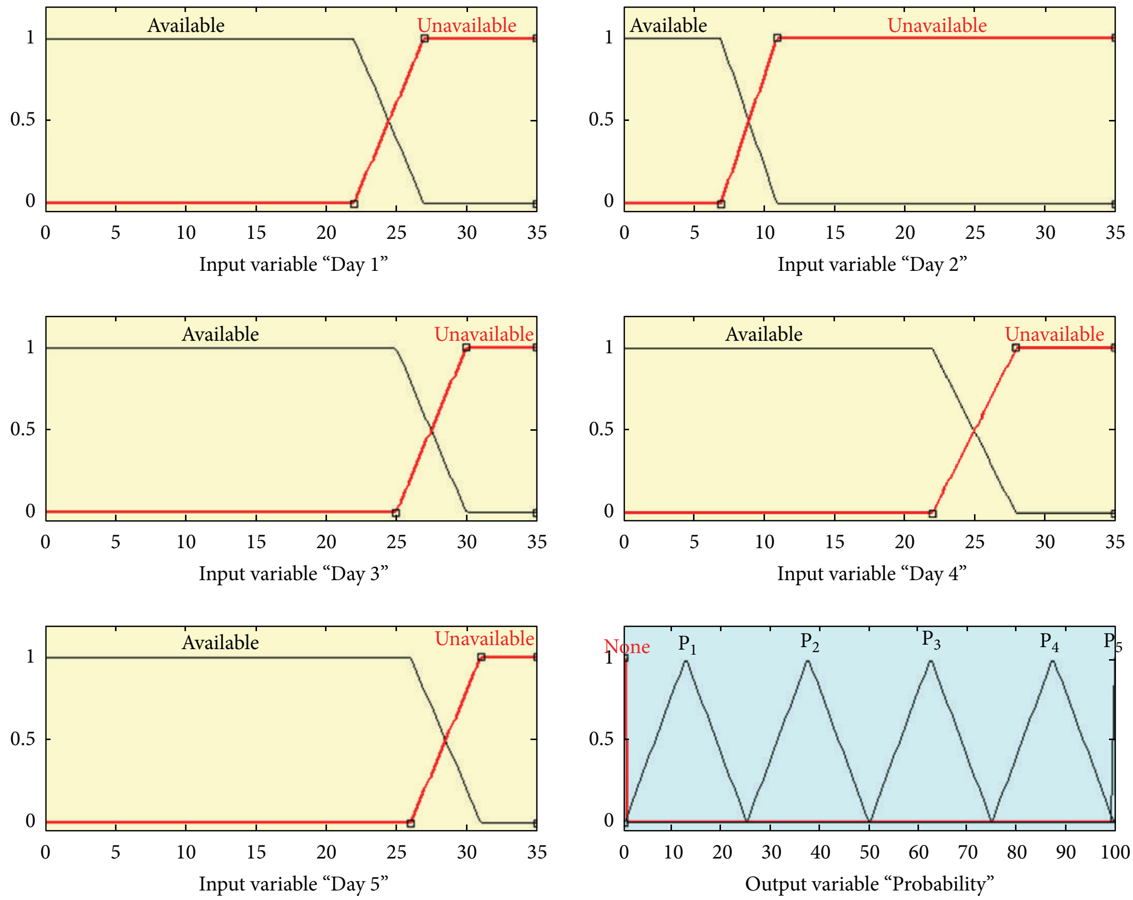

Figure 5: The fuzzy membership functions of input and output for Oats Street station carpark.

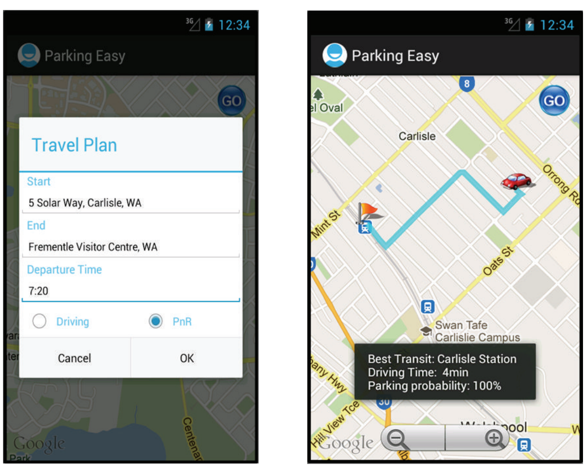

Figure 6: Prototype of parking forecast LBS.

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