An Improved Bus Signal Priority model for Arterial Roads with Co-ordinations

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This research proposes an improved bus signal priority model in urban arterial roads based on infrared beacons for two-way communication. The proposed model is concluded not only signal group state, traffic factors but also recommended bus speed guidance to grant priority to bus for its smooth travel through the intersections of the arterial roads. Due to the important role of speed guidance task in this model, the effect of physical attributes of bus, namely acceleration attributes, on the efficiency of the signal priority model is studied. By developing dynamic linking libraries (DLL) in Paramics, the paper then investigates four scenarios under different considerations of speed guidance and traffic delay modes. Compared to the base case with no priority treatments, the simulation results show that the bus travel time can be improved significantly when applying any the priority mode. The mode with consideration of bus guidance only can better bus service, but it causes negative impacts on general traffic. Meanwhile, the proposed model considering both bus guidance and traffic delay can draw a good performance of reducing bus travel time as well as minimizing the negative delays.

Key Words : *bus signal priority, coordination, arterial, simulation*

1. INTRODUCTION

The positive role of public transportation, especially bus system has been clearly proved. The improvement of bus service can relieve traffic congestion, improve traffic quality as well as attract more people to switch from using private cars to riding buses. Many things to improve bus service are considered not only special policies for bus users but also some priority treatments to bus at bus stops, bus lanes, or signalized intersections. Although improving the performance of public transport usually causes unfavorable conditions for non-bus operations, this is an indispensable way to deal with the current burning problems in urban streets such as traffic congestion, the increase of private car, accidents, environmental pollutions, etc.

In Japan, more than half of prefectures have already deployed bus priority systems. The current priority system which includes bus lanes, warnings to vehicles which are illegally running in the bus lane, and traffic signal preemption can improve convenience for users, encourage the use of public transportation as well as ensure on-time bus operation, bus safety[(27)]. However, there is a pessimistic reality that the fluctuation of bus punctuality is very high, the number of private cars increase, and some bus routes are abolished because of poor passenger demands[13)]. Although the bus signal priority system can improve bus service well, its negative effects on general traffic are significant, causing traffic congestion as well as potential ridership switch[26)]. In a research aiming to introduce the benefit of road side infrared beacon in setting up a new public transportation, an idea for two-communication application in improving the bus system priority has been proposed and conducted trial test[2)]. In this system, road side infrared beacons play important role in two-way communication between bus driver and traffic control center. When the infrared beacon detects a bus, the bus information can be sent to the traffic control center and a recommend speed for bus can be transmitted to bus driver through in-vehicle unit set in bus as well. The study conducted an empirical test and concluded limitedly the benefits to bus. The effects on non-bus vehicles were not studied. Besides, this is just a practical test, a detailed model for this system has not been considered. Moreover, the recommend speed should depend on bus physical attributes, current traffic group signal status as well as the traffic demand on each approach of each intersection. These influences have not been investigated yet. Recently, a similar research was conducted for BRT network[25)]. In this research, the concept of transit speed guidance was used in the model to simulate signal priority systems in order to improve bus efficiency. However, the purpose of bus guidance in that research is just for easy prediction of bus arrival at a certain intersection. Its contribution to the efficiency of signal priority system was not studied enough.

Although there have been man research about signal priority in the past, the priority with bus guidance task has not been received much. Indeed, the California PATH Center[6)] has developed many models to improve bus service and minimize negative impacts on general vehicles at isolated signalized intersection, coordination arterial, ramp metering, etc. Recently, the models for bus signal priority have been developed by considering bus queuing delay at traffic signals when triggering TSP requests[14)] or minimizing the intersection delays[22), 20)]. The models were developed with not only a heuristic algorithm[23)], a dynamic Programming Model[24)], analytical approaches[15)] but also practical approaches[2), 21)]. The development is not also for a single request [14)] but also for multi requests[9), 24)] or for conflicting transit routes[22)]. In summary, utilizing all factors to improve bus service and minimize the traffic delay is the target of this research. Besides traffic volume, signal state, the research would like to analyze in more details the effects of bus guidance task on the network performance. The role of bus attributes is also a objective in this research.

This paper consists of 6 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. Test cases are conducted in Section 4 to comparatively analyze scenarios with different priority modes. Section 5 presents some results as well as analysis of the simulation scenarios. Finally, the paper ends with several conclusions and recommendations presented in Section 6.

2. OBJECTIVES

This paper has two research objectives. The first one is the development of a bus signal priority model in arterials with co-ordinations by introducing bus speed guidance task. This model involves the combination of bus speed guidance and traffic delay minimization to better a bus signal priority system in arterials with co-ordinations. Based on the proposed model, an investigation bus attribute's effects on arterial performances is conducted. The second objective is a simulation based comparative analysis of the proposed model with different priority modes. The studied priority modes includes no priority treatments, granting priority with considerations of speed guidance and traffic delays, granting priority with consideration of traffic delay only and granting priority with consideration of speed guidance only. The comparative results are expected to show the importance of each case in the performance of the traffic network.

3. MODEL DEVELOPMENT

(1) The structure of the model

Usually, concerning bus signal priority in arterial, traditional research studies had trends to control the signal groups to optimize the green bandwidth. A compromise between signal status, green bandwidth and traffic demands is necessary to grant priority to bus and diminish negatives effects on non-bus vehicles simultaneously. Unlike traditional ways of bus priority strategy, the paper develops a model to simulate bus priority through arterials by both signal adjustments (do nothing, green extension or early green) and providing bus driver with recommended speed to traverse smoothly through the arterials.

Being setup at the road side 150m upstream from the first intersection, Infrared beacons can recognize the bus coming and help send bus information to the traffic control center. The current bus speed and bus physical attributes are important for the prediction module to bus arrival time at the stop line of each intersection in the intersection group. Combining with traffic information and signal group status, an optimization program can be done to get the optimal recommended bus speeds and sets of signal timing at each intersection of the group. Based on the two-way communication between bus drivers and traffic control center, the information of recommended speeds is sent back to bus drivers through an In-vehicle unit. Bus drivers can control the bus speed following the speed guidance. At the same time, the control signal will be sent to each intersection in the group to control the signals (early green or green extension or do nothing). The structure of this model is shown in Fig.1

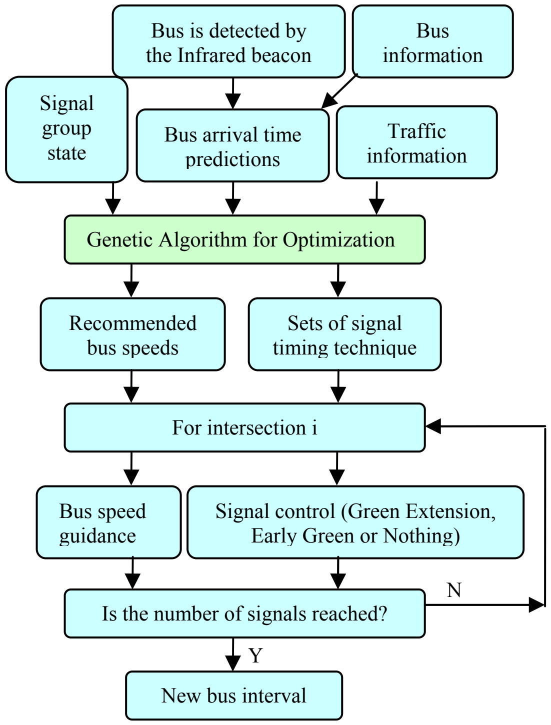


Fig.1 Algorithm to create DLL in Paramics

(2) Bus arrival time prediction

Considering a six-lane arterial with three consecutive signalized intersections, the research proposes that a road side exclusive bus lane and an Infrared beacon are installed as shown in Fig.2

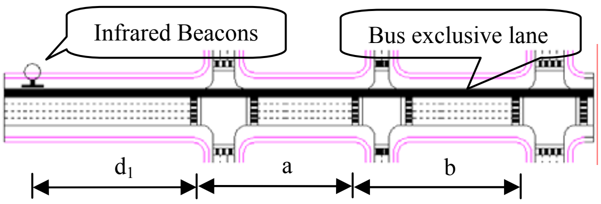


Fig.2 Hypothetical arterial

Bus arrival time prediction is executed at the moment that the bus is detected by infrared beacon. This is the travel time of bus on the road section from the infrared beacon to the stop lines of each intersection in the intersection group. Because of the exclusive lane for bus, bus is assumed to increase speed freely within its physical attribute limit. With the priority treatments at intersection k, the bus can traverse smoothly this intersection without any delay. Therefore, the bus arrival times at the stop lines of intersection k is calculated as a function of the distances and recommended speed. Assuming bus follows a uniform and accelerated motion, the stretch of road that the bus traveled:

$$s = v_0\left(\frac{v_{\max} - v_0}{a_{\max}}\right) + \frac{(v_{\max} - v_0)^2}{2a_{\max}} \qquad (1)$$

The changes in bus acceleration can be divided into two terms: one term with the maximum acceleration and another with no acceleration increase. That is suitable to real situations in which bus will increase speed with maximum its acceleration till the maximum speed. When the maximum speed is reach, the bus cannot increase its speed. Therefore, it will travel at the maximum speed. The illustrations can be seen in Fig.3

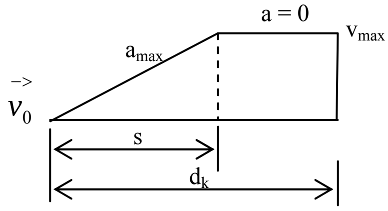


Fig.3 Space and velocity relationship

For intersection k, the bus arrival time is calculated based on following formula:

$$t = \frac{-v_0 + \sqrt{v_0^2 + 2a_{\max} Min(d_k, s)}}{a_{\max}} + \frac{\max(d_k - s, 0)}{v_{\max}} \qquad (2)$$

where

$$v_{\max} = Min(v_{\max}^{vehicle}, v_{\max}^{Link}) \qquad (3)$$

a_{max} (m/s^2) is the maximum bus acceleration

d_k: the distance between the infrared beacon and the stopline of intersection k (m).

v_0: the bus speed at the detect moment (m/s).

v_k: the recommended bus speed to traverse intersection k (m/s).

A vehicle cannot change the speed as fast as possible because of its physical attribute limitation. The recommended speeds should be reasonable in terms of the vehicle dynamics. In this research, the limit characteristics are modeled with the constraint of maximum acceleration and maximum deceleration. Considering on a link with its length of d_{ij}, the relationship between the speed at the head of the link (v_i) and the recommended speed (v_{i+1}) at the end of the link is as follows:

$$\frac{(v_{i+1} - v_i)}{\frac{d_{ij}}{v_i} + \frac{v_{i+1} - v_i}{a_{\max}}} \le a_{\max} \qquad (4)$$

(3) Objective functions

Ultrasonic vehicle detectors set on each approach detect traffic flow every time detector interval (5min in this research). Traditionally, the flow patterns during each green periods of the detection interval are supposed to be parallel to one another. If one detector interval has n green periods, the arrival rate

λ_i in each green phase i can be estimated[12] as the following relationships

$$\lambda_i = \frac{G_i}{\sum_{i=1}^{n} G_i} N \quad (5)$$

Usually, the predicted value of current detector count is calculated based on previous detector intervals. Some research took the average value[14]

The optimization module is to minimize the traffic delay under the boundary constraints of speed, signal cycles, offset, minimum green time for pedestrian, etc. According to HCM2010[19], the minimum green interval to ensure the walking time is expressed as follows:

$$G_{\min,i} = 3.2 + \frac{L_i}{v_p} + \left(0.81\frac{n_p}{w_e}\right) \quad (6)$$

where

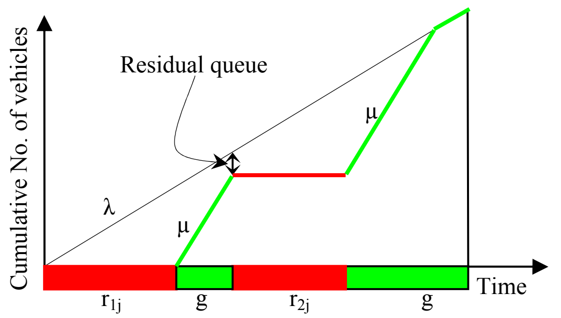
L_i: the width of the intersection at approach i (m)

V_p: is the average walking speed (m/s)

W_e is the width of the crosswalk (m)

N_p is the number of pedestrians

The research assumes that there is no residual queue in each signal cycle. For the early green technique, the delays include non-bus vehicle delays and bus delay as shown in Fig.5



*Source: Meng LI[20]

Fig.4 Early green technique

Assuming that in the most extreme case, the residual queue exists within one cycle. The total delay of a system including 3 consecutive intersections is expressed as follows :

$$d = \sum_{k=1}^{K}\sum_{i=1}^{8}\{\frac{\mu_{ki}}{2}\rho_{ki}(r_{k1i} + r_{k2i} + \delta_{k1i}\cdot\alpha_{k1i} + \alpha_{k2i})^2$$
$$-(r_{k2i} + \alpha_{k2i})\mu_{ki}\min[g_{k1i}, \rho_{ki}\cdot(r_{k1i} + \delta_{k1i}\cdot\alpha_{k1i})]\} \quad (7)$$

where

$$\delta_{k1i} = \begin{cases} 0 & \text{, If } g_{k1i} - (t_{0k} + T_k) \le 0 \\ 1 & \text{, Otherwise} \end{cases} \quad (8)$$

$$\rho_{kji} = \frac{\lambda_{kji}}{\mu_{ki} - \lambda_{kji}} \quad (9)$$

$$v_k(t) \le V_{\max} \quad (10)$$

$v_k(t)$: is the recommended speed at time t at intersection k (m/s)

V_{max}: is the maximum speed of bus (m/s)

K: is the number of studied intersections (intersections)

λ_{kij}: the arrival rate at approach of cycle j at intersection k (veh/s)

μ_{kij}: the saturation rate at approach i of cycle j at intersection k (veh/s)

r_{kij}: the red time for approach i of cycle j at intersection k (veh/s)

g_{kij}: the green time for approach i of cycle j at intersection k (veh/s)

α_{kij}: the adjusted time for approach i of cycle j at intersection k (veh/s)

The total delay in the objective function is the delay of general traffic only. Bus has no delay in this scenario because of continuous traveling of buses through the intersections.

(4) GA for optimization

Genetic algorithm (GA) is robust global optimizer. With the constraints of minimum green time, fixed cycle length, etc, the initial conditions of the GA are known. As shown in the objective function, the variables can be solved with the GA process as following:

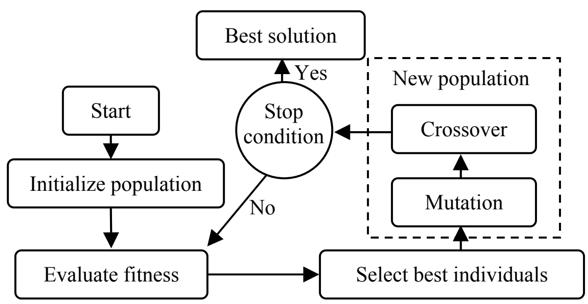


Fig.5 Traditional GA for optimization

4. TEST CASES

For the purpose of exploring the benefit of the proposed model, the research surveys a base arterial with no bus signal priority treatment. After validating the base arterial, two scenarios are applied to this arterial. The first one is bus priority without guidance speed and the second is bus priority with guidance speed as proposal. (one with constant speed and another with dynamic speed changes). The details for each scenario are as follows:

a) Setting up a base case

A hypothetical arterial is built to test the proposed model. The main arterial of the arterial has six lanes. The side streets have two lanes. The detailed outline of the arterial is as follows:

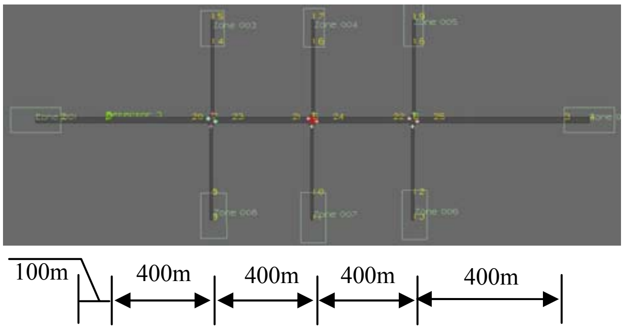


Fig.6 The studied site in Paramics

Assuming the main street traffic volume is 1000vph, the side streets have a traffic volume of 150vph. The signal cycle at the intersections is 140s with the split between the main and the side street of 70%:30%. After checking the network performance, four other scenarios are simulated by developing dynamic linking libraries (DLL) in Paramics[11)]. The details of these scenarios are as follows:

b) Scenario with simple priority treatment (ST1)

This is a simple priority treatment that is deployed popularly in reality. The bus detected moment by infrared beacon is used to predict the bus arrival time at each intersection. At intersection k, if the bus arrives during green phase of bus, there is no priority. If arrival time is in red phase of bus, the techniques of green extension or early green are used to adjust the signal for bus to move smoothly. This scenario is not concerned with bus speed guidance or traffic delay. The simple purpose is to give priority so that bus can traverse continuously the intersections of arterials.

c) Scenario with the consideration of traffic flows only (strategy 2)

The process of granting priority to bus is rather similar to the first scenario. However, how much the amount of time for bus as well as which strategy (green extension, do nothing, early green) needed depends on the demand on each approach. The traffic flows are recorded by traffic detectors.

b) Scenario with the consideration of speed guidance only (strategy 3)

Similar to the second scenario with consideration of traffic flows only, this scenario considers the speed guidance instead of traffic flows. Based on the two-way communication through Infrared beacon, the bus drivers can speed up the bus to traverse the intersections without any stops.

d) Scenario with the considerations of both speed guidance and traffic flows (strategy 4)

Of the four scenarios, this scenario is the most complicated scenario. As already mentioned in the proposed model, this scenario tries to find the best solution by compromising the bus speed and traffic delays.

5. RESULTS AND ANALYSIS

The research compares the results of the studied scenarios to that of the base case (no priority treatment). The bus travel time is improved significantly in the scenario with simple priority treatment when compared with that in the base case. The reduction is up to 28.4% as shown in figure

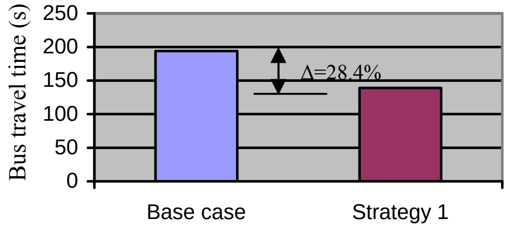


Fig.7 Bus travel time comparison

The priority granted to bus causes slight negative effects on general traffic. Indeed, for the average travel time from zone to zone in the traffic arterial, the increase in the scenario with simple priority treatment is just around 0.71%.

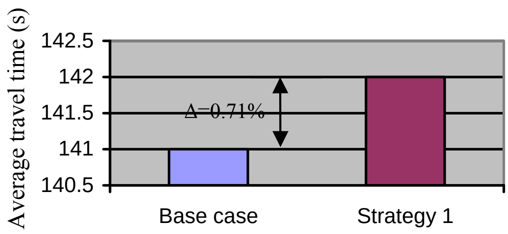


Fig.8 Average travel time comparison

6. CONCLUSIONS

The research aims at two targets. The first one is the development of a bus signal priority model in arterials with co-ordinations. This model involves the combination of bus speed guidance and traffic delay minimization to give priority to bus and minimizing the traffic delays simultaneously. The physical attributes of bus are important factors to improve the efficiency of the signal priority system. Therefore, an investigation bus attribute's effects on arterial performances is conducted. The second objective is a simulation based comparative analysis of the proposed model with different priority modes, including no priority treatments, granting priority with considerations of speed guidance and traffic delays, granting priority with consideration of traffic delay only and granting priority with consideration of speed guidance only. The comparative results the importance of each case in the performance of the traffic network.

The research focused on one-direction bus route only. In reality, there are usually many-direction bus routes in arterials, such as bus routes on two directions of the main streets or even the bus routes from side streets. If the number of bus route increases, the situation becomes more complicated and more realistic. At that moment, conflict priority situations are the objectives needed to be solved. This long-sighted should be a target of future studies.

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