SIGNAL TIMING POLICY FOR TRANSIT PRIORITY: A CASE STUDY OF R296 SECTION, CHIBA*

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1. Introduction and Problem Statement

Japan is general known as a high population density and land use limitation country in the world. Almost roads in Japan are two-direction roads with narrow two lanes. The public bus routes have to be operated along the roads at where mixed with other vehicles because the bus lane could not be available due to insufficient road capacity. The busses normally travel relatively slowly because of their large size; the busses need a longer time for acceleration and deceleration than other vehicles. For the operation service, the busses often stop to load/unload passengers at several bus stops along the bus route. These mentioned reasons cause the busses to have a delay obviously higher than other vehicles, which travel on the shared lane with them. Their operation also interrupts the flow of other vehicles and increases the delay of entire system. Moreover, the bus loses their chance when they have to stop to load/unload passengers at bus stops near to the intersection approaches during green time interval. The vehicles followed these busses, even though they approach those intersections during green time interval, cannot pass through the bus due to the no passing zone. Subsequently, these events increase the long queue and high delay to the bus and entire system.

2. Objective and Scope of Study

The objective of this study is to propose the appropriate progression-based policy for bus priority along the bus arterial route in order to improve level of service of the bus, decreasing delay and stop of the bus and provide the least of bad effect to the rest of traffic. The signal timing policy for bus priority develops the optimal timing plan that provides the priority for the bus by giving the priority along the bus route.

Skabardonis[1)] mentioned that the traffic control strategies favor to transit typically range from changes into fixed-time signal, signal preemption at specific intersections or system wide and real time traffic control systems. However, this study focuses on the signal timing policy for passive traffic control strategy, fixed-time signal setting timing plan based on history data, which can apply instantly without any requirement of supplying facilities to the fixed-time signal control systems, which are typically installed at the intersection along the arterial road in Japan.

3. Methodology

(1) Proposal of Progression-Based Policies

The several progression-based policies able to progress on the specific route according to previous research[1)] were proposed in this research. The proposed progression-based policies could give the priority to the busses by providing progression on the bus route in different ways.

(2) Development of Optimal Signal Timing Plans

The TRANSYT-7F10 (TRAffic Network StudY Tool, United States Version)[2)] was selected to develop the optimal signal timing plan based on each of proposed progression-based policies because of the high performance and flexibility of the TRANSYT-7F10. The TRANSYT-7F10 is known as the one of the most well known traffic signal timing optimization program. This program is designed to optimize traffic signal systems on the basis of cycle length, offsets, and green splits adjustments to improve progression opportunities, reduce delay, stops and fuel consumption. For modeling, TRANSYT-7F provides the objective function, known as the performance index (PI), which can reflect the performance of system, including delay, stops, fuel consumption, and progression. TRANSYT-7F develops a signal timing plan that produces an optimal value of the PI.

(3) Evaluation of Proposed Progression-Based Policy

To evaluate the most suitable progression-based policy for transit priority through setting progression on the bus arterial route, the proposed several proposed progression-based policies tried to be implemented on the selected arterial route. The selected site is a segment of R296, two-way arterial. It serves as a main route connecting between Tsudanuma City and Narashino City, which located in Chiba Prefecture. Through study segment, there are 8 signalized intersections and the public bus route operating in both inbound and outbound direction.

To compare and choose the most suitable policy among different progression-based policies, Skabardonis[1)] suggested that the timing plan developed by the base condition policy should be used to compare against the optimal timing plans of study policies, rather than existing timing plan of study site since the comparison against existing timing plan tends to mask the true

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impacts of any transit priority policy because the improvements may be due to the changes in traffic control that also benefit the transit vehicle. Therefore, in this research, the base condition policy across entire system will be former implemented and later compared the operation performance against one of each proposed progression-based policy. The evaluation was conducted through simulation separately for the busses, the rest of the traffic stream and as all entire system.

It's noted that the base condition is described as a system operating at an optimal cycle length with simultaneous (zero) offsets. The optimal for this policy is defined as the cycle length that produces minimal fuel consumption because the comparison of multiple optimizations reveals that the optimal cycle length for minimizing fuel consumption generally is higher than that for minimizing delay, but considerably lower than that for minimizing stops. The researchers have the same concept with Leonard and Rodegerdts[3)] that the minimal fuel consumption policy represents a reasonable base condition that can be implemented on the selected site.

(4) Determination of Most Appropriate Progression-Based Policy

After comparison the operation performance of proposed progression-based policies against the base condition policy, the providing of bus priority, levels of service of the busses (average delay and total stop), the impact to the rest of traffic and the performance of entire system were considered as the decision criteria. For evaluation of the performance of entire system, the Performance Index, PI (PROS/ID) in TRANSYT-7F10, the value of objective function representative to performance of traffic network was applied. Any system that provides the highest value of PI, it means that the policy of that system yields the highest performance of traffic control through entire system. The progression-based policy which provided the most priority to the busses, effected relatively slightly to the rest of traffic and yielded the highest performance of traffic control through entire system was determined as the most appropriate progression-based policy for bus priority along bus arterial route.

4. Progression – Based Policies

Leonard and Rodegerdts[3)] defined the progression-based policies as that policies focus on maximizing one or more measures of effectiveness that quantify the opportunity to travel along selected routes through the system without being stopped or delayed at signalized intersections. Maximized progression policy can develop signal timing plan that give priority to a specific route, quantifying the opportunity to travel along selected routes through the system without being stopped or delayed at signalized at signalized intersections. Due to flexible functions of TRANSYT-7F10, the program can develop the policies based on maximizing progression in a variety of policies. The following three policies are proposed as the possible representatives:

(1) PROS/DI Policy, P1 (Maximize Progression Policy)

This policy is a combination of two objectives, PROS and DI in order to achieve a compromise between the two objectives. Progression opportunities (PROS) represent the opportunities for vehicles to progress through multiple signals on green. The number of PROS in a given direction, for a given time period (or step), are the number of successive green signals that will be encountered at the design speed without stopping. The aggregate PROS is found by summing the PROS overall time periods in both directions:

$$PROS = \sum_{k=1}^{2} \sum_{j=1}^{N} \sum_{t=1}^{C} PROS_{kjt}$$

Where k is the direction of travel, j is the intersection number, of which there are N and t is the time in units common to the model, up to a cycle length, C.

Disutility Index (DI) is a measure of disadvantageous operation; that is, stops, delay and fuel consumption. Alternatively, it is simply a linear combination of delay and stops, defined as follow.

$$DI = \sum_{i=1}^{n} \left(w_{d_i} d_i + K w_{s_i} s_i \right)$$

Where w_{di} is the delay weighting factors on link i, d_i is the delay on link i, K is the stop penalty factor, S_i is the stops on link i, w_{si} is the stops weighting factors on link I and n is the number of link.

When PROS/DI policy is implemented, the program attempts to weigh maximal progression opportunities along the bus arterial route and produce minimal fuel consumption for the entire system during computation of the objective function. To implement PROS/DI Policy through TRANSYT-7F10, Leonard and Rodegerdts[3)] mentioned as identifying specific routes to receive priority, setting the disutility index to minimize fuel consumption, and setting the PROS weighting factor to the default setting of 100. The objective function of this policy is:

$$PI = \frac{(100 \bullet PROS_e)^{WP}}{DI}$$

Where WP is the relative weight of PROS to the DI (default value is 100%) and $PROS_e$ is the effective PROS, its definition defined in the manual of TRANSYT-7F[2)].

(2) Link-Weighted Delay and Stops Policy, P2 (Maximize Progression Policy)

This policy gives progression by selectively weighting the stops and delays of the through links along the arterial. According to manual of TRANSYT-7F[2], the weight range is from 0 to 9999. The weight coded in TRANSYT-7F, when divided by 100, multiplies the effect of delay/stops within the disutility index for the list of links. For this research, a delay and stops weighting factor of 300% were tried to code only along bus arterial links, multiplying the effect of delay/stops by three. Its objective function is defined as:

$$DI = \sum_{i=1}^{n} \left(3d_i + 3Ks_i\right)$$

(3) PROS[3]/DI Policy, P3 (Maximize Progression Policy)

This progression policy is very similar to P1. Since Leonard and Rodegerdts[3] mentioned that the previous studies revealed that policy PROS/DI tended to favor entire system performance over route performance, the researchers have proposed this policy to emphasize larger bandwidths. To implement this alternative, according to the manual of TRANSYT-7F10[2], the range of PROS weighting is from 1% to 1000% so the researchers tried to select a PROS weighting of 300 (i.e., an exponent of 300% on the PROS term). The objective function of this policy is:

$$PI = \frac{\left(100 \bullet PROS_e\right)^{300}}{DI}$$

Leonard and Rodegerdts[3] documented the input settings required to implement the maximize progression policies in TRANSYT-7F10 and provided the implementation details as table 1.

Table 1: Summary of Base Condition and Progression-based Policies

No.	Policy (Code)	T7F mode	PI	PROS weight	DI	Stop Penalty	I.T. flag
1	Base Condition (BC)	Sim	-	-	-	-	On
2	PROS/DI (P1)	Opt	PROS/DI	100	S&D*	-1 (Fuel)	Off
3	Link-weighted S and D(P2)	Opt	DI	-	S&D*	-1 (Fuel)	Off
4	$PROS^3$/DI (P3)	Opt	PROS/DI	300	S&D*	-1 (Fuel)	Off

Note: Prog = progression; T7F = TRANSYT-7F; Opt = optimization; PI = performance index; PROS = progression opportunities; DI = disutility index; S&D*= stops + delay; I.T. flag = initial timing flag

5. Results and Discussions

The histograms presenting the difference of the performance representative of timing plan (average delay, total stops, fuel consumption and PROS/DI) between the timing plan of base condition policy and the developed signal timing plans of each proposed progression-based policy show followings as figure 1, 2, 3, and 4, respectively.

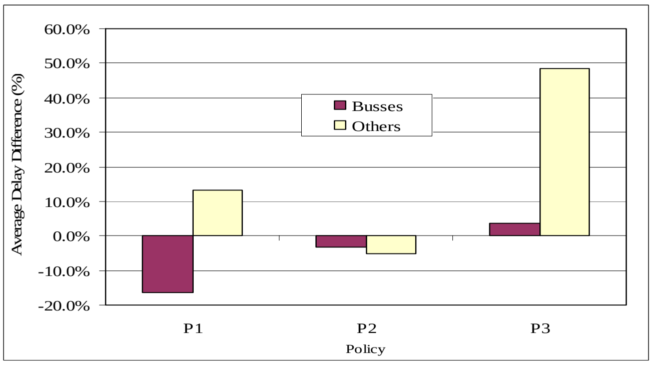

Figure 1: Difference of Average Delay

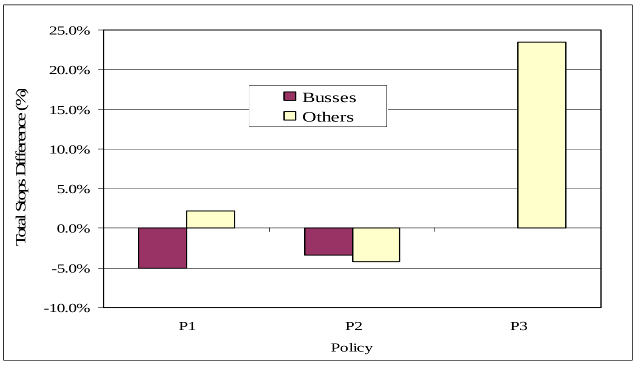

Figure 2: Difference of Total Stops

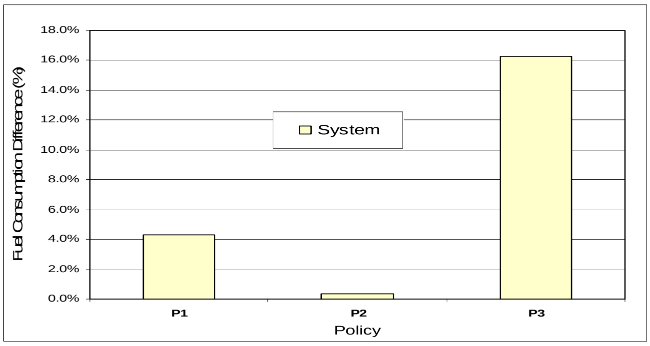

Figure 3: Difference of Fuel Consumption

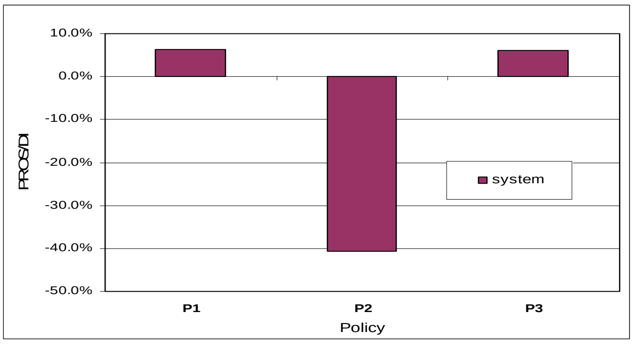

Figure 4: Difference of PROS/DI

- As considering the implementation of the PROS/DI policy (P1), in term of the bus priority, this policy yielded the negative and lowest percentages of difference in average delay and total stops of busses against those of the base condition policy (BC). These mean that this policy produced the average delay and total stops of busses lower than those of the base condition policy and the lowest among those of other progress-based policies. However, for the rest of traffic, the average delay and total stops produced by this policy, in contrast, were slightly higher than those of the base condition policy as shown in figure 1 and 2. These findings can be explained that the objective of this policy developed the optimal signal timing plan progressing only the bus route (alternatively, giving the priority to the busses) but trends to discriminate slightly against turning movements of the rest of traffic along other approaches.
- As considering the implementation of the link-weighted delay and stops policy (P2), the percentages of the difference of average delay and total stops of all vehicles with those of the base condition policy (BC) were negative as shown in figure 1 and 2. These mean that this policy yielded average delay and total stops of all vehicles lower than those of the base condition policy. These findings can be explained that the objective of this policy gave the priority to busses by selectively weighting the stops and delays of the through links along the bus arterial route so the optimal signal timing plan developed by this policy tried to minimize the stops and delays through entire links, including weighted links of bus route at which the busses and other vehicles travel along.
- As considering the implementation of the $PROS^3$/DI Policy (P3), the percentages of the difference of average delay and total stops of all vehicles with those of the base condition policy (BC) were positive as shown in figure 1 and 2. These mean that this policy yielded average delay and total stops of all vehicles higher than those of the base condition policy. These findings can be explained that the objective of this policy tried to emphasize larger bandwidths from P1 through setting higher PROS weighting along bus route. However, since this policy gave too much PROS weighting along bus route, the turning movements of other approaches have been extremely discriminated.
- As considering to accuracy of modeling, from the histograms in figure 3, all progression-based policies consumed the fuel through entire system higher than the base condition policy. As expected, the optimal timing plan of the base condition policy developed based on minimal fuel consumption policy produced the lowest fuel consumption among progression-based policies. This finding can be concluded that the modeling was conducted well.
- As considering in term of the performance of entire system, the PI (PROS/DI) in figure 4. the PROS/DI Policy (P1) yielded the highest percentage difference of PI compared against that of the base condition policy (BC). It means that the optimal timing plan of this policy produced the highest performance of traffic control through overall system among the optimal timing plans of other progression-based policies.

6. Conclusions and Recommendations

- From the revealed results, the implementation of the PROS/DI Policy (P1) yielded the best priority for the busses among the other policies when compared against the base condition policy (BC) and yielded a little bad effect to the rest of traffic. Moreover, in term of overall system, this policy produced the highest traffic control performance. Consequently, this research proposes that the PROS/DI Policy (P1) is the most appropriate policy among proposed progression-based policies of TRANSYT-7F which can develop the optimal signal timing plan providing considerably priority to busses through setting progression to bus route, and providing slightly the bad effect to the rest of traffic.
- This research tried to implement the proposed signal timing policies in only one selected site. To achieve more consistency findings, the future research should try to implement the signal timing policies in many other road systems.
- As previous mentioned, the link-weighted delay and stops policy (P2) and the $PROS^3$/DI Policy (P3) can progress to specific route through a wide range of adaptive weighting. It should be noted that this research tried to apply only one value. Therefore, the sensitivity analysis of various weighting should be further implemented. It may accomplish the better results.
- This proposed policy is the one policy for transit priority of passive signal control strategy. To accomplish better performance of traffic control, the more advance and high technology control strategies are needed for the future research.

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