A Taxi Dispatch System Based on Current Demands and Real-Time Traffic Conditions

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A TAXI DISPATCH SYSTEM BASED ON CURRENT DEMANDS AND REAL-TIME TRAFFIC CONDITIONS

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ABSTRACT: This research involves the study of the existing taxi dispatch system employed by taxi operators in Singapore to handle current bookings. This dispatch system adopts the Global Positioning Systems (GPS), and is based on the nearest-coordinate method, i.e. the taxi assigned for each booking is the one with the shortest, direct, straight-line distance to the customer location. However, the taxi assigned under this system is often not capable of reaching the customer in the shortest time possible. An alternative dispatch system is proposed, whereby the dispatch of taxis is determined by real-time traffic conditions. In this proposed system, the taxi assigned the booking job is the one with the shortest-time path, i.e. it will reach the customer in the shortest time. This dispatch ensures that customers are served within the shortest period of time, resulting in increased customer satisfaction. The effectiveness of both the existing and proposed dispatch systems is investigated through computer simulations. This study presents and analyzes the results from a simulation model of the Singapore Central Business District (CBD) network. Data from the simulations show that the proposed dispatch system is capable of being more efficient in dispatching taxis more quickly; leading to more than 50% reductions in passenger pick up time and average travel distance. A more efficient dispatch system would result in higher standards of customer service, and a more organized taxi fleet to better meet customer demands.

INTRODUCTION

Taxis play an important role in offering personalized service within Singapore's public transport sector (*1*,*2*). With the growing emphasis on customer satisfaction, it is essential for taxi operators to constantly upgrade their systems and facilities to ensure quality service.

Background

This research involves a study of the existing taxi dispatch system employed by taxi operators in Singapore to handle taxi bookings, and which uses the Global Positioning Systems (GPS). This dispatch procedure is based on the nearest-coordinate method, which means the taxi assigned a particular booking is the one that is the nearest to the customer location in terms of straight-line distance. However, the assigned taxi may not essentially be the taxi that is capable of reaching the customer in the shortest time possible. It is therefore hypothesized that a dispatch system based on real-time traffic conditions would be able to ensure that the taxi assigned the booking is in fact the taxi that is capable of reaching the customer in the fastest time. In the proposed system, the taxi assigned the booking will be the one with the shortest travel time as derived from the traffic conditions on the roads at the time the booking call is received. With this proposed system, customers who make bookings may be served within the shortest time possible, bringing a closer match between the supply and demand of taxis, and thus increasing customer satisfaction and making taxi booking more reliable.

Objective

The main objective of this research is to verify the hypothesis that the proposed dispatch system is more efficient than the existing dispatch system in handling taxi bookings, in that it is able to assign the booking to the taxi that is most capable of reaching the customer within the shortest period of time. This hypothesis is verified through microscopic computer simulations (*3*). Simulation runs were performed on a selected network chosen from the Central Business District (CBD) in Singapore. Evaluations on the performances of both systems were then made, based on their efficiency in dispatching taxis, in terms of travel times and travel distances. A sensitivity analysis was also carried out to investigate the influence of 'empty-taxi' rates on the performances of the two systems.

METHOD OF INVESTIGATION

This research began with the identification and analysis of the shortcomings of the existing dispatch system, followed by the collection of all relevant information for simulation purposes. Using the available data, an Application Program Interface (API) program was written to further customize the simulation environment and the coding of the CBD network was carried out simultaneously (*4*,*5*). Following this, simulation runs were carried out to investigate the performances of the two dispatch systems. Results obtained from the simulation runs were then used to compare and evaluate the performances of the two dispatch systems.

Problem Identification and Analysis

The existing taxi dispatch system assigns a booking job to the taxi with the shortest straight-line distance to the customer location. However, as is often the case, the assigned taxi might not be the taxi that is capable of reaching the customer within the shortest time possible.

There have been instances when the assigned taxi happened to be just on the opposite side of the road from where the customer was located. In order to get to the customer, the taxi driver had to make a U-turn at the next available junction where U-turning was allowed, and this junction happened to be some distance away. A similar problem was also encountered on one-way streets, where the taxi-driver would have to travel a long way before turning back to reach the customer. Thus, a taxi might be very near the customer in terms of direct distance, but it had to travel a longer path than a taxi approaching from a longer direct distance.

Hence, it is proposed that a system that dispatches a taxi within the shortest time path, based on real-time traffic conditions would ensure that the taxi assigned to each booking would be the taxi that was able to reach the customer in the fastest time. This would guarantee that each customer who made a booking is served within the shortest possible time, thus increasing operational efficiency and enhancing customer satisfaction.

Data Collection

In order to carry out the simulations, details on how the taxi operators handled each taxi booking were required for writing the API program to simulate the existing dispatch system in a customized simulation environment. Such data was collected through correspondence with the major taxi companies in Singapore, including Comfort Transportation Pte Ltd (*6*), CityCab Pte Ltd (*7*) and TIBS Taxis Pte Ltd (*8*).

The coding of the CBD network, and the details of the geometry and physical layout of the roads were checked and the maps in the street directory *(9)* were referred to. The number of lanes on each road and the locations of the traffic signals were also determined through appropriate road surveys. Data of signal timing and phasing, origin-destination (OD) statistics and information on the demarcation of zones in the CBD area were from the related transportation authorities (*10, 11*).

Network Coding

Using the relevant information, the network of the CBD area was coded in the Paramics environment. The CBD network was chosen because of the heavy and extensive commercial and retail activities in the CBD, making it a concentrated source of taxi bookings, especially during the peak periods. More importantly, the CBD network consists of many one-way streets and few U-turning junctions. These are common features that affect the effectiveness of the existing dispatch system which were discussed earlier, in relation to problem identification and analysis. Hence, the differences between the performances of the two dispatch systems are best highlighted using the CBD network.

The network consists of a total of 894 nodes and 2,558 links. The 100 traffic analysis zones in this network are defined according to the traffic demands of each zone, which is allocated according to the acquired OD data. The total number of taxis running within the CBD is assumed to be approximately 2,000, based on information obtained from both the transportation authority and the taxi companies. Figure 1 provides an overview of the CBD network.

API Programming

An API program was developed to provide models of the two taxi dispatch systems in the Paramics simulation environment. The program incorporated both the existing dispatch system based on the nearest-coordinate method and the proposed dispatch system based on real-time traffic conditions.

Under the existing dispatch system, the program calculated the direct straight-line distances between the available taxis and the demand locations, by making use of the coordinates of the associated links on the network. With all the direct distances determined, the dispatch system then identified the taxi with the shortest straight-line distance to the customer location, and delegated it to travel to the demand location.

Under the proposed dispatch system based on real-time traffic conditions, a link-to-link shortest path algorithm was developed based on Dijkstra’s Algorithm, to search for the shortest paths available for the taxis to reach the demand locations. Using this algorithm, the travel times required by alternative taxis to reach the demand location based on real-time traffic conditions could be determined, and the program then assigned the taxi with the shortest travel time to make its way to the demand location.

In the program, it was assumed that the empty taxis roamed randomly in the CBD waiting for booking calls. It was also assumed that the empty-taxi rate remained constant throughout the simulation period, that is, the number of empty available taxis within the network remained unchanged. Another assumption was that each taxi booking received required immediate attention from the dispatch systems to assign an appropriate taxi to the customer. The drivers of all the empty available taxis were assumed to be equally willing to accept any bookings. Each taxi was also assumed to travel with its shortest time-path to reach the customer, after being assigned the booking.

Simulation Runs

Using the coded network and API program, traffic simulations were then performed to compare the performance levels of both dispatch systems. As each booking was independent, only one booking demand was generated and handled at an allocated time during each simulation run, which lasted an hour.

Extensive simulation runs were conducted on the CBD network to generate the dispatch results of the two systems in handling booking demands in an actual network system. The available taxi densities in the network were varied as a form of sensitivity analysis to evaluate their impact on the performances of the two systems. The empty taxi rates were varied from 5% to 25% of the total taxi fleet in the network. For each empty-taxi rate, demands were generated at 10 different locations. A total of 10 simulation runs were conducted for each of these locations, with the demand times allocated at 5-minute intervals between simulation runs, and were always set to begin after a 10-minute warm-up of the simulation. In all, a total of 500 simulation runs were carried out using the CBD network.

ANALYSIS OF RESULTS

The necessary data required for analysis and evaluation was extracted from the simulation runs through the API program. The time taken for the assigned taxi to reach the designated customer was used as the yardstick to determine which was the better dispatch system of the two. Another factor for consideration was the actual distance traveled by the taxi to reach the customer location.

The simulation results for a particular location at varying times of demand were first presented. This was followed by the simulation results when all the 10 locations were taken into account. The simulation results for varying empty-taxi rates were then finally discussed.

Variations on Demand Times

The empty-taxi rate was initially set at 5% of the total taxi population, which meant that at any one time during the simulation period, there were 100 empty taxis available for meeting booking demands in the CBD. The demand location was first fixed at Parco Bugis, a popular shopping area in the CBD. The demand times were varied at 5-minute intervals for the 10 simulation runs. The simulation results obtained are tabulated in Table1.

From Table 1, it may be observed that there were 9 out of 10 instances where a different taxi was identified by the proposed dispatch system based on real-time traffic conditions. There was only one occasion when an identical taxi was identified. During Run no. 8, it could be seen that the direct distance of the taxi identified by the existing system was 0m, and yet it took a longer time than the other taxi identified by the proposed system, to reach the customer location. This could be due to two possibilities. One was that the taxi was on the opposite side of the road and traveling in the opposite direction. The other possibility was that the taxi had just passed the customer location the instant the booking was received. Hence, to get back to the customer, the taxi had to make a detour, taking a much longer time as a result. With regards to each of the other 9 instances, where different taxis were identified by the two systems, the travel times for the proposed system were always shorter than those of the existing system.

It can be seen from Table 2 that with the proposed system, the times taken for the assigned taxis to arrive at the demand locations were significantly reduced, with an average improvement in travel time of 70.8%. Besides the improvements in travel time, the actual distances traveled by the assigned taxis to reach the customers were also significantly reduced. The average improvement in distance was about 54.7% of the average actual distances traveled by the taxis dispatched under the existing system. Therefore, it can be said that the proposed system is more efficient than the existing system in dispatching taxis.

Variations on Demand Locations

With the empty-taxi rate fixed at 5%, nine other locations were investigated. Again, for each location, 10 simulation runs were conducted with the demand generated at 10 different time intervals. Results favoring the proposed system, similar to the Parco Bugis location, were obtained at each of these nine locations. The differences in the time required for the taxis dispatched by the two systems to reach customers locations are also illustrated in Figure 2. It can be seen that for each location, the average time taken by the assigned taxis to reach the customer location using the proposed dispatch system was significantly less than time taken by taxis using the existing dispatch system.

The average improvements in time for all 10 locations are presented in Table 3. The total average improvement in time for all the locations was 53.6% of the total average time taken by the taxis dispatched under the existing system. Besides savings in time, the proposed system also resulted in significant reduction in the distances traveled to reach the customer. The total average reduction in distance for the 10 locations was 53.2% of the total average travel distances for the taxis dispatched under the existing system. Hence, it can be deduced that the proposed system is clearly more efficient in dispatching taxis, and brings about a better match of taxi, for each taxi booking at all the various locations.

Variations on Empty-Taxi Rates

A total of five sets of simulation runs were conducted using the CBD network. In each set of simulation runs, the proportion of empty taxis on the network was varied. The percentages ranged from 5% to 25% of the total population of 2,000 taxis in the network. For each empty-taxi rate, demands were investigated at the 10 different locations at 10 different time intervals of the simulation period. Due to some constraints in resources, there were some inaccuracies in the results of the last two sets of data. Hence, these two sets of results were disregarded in the analysis. This error will be discussed in relation to limitations and error analysis.

The variations in average travel times of empty-taxi rates are shown in Figure 3. It can be observed that as the empty taxi rate increased from 5% to 15%, the average travel times for both systems decreased. This is because with more empty taxis available on the network to serve booking demands, both the existing and proposed systems were able to identify taxis with both shorter direct distances and shorter time-paths to the customer locations. It may also be observed that for all the variations in rates, the average travel times of the taxis dispatched under the proposed system were considerably shorter than those of the taxis dispatched by the existing system. Therefore, the proposed system proves to be more efficient than the existing system in varying empty-taxi rates.

The average reductions in travel times and distances brought about by the proposed system for the first three sets of simulation runs are summarized in Table 4 and Table 5. It can be observed that with varying empty-taxi rates, there were always average time reductions under the proposed dispatch system. The average time improvements for all three empty-taxi rates was 90 seconds, which was about 57.7% of the average travel time taken by the taxis dispatched under the existing system. Together with average time reductions, the proposed system also brought about considerable reductions in distances as well. The total average improvement in distance traveled was approximately 59.2% of the total average distance traveled by the taxis dispatched under the existing system. This again, reaffirms the more efficient performance of the proposed system based on real-time traffic conditions at the various empty taxi rates, compared to the existing system based on the coordinate method.

As was discussed earlier, there were instances where the taxi chosen for dispatch under the proposed system based on the real-time traffic information method was identical to the taxi dispatched under the existing system based on the coordinate method. There were also rare adverse occurrences where the taxi dispatched by the proposed system took a longer time than the taxi selected by the existing system to reach the customer location. The relevant statistics are tabulated in Table 6.

From Table 6, it can be seen that among the 300 simulation runs conducted, there were 210 cases where the proposed system identified a taxi that came faster, 82 cases where it identified the same taxi, and eight cases where it identified a taxi that came more slowly. That means the proposed system was more efficient 70% of the time, as efficient 27% of the time, and less efficient only 3% of the time, than the existing system. For the 3% of the adverse cases, the reason for a slower taxi was a disparity between the instantaneous and the actual travel times experienced (also known as ideal travel time, based on predictive traffic conditions). This was most probably caused by a change in the traffic conditions while the taxi was on its way to the customer location, resulting in its taking a longer travel time than was estimated. However, these occurrences were rare, occurring only eight times out of 300 simulation runs.

Thus, it may be concluded that the performance level of the proposed system based on real-time traffic conditions is indeed more efficient than the existing system based on the coordinate method. With the proposed system, not only is the waiting time effectively decreased under all the general circumstances considered, but the distance that the assigned taxi has to travel is also significantly reduced.

LIMITATIONS AND ERROR ANALYSIS

Due to the constraints of time and available resources, a couple of aspects of this research had to be compromised. This led to some slight inaccuracies and discrepancies in the results obtained. First, we will address the constraints leading to the discrepancies between estimated and actual travel times. Following this, the limitations of computational resources resulting in inaccuracies of some results will be reported.

Estimation Constraints

Due to the unavailability of accurate means for predicting the delays at intersections that the taxis would encounter while on their way to pick up customers, the delays caused by signal were omitted from the estimation of travel times when selecting the taxi to be dispatched to a customer. This gave rise to the disparities between the estimated arrival time during the dispatching process and the actual time measured to reach the customer. The graph in Figure 4 shows the estimated and actual travel times of the taxis dispatched under the proposed system to the demand location at Parco Bugis, at an empty taxi rate of 5% of the total taxi population.

From Figure 4, it can be observed that other than Runs 1, 2 and 9, there were significant disparities between the estimated and the actual arrival times. These disparities were most probably equivalent to the delays encountered by the assigned taxis at the intersections, which were not included in the calculation of the estimated travel times when selecting the nearest" taxi. For Runs 1, 2 and 9, there were few differences between the estimated and actual travel times. This is likely to be because the taxis dispatched in these runs were not intercepted by any intersection delays, while on their way to the customer locations. However, it is noted that the actual travel times were fairly short, ranging from one to three minutes. Therefore, the inclusion of any signal delay might on the whole lead to even greater disparities between the estimated and actual arrival times. Unless there exists means to predict the signal delays accurately that would be encountered by an individual vehicle on its designated route, it is difficult to bridge the discrepancies between the estimated and actual arrival times.

Therefore, the chosen taxi in the microscopic traffic simulation may or may not be the fastest one that should have been dispatched in terms of the actual travel time because of the aforementioned limitations. However, even with this imperfection, the proposed dispatch system has functioned well based on the estimation of travel time without taking into account the intersection delays, and has outperformed the existing system, as shown by our simulation study. This imperfection may cause the simulation results to err on the safe side, if any inaccuracies were to have resulted from it, without diminishing the validity of the proposed dispatching system.

Limitations on Computational Resources

With regards to the existing dispatch system, all the available direct distances of the taxi to the customer locations were calculated, as this process required relatively little storage space and computation time. However, for the proposed dispatch system, the determination of the shortest path for each available taxi required a considerably larger amount of memory space and calculation time. Due to the speed and memory limitations of available computers, it was not a feasible option to establish the shortest paths of all the available taxis. Hence, some modifications were made in the API program to overcome this constraint of resources, and to expedite the simulation process. It was assumed that the taxi with the shortest time path would be among the 20 nearest taxis that had the shortest direct distances to the customer location.

A graph of the average travel times for all the empty taxi rates can be found in Figure 5. For the existing system, the travel times started to fluctuate beyond an empty taxi rate of 15%. This is not an unexpected phenomenon since there is no direct correlation between the direct distance to the customer and the time taken for the taxi to arrive at the customer location. Therefore, although the system was able to locate a taxi that had a shorter direct distance than at a lower empty-taxi rate, it did not guarantee that that taxi would reach the customer location in a shorter time.

However, the travel times started to increase under the proposed system, beginning from empty-taxi rate 15% onwards. This should not have been the case, as an increase in the number of available taxis should have increased the probability of the system locating a taxi that had a shorter travel path and thus, lead to improved timing. Therefore, this reverse trend was deemed to be an error, and most likely to have been due to the assumption made in the API program. This assumption is fairly acceptable when empty taxi rates are low. However, when the empty-taxi rate increases up to a certain point, approximately 15% to 20% in this case, the search locus becomes too small to capture the taxi with the shortest time path out of all the available taxis on the network. Hence, the taxi assigned would simply be the most suitable among the 20 taxis, and not among all the available taxis.

However, as mentioned earlier, the API program did work well for empty taxi rates 5% to 15%, which was the approximate variation for the taxi population traversing within the actual CBD, based on information from the taxi companies. Therefore, the assumption is justified for this range of empty-taxi rates. If there were to be any inaccurate results, the assumption would have again caused the results to err on the conservative side. As such, the performance of the proposed system would have been underestimated.

However, if a high performance computing facility were available, the search for the taxi with the shortest time path could be extended to include all the available taxis on the network. As such, this error would not have occurred at all. Thus, if taxi companies do adopt this proposed system of dispatch based on real-time traffic conditions, the state-of-the-art technology to be used would not pose this limitation and result in any of such inaccuracies. The timing would be expected to improve with the increase in empty-taxi rates, with other factors remaining constant. The proposed dispatch system would be able to assign bookings to the most suitable taxi with the shortest time path based on real-time traffic conditions, ensuring that each customer is being served within the shortest time possible.

CONCLUSION

This study investigates the effectiveness of the existing dispatch system based on the nearest-coordinate method in comparison with the proposed dispatch system based on real-time traffic conditions. Through a microscopic simulation model based on the CBD network, the potential benefits of the proposed dispatching method are demonstrated and evaluated.

From the analysis of the simulation results, it is clear that the proposed system yields significant time savings in meeting customer bookings. This effectively reduces the amount of customer waiting time, as each customer would be served within the shortest period of time possible by the most suitable taxi, thus increasing customer satisfaction. Besides benefiting the customers, taxi drivers also stand to gain from this proposed system. With a decrease in the traveling time taken to reach the customers, the empty cruise times of the taxis are also shortened as a result. Moreover, the distances that the assigned taxis have to travel to reach customers are also significantly reduced. This would help the taxi drivers to cut down on any unnecessary petrol consumption.

On the whole, this proposed system would enable taxi companies to reduce the passenger pick up time, hence improving the accuracy and efficiency of their dispatch systems, and thus delivering a higher level of service to the customers. With a reduction in waiting times, more customers would be willing to hire taxis through bookings, rather than use other means of hiring them. This would allow the taxi operators to better manage and optimize their taxi fleets, as a better match of demand and supply of taxis could be met.

SUGGESTIONS FOR FUTURE RESEARCH

To further enhance the performance of the proposed system and utilize the system to its full potential, some directions for future research are proposed.

Estimation of Signal Delays

Research can be conducted to derive and discover new ways or methods to obtain accurate estimations of the signal delays, so that they can be incorporated into the estimated travel times. This would help to provide a better estimate of the arrival time of a taxi during the decision-making moment of dispatch. A function to accurately predict the delays caused by signals that an individual vehicle experiences at intersections, would enhance the accuracy of the proposed system.

Simulation Model

In entertaining customer-booking requests, it is often necessary to inform the customer of the approximate time of arrival of the assigned taxi. Currently, the estimation of this time that is being conveyed to the customer is predicted by the taxi driver, based on his or her own judgment and experience. This is often an inaccurate estimate. By implementing the simulation model presented in this research, more accurate prediction of the time of arrival can be made possible.

With such a simulation system running at a faster pace alongside the actual dispatch system, each customer location can be entered into the simulation system, along with the dispatch and pick up time simulated in the network model, based on the existing traffic conditions. The time, at which the assigned taxi in the simulation model arrives at the customer location, can then be reported as the estimated time of arrival to the customer in the actual situation. This way, a more realistic measure of the time of arrival can be obtained.

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LIST OF TABLES AND FIGURES

Table 1 Simulation Results with Demand Location at Parco Bugis

Run no.	Taxi Identified	Direct Distance (m)		Estimated Travel Time (sec)		Actual Travel Time (sec)	
		Current System	Proposed System	Current System	Proposed System	Current System	Proposed System
1	*Different*	*34*	*406*	*58*	*17*	*144*	*11*
2	*Different*	*124*	*587*	*71*	*36*	*139*	*34*
3	*Same*	*34*	*34*	*58*	*58*	*149*	*149*
4	*Different*	*104*	*352*	*67*	*17*	*303*	*66*
5	*Different*	*181*	*635*	*68*	*35*	*157*	*57*
6	*Different*	*34*	*352*	*63*	*17*	*290*	*67*
7	*Different*	*211*	*520*	*56*	*26*	*132*	*86*
8	*Different*	*0*	*539*	*74*	*19*	*242*	*34*
9	*Different*	*39*	*406*	*72*	*17*	*292*	*13*
10	*Different*	*94*	*533*	*65*	*34*	*152*	*68*
Average		*86*	*436*	*65*	*28*	*200*	*58*

Table 2 Improvements in Travel Times and Distances with Demand Location at Parco Bugis

Run No.	Taxi Identified	Improvement in Time		Improvement in Distance	
		sec	%	m	%
1	*Different*	*133*	*92.3*	*39*	*3.1*
2	*Different*	*105*	*75.5*	*1099*	*87.0*
3	*Same*	*0*	*0.0*	*0*	*0.0*
4	*Different*	*237*	*78.2*	*1099*	*87.0*
5	*Different*	*100*	*63.6*	*46*	*3.7*
6	*Different*	*223*	*77.0*	*1010*	*86.0*
7	*Different*	*46*	*35.0*	*1099*	*87.0*
8	*Different*	*208*	*86.1*	*1153*	*91.3*
9	*Different*	*279*	*95.7*	*872*	*71.0*
10	*Different*	*84*	*55.1*	*531*	*36.4*
Average		*141*	*70.8*	*695*	*54.7*

Table 3 Time Improvements of Various Demand Locations

Location No.	Demand Location	Average Improvement in Time		Average Improvement in Distance	
		sec	%	m	%
1	*Parco Bugis*	*142*	*70.8*	*772*	*60.7*
2	*Golden Mile*	*66*	*28.9*	*1066*	*40.1*
3	*Raffles Place*	*109*	*55.6*	*1056*	*62.8*
4	*Suntec City*	*55*	*31.1*	*818*	*44.0*
5	*Mt Elizabeth*	*68*	*55.3*	*563*	*53.2*
6	*Shenton Way*	*153*	*70.8*	*1215*	*54.7*
7	*Maxwell Rd*	*93*	*60.0*	*1122*	*64.3*
8	*Chinatown*	*65*	*51.6*	*606*	*43.0*
9	*Orchard Rd*	*129*	*80.1*	*1042*	*70.1*
10	*Selegie Rd*	*24*	*24.7*	*530*	*47.2*
Total Average		*90*	*53.6*	*879*	*53.2*

Table 4 Average Time Improvements for Varying Empty Taxi Rates

Empty Taxi Rate (%)	Number of Available Empty Taxis	Average Travel Time (sec)		Average Improvement in Time	
		Current System	Proposed System	sec	%
5	*100*	*168*	*78*	*90*	*53.6*
10	*200*	*154*	*62*	*92*	*59.8*
15	*300*	*146*	*59*	*87*	*59.6*
Total Average		*156*	*66*	*90*	*57.7*

Table 5 Average Distance Improvements for Varying Empty Taxi Rates

Empty Taxi Rate (%)	Number of Available Empty Taxis	Average Travel Distance (m)		Average Improvement in Distance	
		Current System	Proposed System	m	%
5	*100*	*1651*	*772*	*879*	*53.2*
10	*200*	*1644*	*647*	*997*	*60.6*
15	*300*	*1572*	*572*	*1000*	*63.6*
Total Average		*1408*	*681*	*958*	*59.2*

Table 6 Summary of Simulation Runs

Empty Taxi Rate (%)	Number of Available Empty Taxis	Number of Simulation Runs	Number of Positive Cases	Identical Taxi Occurrences	Number of Adverse Cases
5	*100*	*100*	*71*	*27*	*2*
10	*200*	*100*	*69*	*29*	*2*
15	*300*	*100*	*70*	*26*	*4*
Total		*300*	*210*	*82*	*8*

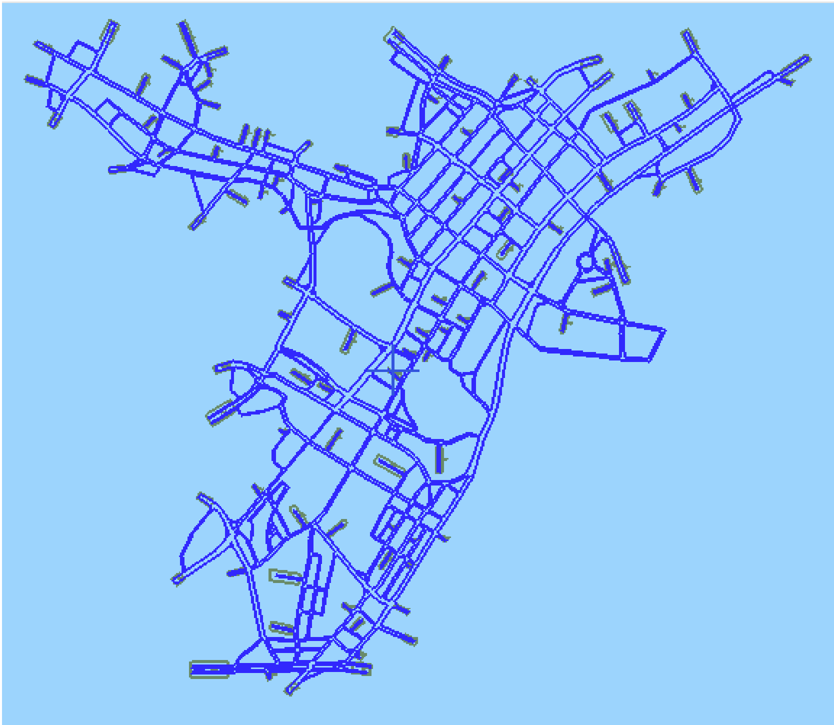

Figure 1 Overview of the CBD Network

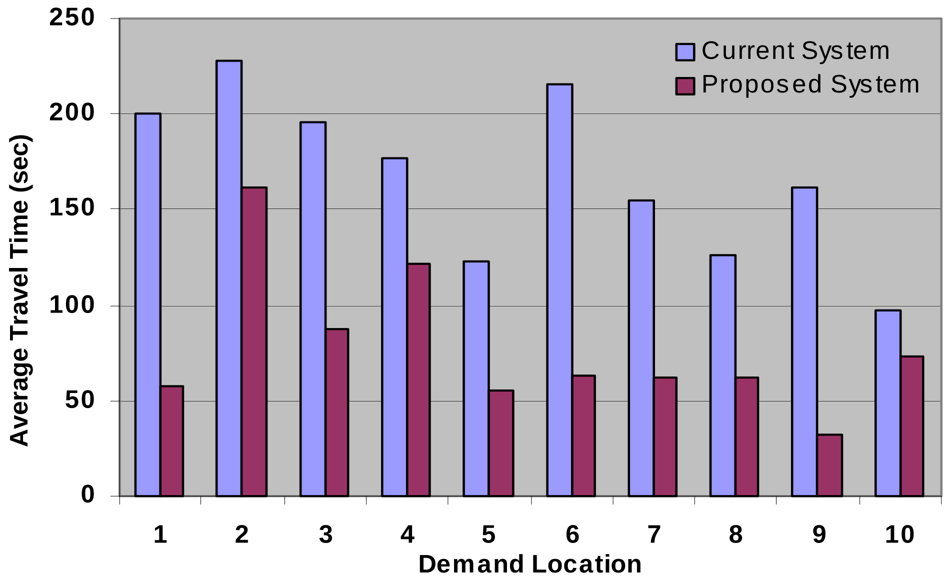

Figure 2 Comparisons of Average Travel Times at Various Locations

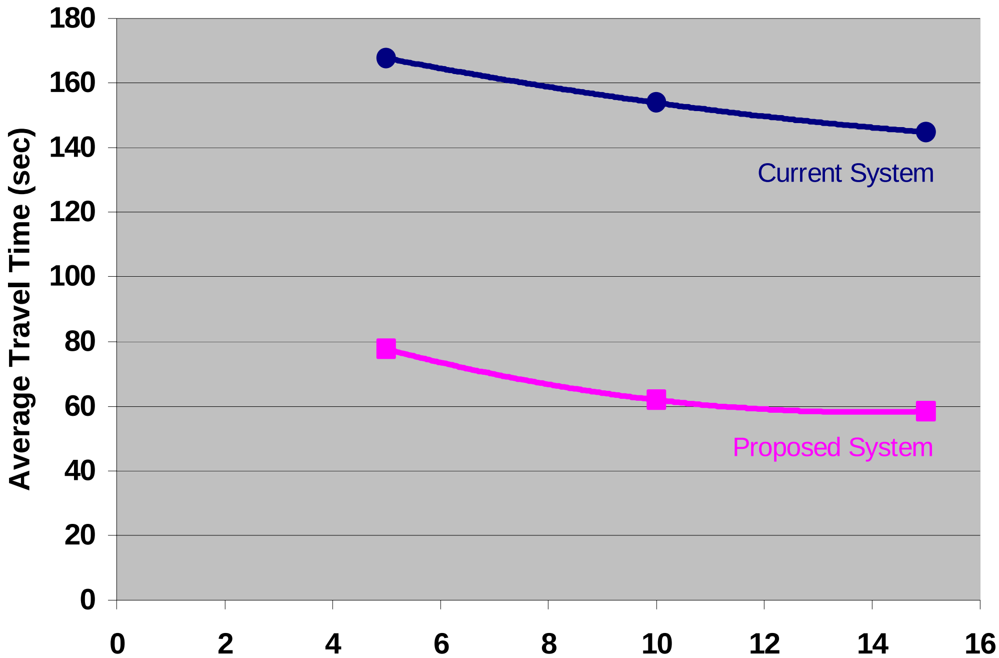

Figure 3 Variations of Average Travel Times with Empty Taxi Rates

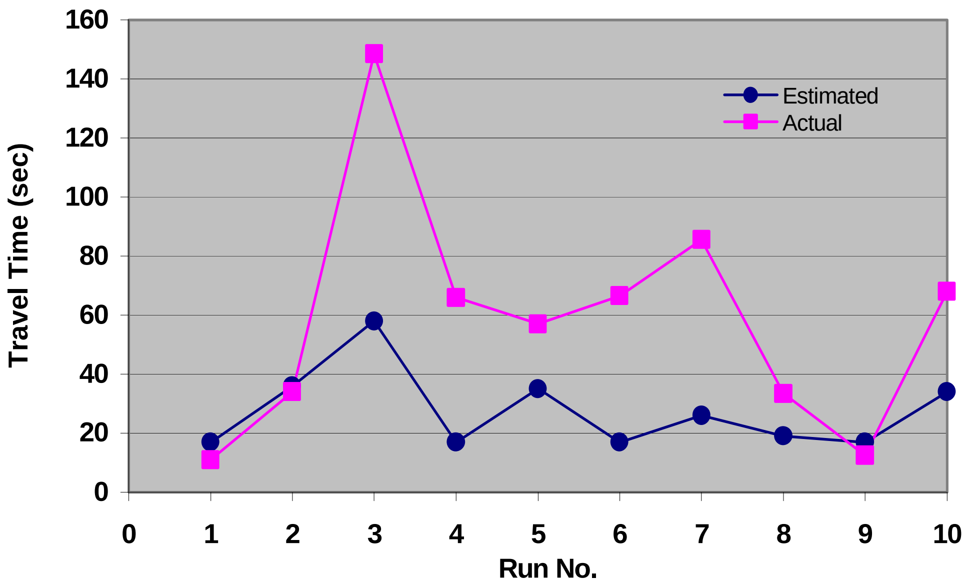

Figure 4 Estimated and Actual Travel Times at Parco Bugis

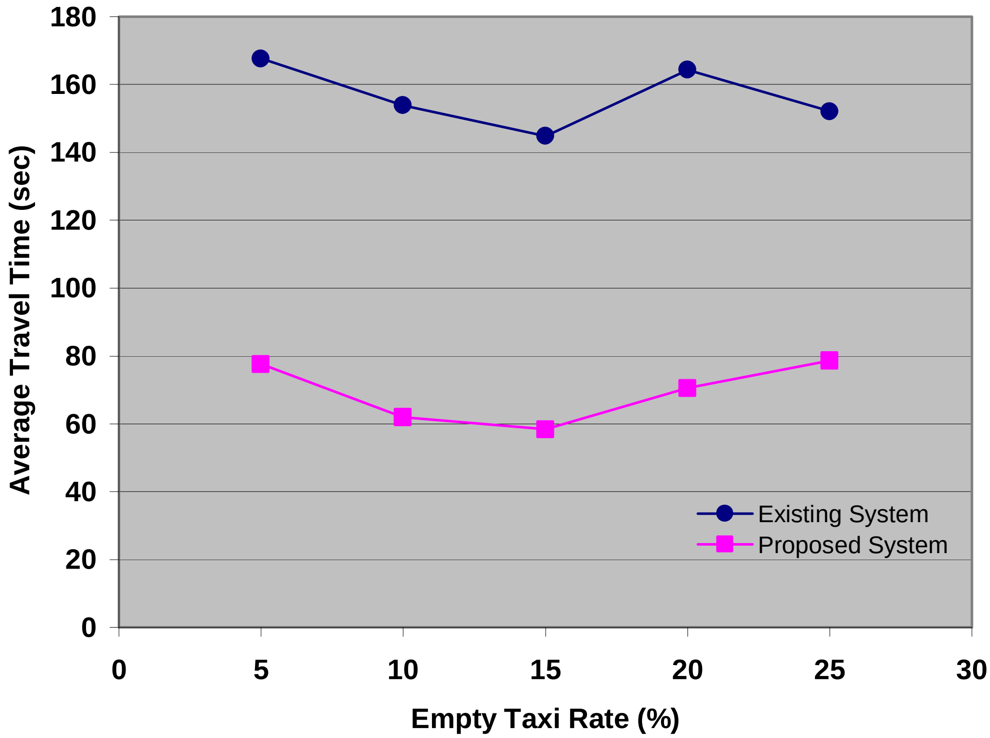

Figure 5 Variation of Average Travel Times with Empty Taxi Rates