Development and Evaluation of Traffic Management Strategies for Personal Rapid Transit

Pengjun Zheng
David Jeffery
Mike McDonald
Transportation Research Group, School of Civil Engineering and the Environment
University of Southampton
Highfield, Southampton, SO17 1BJ, UK
E-mail: (p.zheng; d.j.jeffery; mm7)@soton.ac.uk

KEYWORDS
Personal Rapid Transit, Optimisation, Traffic Management, Simulation

ABSTRACT

This paper describes a simulation study of traffic management opportunities with an extended Personal Rapid Transit (PRT) network at Heathrow airport. The investigation was based on the Citymobil reference scenario of the Heathrow airport PRT Demonstrator between Terminal 5 and a car park, but modified to allow investigation of a wider area including links to Terminal 1 to 3 and car parks. A predictive demand management strategy was identified to be incorporated in both local vehicle dispatching and wide network operation. The impacts of the proposed management strategy were evaluated using a microscopic PRT simulation model – Hermes which was specially modified for this research by the developer. Simulation results suggested a significant reduction in average waiting time across all stations in the test network as a result of the implementation of the proposed traffic management strategy. Despite the fact that PRT is a demand responsive service with its operation optimised through a control algorithm, this investigation has shown that the service level can be further improved by incorporating traffic management measures such as demand prediction.

INTRODUCTION

PRT (Personal Rapid Transit) is a public transport system that uses small automated vehicles running on a fully segregated guide-way and with off-line stations (e.g. Lowson, 2003; Lowson, 2005; Cottrell, 2008). The vehicles can run directly from origin to destination with no intermediate stops. PRT represents an automated transport system that has evolved from the point of view of a public transport operator rather than an automobile manufacturer.

The primary objective of PRT is to provide an alternative PT (public transport) system that is demand responsive and particularly attractive to users because it offers minimal waiting times and a travel experience that is very close to travelling by private car or taxi. In principle, PRT systems can also be used to transport goods.

Past research on PRT has mainly been focused on the control of PRT vehicles and optimisation of PRT networks (e.g. Won, et al., 2006; Kai, et al., 2005; Anderson, 2003), i.e., operational management. Research on the traffic management issues of PRT system has hardly been reported. This paper presents a simulation study of the impacts of potential traffic management strategies for PRT systems. It is revealed that traffic management is a viable approach to further enhance operation efficiency of PRT systems.

TRAFFIC MANAGEMT OPPORTUNITIES

The traffic management opportunities with PRT are related to the efficient operation of vehicles in a segregated and closed network. They are similar to metro systems, which also do not interact with conventional traffic; but are different because the stations and stops are off-line in a PRT system, so that vehicles can travel direct to the destinations specified by the passengers without making any intermediate stops.

There are many types of traffic management measures for traditional transport system such as incident management, route guidance and priority control (e.g. Wren, et al., 1996; Gartner, et al., 2002; Bretherton, et al., 2002). PRT systems have their own unique routing control algorithms and all PRT vehicles are treated with equal priority. Thus, some traditional traffic management measures are not applicable to the PRT systems. However, one of the most important traffic management measures, that of demand management, is relevant because PRT systems are driven by the demands at stations across the networks. Although demand is determined by external factors, it can be predicted based on historical patterns and demand generation mechanisms. Demand management based on prediction allows the PRT control system to actively respond to changing demands thus improving operational efficiency.

Based on the analysis of traffic management opportunities, a predictive demand management strategy was proposed and traffic management strategies incorporating both local and network predictive demand are developed. The objective was to reduce waiting times at stations by guiding the PRT operations based on predictive demand rather than responding in a reactive way. As PRT is a traffic responsive system, time delay is unavoidable in response to a local demand arising at a station or overall network demand change. By running the system based on predictive demand, it is possible to reduce system response delay. It is expected that if the actual traffic demand is close to the predicted traffic demand, then optimised vehicle dispatching and relocation can be realised with minimum response time.

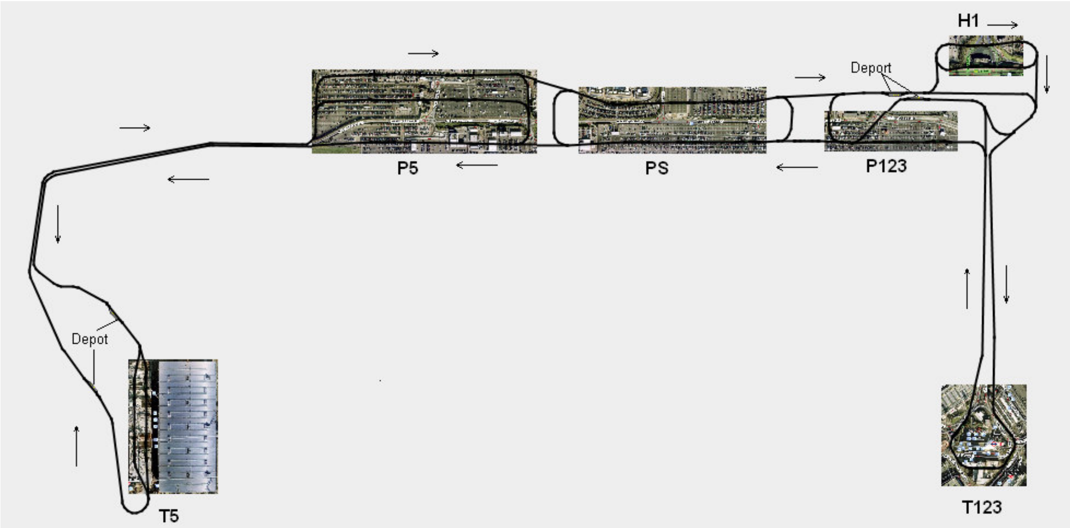

Fig. 1: PRT network investigated in Simulation

However, if actual demand is not consistent with the predicted demand, then either resources may be wasted (demand lower than predicted) or the quality of service may not be improved (demand greater than predicted) because part of the demand will have to be met in a responsive mode.

Two demand management strategies were considered in this investigation. The first is a 'local demand prediction tactic' which predicts local demands at a station within a time window of travel time for an empty vehicle to be dispatched from a depot (which provides empty vehicles to the station in question) to the station. The second is a 'long term demand prediction strategy' which estimates traffic demand changes for near future for all stations (5~10 minutes) based on long term trends in demand.

SIMULATION STUDY

A simulation study was carried out to investigate predictive demand management strategies for PRT operation. Traffic management strategies incorporating the predictive demand with a demand responsive traffic service were tested. The investigation was carried out at two different levels. At the vehicle dispatching level, a local demand prediction tactic was used. At service level, a predictive demand program was examined.

A dedicated PRT simulation model, PRT Hermes (Xithalis, 2008) was used in the investigation, as it allowed the implementation of a demand program to simulate different demand inputs. Additionally, Hermes has the functionalities necessary to model PRT networks with different system specifications.

The investigation required some minor modifications to the software in order to implement the demand management strategies. Following correspondences with the developer of Hermes, necessary modifications to the simulation model were made to allow demand to be specified in two separate demand programs:

1) Demand: the PRT operation (vehicle dispatching and relocation etc.) within the simulator is calculated based on this demand
2) Actual demand: the actual generation of travel demand is calculated based on this demand.

The developer has also modified Hermes to allow an OD-matrix representation of demand which allows travel demand between stations to be conveniently represented in the simulation. The modified version of Hermes is capable of reproducing PRT operations under both demand responsive and predictive demand responsive modes, and the modified Hermes was used for the investigation of PRT operation under the proposed traffic management strategies.

A 'local demand prediction tactic' was incorporated in the Hermes simulation, which is used for empty vehicle prediction in vehicle dispatching. The general logic, as described by the author of the Hermes simulation model, can be summarised as follows:

- Each station has a source capacitor (depot) which provides empty vehicles.
- Assuming it takes *x* minutes for an empty vehicle to travel from the source capacitor to a station.
- The prediction algorithm constantly predicts the needs for empty vehicles at the station *x* minutes in advance taking the following into account:
  - The number of vehicles (full and empty) currently present in the station berths
  - The number of vehicles (full and empty) currently underway towards the station that will arrive within the next x minutes.
  - The number of passengers that are expected to arrive within the next x minutes, based on current average rate of arrivals
- The number of spare vehicles that should be available at the station after all passengers get serviced

The demand prediction for vehicle dispatching is very much for the short term only, i.e., within the travel time between a depot and a station. The operation of PRT with and without this 'local demand prediction tactic' was investigated by comparing passenger waiting times at stations

The 'long term demand prediction strategy' was focused on the daily changes in demand, e.g. demand rising before the morning peak and falling after the evening peak. By running a PRT system on predictive demand, resources such as relocation of vehicles (e.g. at different depots) can be pre-arranged to meet an anticipated increase or decline in the demand, which may improve the responsive service offered by PRT. It is expected that if the actual passenger demand is close to the predicted demand, then the optimized vehicle relocation should be best. If the actual demand is not consistent with the predicted demand, then either resources will be wasted (demand lower than predicted) or the quality of service will be poor (demand greater than predicted). The operation of PRT based on both predictive and non-predictive demands was examined in the simulation study.

The PRT network investigated in the research is shown in Figure 1. An extended network was used which consists of 23 stations serving four terminals, the main car parks and a hotel to the north of the airport. The network consists of 16505 m of guide-way. The distribution of the stations at different locations is summarised in Table 1. Terminal 5 and Terminals 1-2-3 together have four and three stations respectively, whilst the car parks have 14 stations. There are 4 depots, two close to Terminal 5 and another two close to Terminal 1-2-3 (as shown in Figure 1).

Table. 1: Stations in the Simulated Network

Label on map	Stations	Description
T5	1, 2, 3, 4	Terminal 5
T123	5, 6, 7	Terminal 1, 2 and 3
P5	8, 9, 10, 11, 12	Car park close to Terminal 5
PS	13, 14, 15, 16, 17, 18	Shared car park by all
P123	19, 20, 21	Car park close to Terminal 1, 2, 3
H1	22, 23	Hotel

A travel demand profile with typical morning and afternoon peaks was constructed to mimic travel demand patterns between terminals, car parks and the hotel. The base demands between them are shown in Table 2. The average total demand over the network is 5355 vph.

Table. 2: Base Demand between Destinations (vph)

	T5	T123	P5	P123	PS	H1	Sum
T5	0	360	1000	24	12	40	1436
T123	120	0	15	900	135	60	1230
P5	900	30	0	60	30	10	1030
P123	48	990	60	0	36	60	1194
PS	24	135	30	36	0	30	255
H1	24	66	10	60	30	20	210
Sum	1116	1581	1115	1080	243	220	5355

The total demand over the network across a day is shown in Figure 2, which is expressed in number of vehicles rather than number of passengers. Depending on the capacity of the vehicle (2 passengers in Hermes), a group of passengers with the same destination may share a ride. In this investigation, only vehicle demand was considered. It is assumed that a vehicle will be dispatched no matter whether one or more passengers request it.

The maximum total demand is about twice the base demand. The demand profile is constructed to mimic a typical two-peak everyday traffic profile. It should be noted that the profile is indicative and is not intended to reflect actual timings of passenger demand peaks. Overall, the profile covers low demand, high demand and transitional demand scenarios as are to be expected in real life.

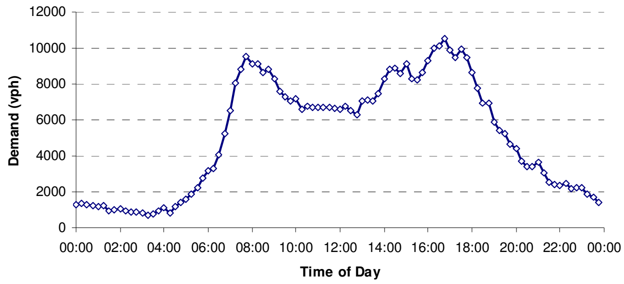

Fig. 2: Total Demand Profile in Simulation

For the investigation of the predictive demand management strategy, simulations were run for 6 different demand situations as follows:

- Low Demand 00:00~04:55
- Rising Demand 05:00~06:55
- Morning Peak 07:00~08:55
- Medium Demand 09:00~15:55
- Afternoon Peak 16:00~17:55
- Falling Demand 18:00~21:55

This was considered to be necessary as the predictive demand management strategy might perform differently at different demand situations. For example, it can be expected that a predictive demand strategy is not effective when travel demand is stable because then, predictive demand is always similar to the current demand. Predictive demand should be more effective if clear trends such as a rising or falling demand are evident

The basic settings used for the simulations are:

- Vehicle speed 10m/s (36 km/h), which is believed to be close to the operation speed of the Heathrow PRT system
- The minimum headway between PRT vehicles is 0.5 second, which is believed to be practical technically, and is able to accommodate the demand profile proposed in this investigation.

The effects of both the local demand prediction tactic for vehicle dispatching and the long term demand prediction strategy were then investigated based on the above simulation settings for the PRT network, traffic demand and traffic management strategy.

RESULTS

For the local demand prediction tactic investigation, a with-and-without prediction approach was taken over the whole period of the demand profile. The results are shown in Figure 3. The average waiting time across all stations was reduced from 29 seconds to 26, e.g. by 11.5% with the local demand prediction tactic implemented. The difference is statistically signification ($t=2.80$, $p<0.05$), so the introduction of demand prediction in vehicle dispatching can lead to a small but significant reduction in passenger waiting times at stations,

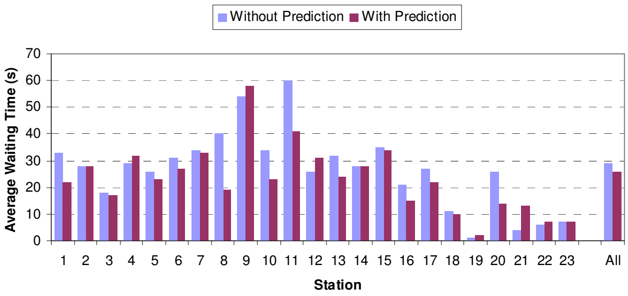

Fig 3: Average Waiting Times at Stations

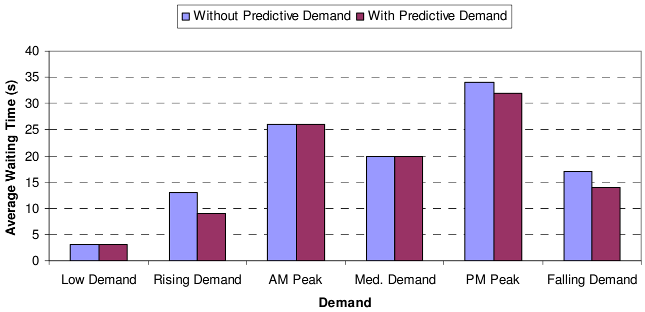

Fig 4: Average Waiting Times for Different Demand Periods

For the long term demand prediction strategy investigation, a with-and-without predictive demand approach was adopted based on the six demand situations described above. The results are shown in Figure 4. The maximum number of vehicles used for AM and PM peaks are 1020 and 1117 vehicles respectively. It can be observed from the figure that the average waiting times remain unchanged for low demand, medium demand and AM peak situations. This may be explained by that fact that travel demand in these periods is relatively stable, and predictive demand is basically the same as the current demand. In these conditions, no advantages in terms of waiting time reduction can be expected from predictive demand. On the other hand, reductions of waiting times can be found from applying the predictive demand strategy in rising, falling and PM peak demand situations. This is clearly an indication that the long term demand prediction strategy is helpful to the operation of PRT when traffic demand is varying and showing a clear trend. It should be noted that the PM peak demand (16:00~17:55) shows an overall trend of falling demand in this investigation. This may explain why the predictive demand strategy is effective for the PM peak scenario. However, the t-test reveals that the reduction in average waiting time for this scenario is not statistically significant ($t=0.61$, $p>0.05$).

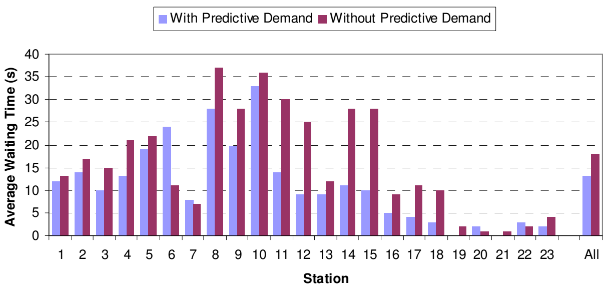

Fig 5: Comparison of Waiting Times for Rising Demand

Station-by-station comparisons of waiting times for simulation runs with and without the long term demand prediction strategy are shown in Figure 5 and Figure 6 for rising and falling demand situations respectively. In both situations, average waiting time is significantly less. For the rising demand situation, the average waiting time at all stations is about 5 seconds or 26% less with the predictive demand strategy than without. The difference is statistically significant ($t=3.46$, $p<0.05$). For the falling demand situation, the average waiting time at all stations is about 4 seconds or 20% less with the predictive demand strategy. The difference is statistically significant ($t=2.80$, $p<0.05$).

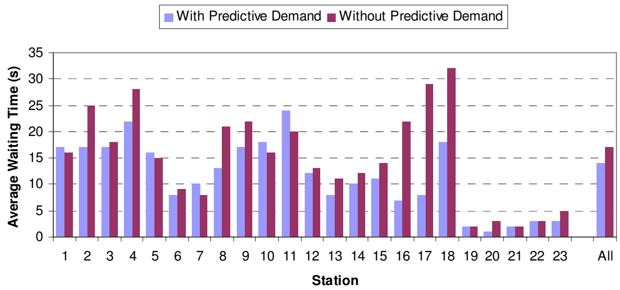

Fig. 6: Comparison of Waiting Times for Falling Demand

It is clear from the simulation results that introduction of a local demand prediction tactic in vehicle dispatching and the introduction of a long term demand prediction strategy in resource distribution can significantly reduce passenger waiting time at stations, and thus improve PRT operation and level of service overall.

CONCLUSION AND DISCUSSION

PRT is a demand-responsive transportation service where vehicles are dispatched in response to demand in real-time. Whilst the operational efficiency of the PRT system can be improved by proper network design (e.g. topology of tracks, arrangement of stations and depots) and optimal vehicle dispatching and control algorithms, traffic management strategies for PRT system are explored and investigated in this work package.

A traffic management strategy for PRT operation – based on predictive demand management - was proposed and tested using the Hermes simulation model. The investigation was carried out at both local level for vehicle dispatching (using a local demand prediction tactic) and network operational level (using a long term demand prediction strategy) to quantify the effects of the 2 methods on the operation of PRT system based on an extended Heathrow network.

With the local demand prediction tactic for vehicle dispatching, demand for empty vehicles at a station were predicted using a local demand predication algorithm. This tactic would allow vehicles to be dispatched in advance to cover the travel time between a depot and a station and thus reduce passenger waiting time at a station.

With the long term demand prediction strategy for network operation, passenger demand for the PRT network was predicted using a global demand predication algorithm. This strategy would allow the network operation (e.g. relocation of vehicles, number of vehicles in operation) to be ready for rising/falling demands in advance and thus reduce passenger waiting time across the network.

Simulation results revealed a significant reduction of 11.5% in average waiting time across all stations in the test network as a result of using the local demand predication tactic. The effects of using the long term demand prediction strategy are significant for scenarios with both rising and falling travel demands, with reductions in average waiting time of 26% and 20% respectively. When overall network demand is stable, waiting time is not significantly different for scenarios with and without the long term demand prediction strategy. This is expected as demand and predictive demand for the network are basically identical when network demand is stable.

It can be concluded, based on the simulation results that both the local demand prediction tactic for vehicle dispatching and the long term demand prediction strategy for network operation can enhance the service level of a PRT system by significantly reducing the average waiting time at stations. Despite the fact that PRT is a demand responsive service, the service level can be improved by traffic management measures such as those investigated in this research.

It should be noted that the investigation was based on the assumption that there are no limits on the number of vehicles which can be put into service. In a real system, it may not be possible to provide this maximum number of vehicles required because of constraints in initial investment. However, in the long run, it is usually the network capacity rather than number of vehicles which limit the capacity of a transport service, especially in situations where demands are high (e.g. as in this investigation). The assumption of unlimited vehicle provision may therefore be realistic for a well developed PRT system. As the average waiting times for PRT system is low (with sufficient vehicle supply), the absolute reductions in average waiting time is relatively small although the percentage is high. However, it should be noted that such reduction in average waiting time could be manifested as big waiting time reductions in some extreme cases (e.g. long waiting passengers). The simulation investigation may help understand and design a system so as to limit the worst case experiences.

It is not possible to implement the proposed traffic management strategies independent of the PRT operation as predictive demands need to be incorporated into the PRT core operation algorithm in order to influence operations such as vehicle dispatching, vehicle relocation and vehicle provision etc. Meanwhile, significant deviation between predictive and actual demands can result in reductions of operational efficiency of the PRT system. In this investigation, the network demand is predicted using a historical profile which is believed to be realistic. There may be occasions when abnormal network demands occur. In such cases a supplementary traffic demand sensing mechanism and prediction algorithm may be required to ensure travel demand can still be predicted with reasonable accuracy.

Whilst traffic management strategies may have wider impacts on the PRT operation, certain impacts, such as journey time, safety, accessibility, vehicle occupancy and trips made, are more associated with system and service design rather than traffic management. Journey time will be determined by design speed (with the synchronous control system used in HERMES, congestion is not possible on the track. excessive demands will be kept on stations and revealed as increased waiting time). Safety is a combination of vehicle design such as protection to passengers, and system design such as operating speed and hardware/software reliability. Accessibility is determined by network design and station/vehicle design. Vehicle occupancy and trips made are mainly determined by vehicle capacity and demands at stations. These are unlike to be affected by the proposed traffic management strategy.

ACKNOWLEDGEMENT

We would like to thank Christos Xithalis, the developer of the Hermes simulation model, for providing and making relevant modifications to the model to accommodate the simulation reported in this paper.

REFERENCES

1. Anderson, J. E. 2003. "Control of Personal Rapid Transit Systems." *Telektronikk*, Vol. 99, No. 1, 108-116
2. Bretherton, D., Bowen, G., Wood, K. 2002. 'Effective urban traffic management and control - SCOOT VERSION 4.4'. Proceedings of *European Transport Conference Proceedings*. Cambridge
3. Christos Xithalis, 2008, PRT Hermes (http://students.ceid.upatras.gr/~xithalis/index_en.html)
4. Cottrell, W. D. 2008. "New-generation Personal Rapid Transit Technologies – Overview and Comparison" *Transportation Research Record*, Vol. 2042, 101-108
5. Gartner, N. H.; Pooran, F. J.; Andrews, C. M. 2002. 'Optimise polices for adaptive control strategy in real-time traffic adaptive control systems: implementation and field testing.' *Transportation Research Record*. 2002. Vol. 1811, 148-156.
6. Johnson, R. E. 2005. "Doubling Personal Rapid Transit Capacity with Ridesharing" *Transportation Research Record*, Vol. 1930, 107-112
7. Kai, C.; Matsuda, R.; Yano, Y.; Hamamatsu, Y. 2005. "An Analysis of Double Queue on PRT System and a Control Strategy for Merging" *Transactions of the Institute of Electrical Engineers of Japan*, Vol. 125-D, No. 6, 645-651
8. Lowson, M. 2003. "New Approach to Effective and Sustainable Urban Transport." *Transportation Research Record*, Vol. 1838, 42-49.
9. Lowson, M. 2005. "Personal Rapid Transit for Airport Applications" *Transportation Research Record*, Vol. 1930, 99-106
10. Won, J.; Choe, H.; Karray, F. 2006. "Optimal Design of Personal Rapid Transit" *Proceedings of IEEE Intelligent Transportation Systems Conference*, pp. 6
11. Wren, A. and Laughlin, K. 1996. 'Hampshire County Council, UK, ROMANS: road management system for Europe.' *Proceedings of European Transport Conference*