MICROSCOPIC ANALYSIS OF BUS ARRIVAL TIME AT SIGNALIZED INTERSECTION FOR BUS PRIORITY SYSTEM*

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1. Introduction

Traffic congestion is a common problem faced by the most urban center. The rising numbers of auto ownership and at the same time limited road way space has intensified the situation with increased travel time in road networks. The traffic congestion has affected on the life of people by causing both physical and mental stresses. Congestion increases the cost of travel directly through the waste of travelers' time and indirectly through increased cost in system operation. At the same time, it contributes to lowered air quality, increases noise pollution, and adds driver stress and thus declining public transit usage[9)]. Many Metropolitan governments in the world have invested significant amounts of budget in the extension of infrastructures and development of new public transportation system to overcome this problem. The improvement of existing public bus system is a low capital cost measures as well as an efficient public bus service can reduce automobile dependence of cities. In reality, buses use same right of way with other traffic. The interaction of buses with other traffic affects its speed. Moreover, traffic signal further increases delays to buses. Thus, buses have large travel time, high variation in travel time etc. Overall result is the perception of people about bus as slow, infrequent, late and unreliable mode in spite of being main urban travel mode as well as supportive mode to urban rail networks.

Transportation experts are exploring different alternatives of improved bus service to increase speed and reliability with reduced cost of investment. A systematic improvement in existing bus system is popularly recognized as Bus Rapid Transit (BRT) system. BRT systems are designed to increase the level and quality of bus service through the integration of vehicles, facilities, services and Intelligent Transportation Systems, ITS[5)]. Many cities around the world are implementing ITS based BRT system as a more effective transportation solution. Moreover application of advanced technologies such as bus signal priority, advanced communication systems, automated scheduling and dispatch systems, and real-time traveler information at stations and on vehicles are proved to be cost effective solution.

Nowadays, Bus Signal Priority (BSP) have considered broadly for improving bus service performance by reducing stopped delay of buses at signalized intersection. Traffic signal systems can be altered to give priority for public buses approaching at traffic signal. Bus signal priority is well known in Japan as Public Transport Priority System (PTPS). PTPS is the one of the advanced systems of Universal Traffic Management System of Japan and more than half of prefectures in Japan are implementing PTPS[10)]. Signal priority for buses have been practicing for a long time and with invention of new technologies in the field of intelligent transport system, opportunities for new applications are still increasing for better performance. Due to the advancement in technologies, it is possible to examine and deploy bus signal priority for transit vehicles in varieties of areas using different detection systems and architectures[3)]. Major uncertainty for bus signal priority is to determine time when bus will arrive at stop line of intersection and then deciding bus priority strategies. The bus arrival time includes bus dwell time and bus travel time up to intersection is of primary interest for bus signal priority, where as for the real time bus information system stop to stop bus arrival information is desired for disseminating information of when next bus will be available at the bus stop to the passengers. The variation in traffic condition, competition of bus with other vehicles, passenger activities of boarding and alighting etc results uncertain bus arrival time to the intersection, which is major problem in bus operation. ITS technologies including smart buses technologies and detection, various estimation techniques, and simulation techniques can assist for effective estimation of bus arrival time.

It is hypothesized that a bus arrival time prediction model considering traffic congestion and dwell time will give a superior result compared to simple conventional prediction models[5)]. This research attempt to consider traffic signal status and queue discharge headway while estimating bus arrival time estimation. The required data would be available through the application of smart bus technologies.

2. Existing Problem

The Bus priority depends on precise prediction of presence of bus in advance of signalized intersection and estimation

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of bus arrival time at intersection stop line. The effective bus arrival estimation depends on the quality and accuracy associated with collected data, data collection methods and estimation techniques. Statistically reliable and accurate data, advance computation technique will help to predict precise arrival estimation. However, these methods take time and cost which is quite unsuitable for online prediction method. This research will explore method for estimating the dwell time and bus arrival time at intersection with consideration of schedule adherence, signal state etc. Also, the real time information sharing among bus, bus operator, traffic controller, road side infrastructures may enhance effectiveness of bus signal priority. The strategies like BSP are completely under control of traffic controller. Coordinate efforts through information sharing, integration of smart bus technology and BSP can be better option for improve transportation network performance through better trade off between bus and auto users benefit and system wide cost.

3. Review of Past Studies

(1) Overview of BRT and ITS Technologies

BRT as a flexible, high performance rapid transit mode that combines a variety of physical, operating and system elements into a permanently integrated system with a quality image and unique identity[6)]. By 1974, Curitiba, Brazil, had opened bus transit system with exclusive busway that was one of the successful implementation. Simlarly, BRT in Ottawa (Canada), Bogotá's TransMilenio BRT, The South East Busway in Brisbane (Australia) are some examples of recent success in BRT. Following successful BRT in the case of South American cities, many Asian cities such as Nagoya, Taipei, Seoul and Jakarta, Manila, Kunming etc are operating BRT systems since 1990.

With the advancement of technology, ITS applications such as smart bus technologies are found to be essential complements for overall bus operations enhancement. Smart buses have a new, integrated, multi-function computer and communications system, on-board capabilities that monitor and report on the operational and maintenance status of the bus, as well as its current location and schedule. It can assist to enhance bus signal priority system, give automatic information to riders, automatically count passengers, electronic fare collection system etc.

(2) Bus Arrival Time Estimation

Various methods have been developed ranging from simple to complex methods for bus arrival time prediction including time series, regression, artificial neural network[2)], and Kalman filtering techniques[4)] etc. Advanced technologies such as advanced vehicle location system, passenger count systems etc. are used to gather data at various time intervals. Most of bus prediction methods are targeted to provide the bus arrival time for a bus traveler information system. The concepts are applied for predicting bus arrival time for bus signal priority for increasing bus priority performance.

(3) Bus Signal Priority Strategies

Bus priority modifies the normal signal operation process to prioritize qualified transit vehicles through signalized intersections so that it can reduce travel time, increases service reliability of bus, and reduce bus driver stress with minimal impact on other traffic[1)]. New and rapid advances in traffic/bus detection and communication technologies[11)], and well-defined priority algorithms have made Transit Signal Priority (TSP) more appealing or acceptable to more road users of all modes[8)]. The bus priority in Japan is known as PTPS. The PTPS and the reserved bus lane have been used on a 5.7km arterial roadway section during morning peak period in Sapporo city for the first time in April 1996. An infrared beacon located at bus stop is used to detect an approaching bus and send the bus ID to the traffic control center. Then, traffic controller activates priority signal plan. The use of the PTPS and the reserved bus lane has significant impact on the bus travel times and their variation[12)]. PTPS has two control functions namely macroscopic and microscopic control. Macro control is a priority coordinated signal control by giving green band to buses. Then, micro control system release buses that reached out through-band of the macro control[7)].

4. Bus Signal Priority System

Bus signal priority system consist of three models namely bus arrival prediction model, bus signal priority control model and evaluation model. Bus operator and Traffic control center shares necessary bus and traffic information through advanced technologies on real time. BSP system receives information from the traffic and bus detection systems on the road. BSP system is, then, activated as soon as system detects bus arrival. Arrival prediction model estimates arrival time for the

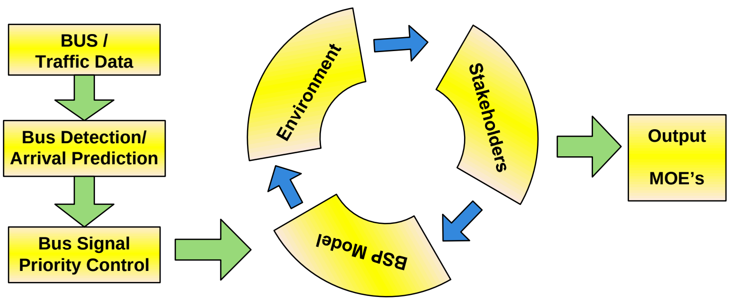

Figure 1 Bus Signal Priority System

current signal timing plan based upon available data from smart bus technologies. Bus signal priority control selects suitable priority from BSP plan which include green extension, red truncation, phase insertion etc, based on the arrival prediction. Finally, the performance evaluation analyzes the effects of BSP model on road environment and stakeholders through measures of performances.

5. Procedure of Bus Arrival Estimation

The detection of approaching bus, its speed, dwell time data and other traffic data are important for prediction of bus arrival at intersection. Dwell time estimation in turn requires data on passenger arrival distribution, and their boarding and alighting activities, door opening and closing time, fraction of disabled and elderly people, fare collection methods, numbers of passengers on board etc. Bus arrival time composed of bus dwell time plus bus travel time since bus detection up to intersection stop line. Smart bus technologies such as advance vehicle location, communication and detection technologies are applied to find those required information. It is to be note that bus arrival at intersection is governed by bus speed, queue at intersection, queue discharge headway, signal status, traffic volume etc. Many of present prediction techniques used for the estimation of bus arrival time can not consider effects of signal state at signalized intersection during bus movement. An attempt was made to model bus arrival time for bus signal priority considering above issue.

Also, the detector location effects estimation procedure. Bus detection can be made possible in two ways, downstream to bus stop and upstream to bus stop. Downstream detection option detects bus as soon as bus leaves bus stop or after the bus door fully closed condition. Bus arrival time is the time required to travel from bus stop to the intersection stop line. When the vehicle queue extends beyond the bus stop, upstream detection option is suitable. Bus is detected before it arrives at bus stop. In this case, the bus arrival time is summation of bus dwell time and bus travel time. Bus dwell time variability adds extra variation in estimation in this case. In this study, following two sub topics explains, regression estimation and headway based estimation of bus arrival time.

(1) Regression Method

The simple or multiple regression analysis is a simple method of predicting bus arrival time. The determinants can be bus schedule delay, bus dwell time, bus speed, traffic volume etc. Similarly, various regression analysis including weighted least square etc. are to be performed to accept appropriate estimation model. Regression models can be developed in order to evaluate the relationships between determinants and dwell time as well. The determinants of dwell time at a specific bus stop could include passenger loads, bus headways, schedule adherence, time of day, and dwell time at adjacent upstream stop. The most significant relationship in this study was the simple linear regression with bus arrival time dependent upon schedule delay. An estimated regression line is shown in Figure 2. It can be seen that the estimated regression coefficients (i.e. parameters) were significant at the significance level, $\alpha = 0.05$. The R^2 value for the simple regression model was 0.67. etc.

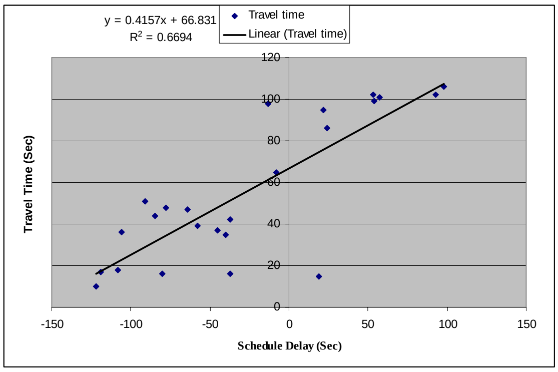

Figure 2 Travel Time vs Schedule Delay

(2) Signal State and Headway Based Estimation

Bus arrival at intersection is affected by traffic volume queuing in front of bus, queue discharge headway and signal status. In this case, minimum two detectors are used to measure numbers of queued vehicles ahead of bus. . Two cases considered are:

(a) Downstream Detection

In this case, detector is located right downstream of bus stop. Bus detection may be either in green time or in red time. Figure 3 shows the variation of observed and predicted travel time based upon this method. The predicted values are found consistent with observed travel time variations.

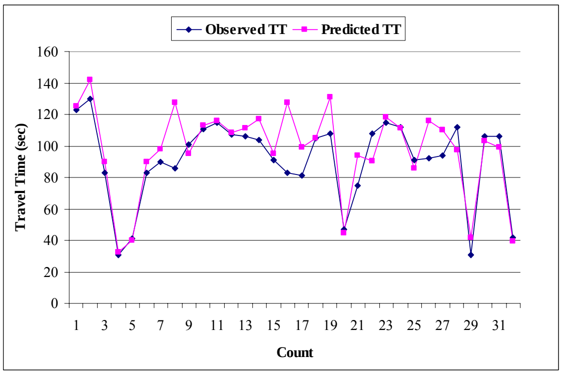

Figure 3 Observed and Predicted TT

(i) Bus is detected when signal is green

Let,

C = Cycle time, sec.

R_n = Red time for bus direction 'n', sec

Q_{total}= Vehicles in front of bus in queue, veh.

$Q_{discharge}$= Vehicles discharged in given green time G_n, veh.

t_{ave} = average travel time from point of detection to intersection stop line with average speed, sec

G_n, G_{remain}= Green time and Remaining green when bus has detected, sec= Green time for bus direction 'n', sec

HW_{queue}= Average Queue discharge headway, veh/sec

t_{queue}= Total accumulated time to discharge queue, sec.

- If $t_{ave} \le G_{remain}$, detected bus can move up to intersection stop line. Then, The bus travel time = t_{ave}

- If $t_{ave} > G_{remain}$, detected bus can not move up to intersection stop line and will stop behind Intersection queue
  The bus travel time = $G_{remain} + R_n + Q_{discharge} * HW_{queue}$

(ii) Bus is detected when signal is red

- If bus can discharge in nearest bus phase, The bus travel time = $R_{n(remain)} + Q_{total} * HW_{queue}$
  - If bus can discharge in nearest bus phase, bus has to wait for next phase
    The bus travel time = $R_{n(remain)} + C + (Q_{total} - Q_{discharge}) * HW_{queue}$

(b) Upstream Detection

Upstream detection is suitable in the case of queue from signalized intersection extends beyond the bus stop. Bus trapped in the queue before reaching to the bus stop. Queue discharge is necessary to allow bus to the bus stop. Total bus travel time from bus detector to the intersection stop line comprises of bus travel time from detector to bus stop, bus dwell time and bus stop travel time from stop to intersection stop line.

6. Conclusion

ITS technologies have produced wide options for developing new strategies in bus operation. The ITS oriented BRT systems such as bus signal priority is gaining popularity around the world. The real time data collection, bus arrival time prediction, and then selection of suitable bus priority rule are important components of BSP. Much attention has poured on the bus arrival prediction model for BSP and for real time traveler's information. This paper explains bus arrival estimation considering signal stage at the time of bus detection and discharge headway of queue. Though the method is simple, the method shows consistency with observed data. It may be useful for the improved prediction of bus arrival for further developing signal priority strategies. Also, arrival time prediction can be improved if other real-time data such as variability in passenger demand at any given bus stop, traffic congestion measures, signals including progression, delay due to traffic congestion or accident; incident information, exclusive bus lanes, etc. are available. Integration with bus signal priority can improve system performance in terms of gain in speed and reduction in delay. Furthermore, the application of smart bus operation technologies such as lane assistant technology, precision docking etc will help to enhance effectiveness of bus signal priority for BRT.

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