Bus Priority Strategy Comparisons at Signalized Intersections

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This research conducts a comparison among bus priority strategies at isolated intersections. The bus priority strategies considered in this study includes bus signal priority strategy with timing techniques such as early green, green extension, phase insertion; bus preemption strategy without queue jump lanes; and bus preemption strategy with queue jump lanes. Whereas the bus signal priority strategy uses the above timing techniques to grant signal priority to bus based on the delay minimization method, the two latter bus preemption strategies use private transit phases based mainly on the accuracy of bus arrival prediction model. The paper results show that the bus priority strategies can improve bus travel time significantly, making the bus travel time reduce around 32.7%, 33.8%, and 35.1% respectively for bus signal priority, bus preemption with and without bus private lanes. However, these priority strategies cause an increase in car travel time, up to 15.2% for the preemption strategy with queue jump lanes. The bus signal priority strategy which can improve bus service and minimize impacts on non-bus vehicles simultaneously has a good performance in comparison with the other strategies.

Key Words : *bus signal priority, intersection, Paramics, simulation*

1. INTRODUCTION

There are many ways to improve bus service in urban areas, from considerations on bus lane, bus stop, bus station [15] to developments of traffic signal priority at intersections. Deploying and improving public transport system in general as well as bus system in particular is an indispensable trend to relieve traffic congestion and improve traffic quality. However, improving the performance of public transport usually causes unfavorable conditions for non-bus operations, especially at signalized intersections. Many priority schemes have already deployed at signalized intersections, such as bus signal priority, jump lane design, special preemption deployment, etc. and the reality has proved their effectiveness. However, a comprehensive comparison of the effectiveness among schemes has received less attention. In addition, the current algorithms of bus signal timing techniques and bus arrival prediction model are not strong enough to utilize the actual capability of the bus service and available infrastructures as well. Therefore, developing a strong model to adapt to complex traffic situations as well as conducting a comparison among bus priority strategies at signalized intersections is necessary.

Concerning with bus preemption studies, Wilbur Smith, Los Angeles [18] firstly conducted preemption experiment and concluded the significant effect of preemption strategy in improving bus service. TSP implementations with timing techniques such as early green, green extension, phase insertion were developed by previous research studies, such as in [1], [2], [4],[9],],[14],],[17],],[19],],[10]. The California PATH Center [7] has developed many models to improve bus service and minimize negative impacts on general vehicles at isolated signalized intersection, coordination arterial, ramp metering, etc. Despite the very good progress in the transit signal priority studies, there are still lacks of reliable optimal which is strong enough to get a good stable optimum point. Moreover, a comprehensive comparison to know the advantages of bus strategies has received few attentions. This information is useful for city planners, or traffic engineers to decide whether the chosen bus priority strategy is proper or not.

This paper consists of 5 main parts; each part deals with its relevant aspects. This research's overview and literature review are presented in this section, Section1 – Introduction. For the part of literature Review, the theoretical background of the research is discussed. The research objectives are presented and elaborated in Section 2. Section 3 describes in detail the methodology used in this paper. A case study is scrutinized in Section 4 to evaluate the real improvement when the model is applied to the actual case. And finally, the paper ends with several conclusions and recommendations presented in Section 5.

2. OBJECTIVE

To comparatively analyze the effects of bus priority strategies, the research simulates three bus priority strategies at insolated signalized intersections. The bus priority strategies include bus signal priority strategy with timing techniques such as early green, green extension, phase insertion; bus preemption strategy without queue jump lanes; and bus preemption strategy with queue jump lanes. Based on the proposed models for bus arrival time prediction and signal timing technique, the research investigates the advantages as well as disadvantages of using the bus priority strategies at signalized intersections.

3. MODEL DEVELOPMENT

(1) Bus signal priority scenario

When a prioritized bus comes, the signal controller will receive the bus information through detector systems. The signal controller will determine the time, and what kind of signal timing techniques needed to grant priority to bus. The signal timing techniques here includes green extension, early green and phase insertion (figure 1). Beside that, a process of predicting bus arrival time as well as estimating the traffic situation to decide the strategy of signal priority, the priority window is the most important. The decisions of granting priority to bus depend on the result of optimization function. The research tries to optimize the signal timing by minimizing the objective function

$$min \sum_{A=1}^{n} D_{Auto} + \sum_{B=1}^{m} D_{Bus} \quad (1a)$$

where D_{Auto}, D_{Bus} are the total delay of general vehicles and buses, respectively at the considered intersection.

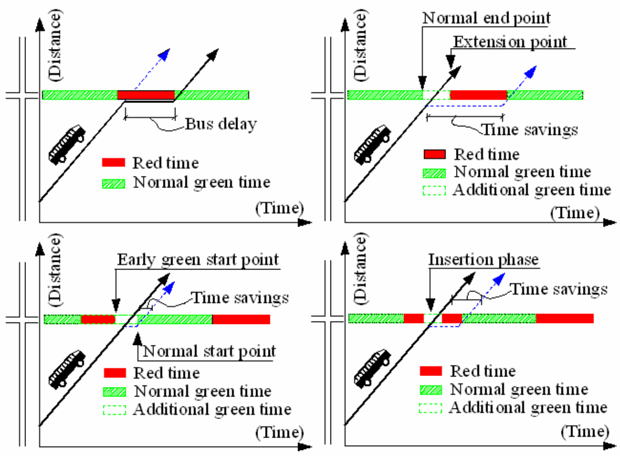


Fig.1 Signal timing strategies at intersections.

At every cycle, the mathematic program runs once to optimize the signal timing. The priority windows have the starting time and ending time following the formulas

$$W_{St} = G_{St}^{i,k} + G_{\min imum}^{i,k} \quad (1b)$$

$$W_{End} = G_{St}^{i+1,k} - G_{\min imum}^{i+1,k} + E_{End}^{i+1,k} \quad (1c)$$

where $G_{St}^{i,k}$ is starting time of phase i, cycle k; $G_{\min imum}^{i,k}$ is minimum green time of phase i, cycle k and $E_{End}^{i,k}$ is the ending time of phase i, cycle k.

(2) Preemption without queue jump lanes

This priority strategy uses a private phase for prioritized vehicles. It means that once the strategy is activated, only the phase for prioritized vehicles is on and prioritized vehicles can travel continuously through signalized intersections. Because of without queue jump lanes, prioritized vehicles travel in the same lanes with non-prioritized vehicles. This scenario can be seen clearly in the case of emergency vehicles coming with long queues at intersections. At this moment, the emergency vehicles have to travel through the intersection slowly until the queue dissipations. However, for the purpose of comparison, this preemption strategy is considered for bus.

Because of its emergency, emergency vehicles usually have its private priority phase. This emergency phase allows emergency vehicles to traverse road segments or signalized intersections as fast as possible.

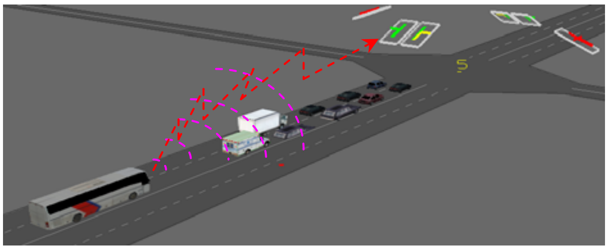


Fig.2 Preemption without queue jump lane in Paramics

(3) Preemption with queue jump lane.

To overcome the bus delays caused by long queues at intersections, some cities build queue jump lane system at intersections. This queue jump lane is designed as a private lane paralleling with the main street, using a specific phase only for bus uses. Once bus enters the queue jump lane, the bus information will be sent to signal operator by detector systems. At this moment, the travel time prediction model is used based on the relationship between the remaining distance to the intersection and the travel speed.

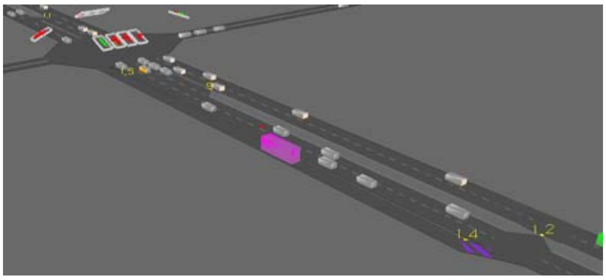


Fig.3 Preemption with queue jump lane in Paramics

The bus travel time prediction model is as follows

$$T = t_{travel} + t_{Dwell} \tag{1d}$$

$$t_{travel} = L / v_{estimate} \tag{1e}$$

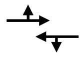
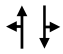
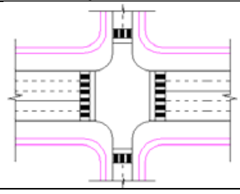
where T, t_{travel}, t_{Dwell}, and L $v_{estimate}$ are the predicted bus arrival time, bus travel time on considered links, bus dwell time, and the distance to the intersection, respectively. The estimated velocity is a function of initial detected velocity, bus maximum acceleration, bus maximum deceleration and aggressive probability of bus's driver.

4. A CASE STUDY

(1) A study intersection

The simulation test is an intersection in Nagaoka, Niigata prefecture. Three cameras are required at this intersection. One is located at the signals to observe go-straight flows, turning flows and the two others are located at the upstream and downstream of the main street to collect travel time, traffic flow and traffic proportion.

Table 1 Traffic signal at the study intersection.

		
G = 82s	G = 36s	
Y = 4s	Y = 4s	
R = 2s	R = 2s	

The information extracted from the recorded cameras and directly measured at the study intersection is used to input and to calibrate, validate in Paramics. After validating the current base case, three proposed scenarios including bus signal priority scenario, bus preemption with and without queue jump lane are developed based on this base case.

(2) Simulation validations

After validate the reasonableness of operating parameters such as traffic signal, lane operations, etc. the research conducts a comparison between the simulation result and observation data to validate the result. The results are output from 10 running in Paramics with different seed values. As can be seen in figure 4, the simulation values and the observation data are closely distributed along the 45 degree line with a very high value of R square. For the travel time validation, a comparison between the simulated result and observed data is conducted for the vehicles traveling in two directions of the main street.

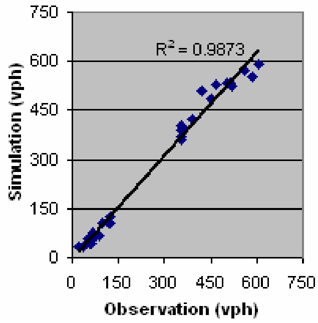


Fig.4 Flow rate validation

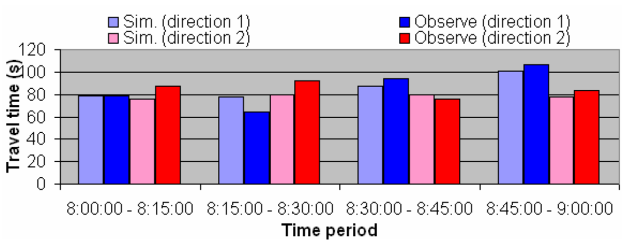


Fig.5 Vehicle travel time validation

From the above figure, it is easy to conclude that the observation data and simulation value are approximately same. The relative errors are all small with the average relative error of the comparison is around 9%

(3) Comparison analysis

The vehicle travel times in four scenarios including base scenario, bus priority, preemption 1 (without queue jump lane) and preemption 2 (with queue jump lane) are compared at each interval of 15 minute.

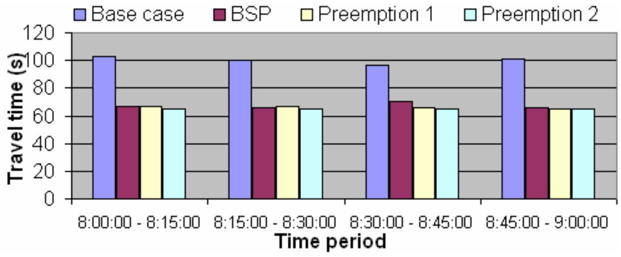


Fig.6 Bus travel time comparison

For the bus travel time, bus priority strategies can reduce bus travel time so much, up to 32.7%, 33.8% and 35.1% respectively for bus signal priority, bus preemption without and with queue jump lane. However, for the car travel time, the effect is negative. The details are as the following figure:

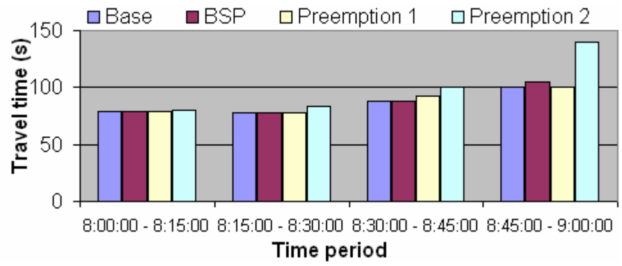


Fig.7 Vehicle travel time comparison

The priority strategies cause increases in car travel time. Compared with the current base case, the bus preemption with queue jump lane causes the most negative impacts on car travel. The increase is up to 15.2% in comparison with the car travel time in the current base case.

5. CONCLUSION

The research conducts a comparative analysis of bus priority strategies at an isolated signalized intersection through the development of a model for bus arrival prediction and signal timing technique. The result shows that with bus priority strategies, the bus travel time is improved significantly. However, it impacts negatively on the travel of general vehicles. The bus priority signal strategy which can improve the bus service and reduce negative effects on general vehicles is the most proper strategy, compared with the effectiveness of bus preemption strategy with and without queue jump lanes. The bus preemption with queue jump lane is just proper in extremely emergency case such as the uses of ambulance, fire truck, etc.

The deviations of bus travel time from simulation model are 5.91s, 2.26s and 2.41s for the case of bus signal priority, bus preemption without and with jump lane, respectively. The values show that the stableness of the proposed model for bus signal priority is not so good, compared with that for bus preemption with and without jump lanes. A careful consideration on improving the bus arrival prediction model as well as signal timing technique mode is necessary for future works. In addition, a co-ordination in adaptive network is a realistic and important aspect. Thus, not only for isolated signalized intersections, but also for arterial roads or grid networks with many intersections are promising objectives needed to be studied.

ACKNOWLEDGMENT: The authors would like to take this opportunity to express gratitude to the university's professors and members in Urban Transportation Lab, Nagaoka University of technology for their comments and supports in conducting the research as well as data collection.

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(Received August 5th, 2011)