EVALUATION OF BUS PRIORITY SYSTEM WITH MICROSCOPIC SIMULATION MODEL*

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1. Introduction

Currently, traffic congestion, environment pollution and accidents are the major problems in the urban areas. Especially in the medium size cities, people have a strong perception that private car is the most suitable mode when compared to existing public transport system and continuously thinking of owning a car. If appropriate management measures / policies are not implemented, this can make the situation more worse in terms of increasing the number of cars on the urban roads thus congestion and high travel times.

Travel Demand Management (TDM) is considered to be most suitable for such kind of situations. Out of them, encouraging public transport system is most appropriate in the present context. On the other hand, microscopic simulation analysis has received higher attention in the last decade as they try to analyze individual vehicle behavior and they are also capable of using behavioral models that can account for drivers' reactions[1), 2)]. It is possible to describe any local problem and driver decision to current traffic condition by microscopic simulation. And also combination of various transport policies can be evaluated and public transport polices can be considered at micro-level.

In the recent past, many microscopic simulation models have been developed[1), 2), 3)]. Generally, probabilistic approach in traffic models namely route choice and lane change, is considered to capture drivers' decisions. However, these approaches do not incorporate the uncertainties of driver perception and decisions[4)]. Several approaches have recently become popular in attempting to overcome these problems, including those based on Artificial Intelligence (AI). Out of these AI techniques, Fuzzy logic allows the introduction of quantifiable degree of uncertainty into the modeling process in order to react to natural or subjective perception of real variables. In this direction, car-following model based on fuzzy inference rules system have been developed by fuzzifying existing formulations[5)]. In the recent times, an attempt has also been made to incorporate fuzzy logic approach in car-following and lane changing model as well[4)].

The main purpose of this study is to provide a basis for evaluating public transport policy particularly bus priority measures. In order to accomplish this task, an attempt has been made to develop a microscopic simulation model which considers public transport policies. The following two types of bus priority policies have been considered for evaluation. They are:

- *Bus Lanes* i.e. special lanes dedicated to buses to insure high quality transit service. Two types of bus lanes have been considered. They are:
  - *Exclusive Bus Lanes*
  - *Priority Bus Lanes*
- *Signal Priority for Buses at Intersections* i.e. traffic signals would be changed to green which allows a bus to avoid stopping, when it is found near to intersection.

In the present study, fuzzy reasoning approach has also been considered in the analysis of lane change and route choice. A part of the Gifu city network has been considered to demonstrate the validity and applicability of the developed simulation model. For this purpose, comparison between estimated values from simulation model and observed data has been carried out. By comparing the evaluation parameters for without and with policies, their effectiveness has been assessed.

2. Microscopic Simulation Model

(1) Model Structure

Recently, a microscopic simulation model has already been established to evaluate particularly public transport policies by the authors[6), 7)]. The basic components involved in this microscopic simulation model are vehicle generation and vehicle movement. Firstly, vehicles would be generated on the network from the vehicular, OD (origin and destination) and network data. Time headways between the vehicles at all origin nodes have been estimated by assuming exponential distribution to generate vehicles on the network. As the poison distribution is generally used for low congestion condition[3)], the exponential distribution has been adopted and the headways are randomly drawn. Then the vehicles would be generated based on calculated headways. From the OD data, route to be followed would be assigned based on fuzzy logic reasoning, which is a unique feature of the present simulation model. Secondly, vehicular movements would be estimated from the traffic models such as car-following and lane changing models. The formulations involved in the above mentioned traffic models such as car-following, lane change and route choice model have been described in detail in the previous publication of the authors[6), 7)]. However, a

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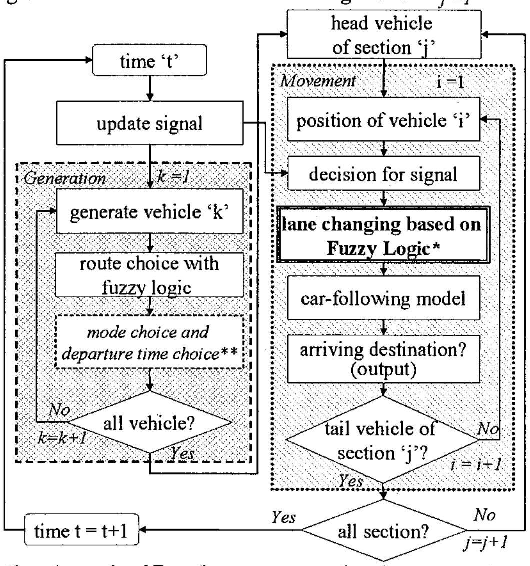
brief description of these models has been given in the next sections. The lane change model has been considered based on fuzzy reasoning approach in this study and the formulations have been described in the subsequent section in detail. However, mode choice and departure time models have been proposed to consider in future scope of the study. The processes involved in the present simulation model have been given in the form of flow chart in **Figure 1.**



*Note: * considered Fuzzy Reasoning approach in the present study*
*** to be incorporated in future*

Figure 1: Flow Chart for the Present Simulation Model

(2) Car-following Model

The car-following model was incorporated in the present model by considering Gipps[8] and Hidas[9] models, which are considered to be the fundamental models in car-following formulation. The acceleration of each vehicle has been estimated based on leader vehicle behaviour using these formulations. From that, vehicle position on the network would be updated in every time interval.

(3) Route Choice with Fuzzy Logic

In the present study, it is assumed that driver choose his route based on possibility index, which represents possibility of choosing that route. To compare the possibility indexes of all available routes, it is necessary to have a fuzzy goal (F_g). Fuzzy goal and route travel time are considered as fuzzy variables[10), 11)] as shown in **Figure 2**. The possibility index for a route is the superior of the minimum of membership functions of fuzzy goal and route travel time and in other words the meeting point of these two curves i.e. fuzzy goal function and route travel time fuzzy membership function[12)]. The possibility indexes for all the available routes have been calculated and finally driver selects the route, which has maximum possibility index. The present model is also capable of using input which has fuzziness and this is considered as unique feature of the present model and details can be found in the previous study of the authors[6), 7)].

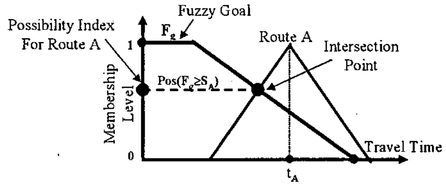


Figure 2: Fuzzy Goal and Possibility Index for a Route

(4) Lane Change Model

The process of lane changing includes estimation of purpose, target lane, necessity level and feasibility. After deciding the purpose, target lane and necessity level, feasibility would be checked based on the gap availability in the target lane. As explained in Eq (1) and Eq (2), the conditions have to be satisfied for the feasible situation[6)].

$$X_{TL} - X_S \ge V_{TL} * t_{TL} + \frac{t_{TL} * (t_{TL}+1)}{2} * D_{TL} + V_S * t_S + \frac{t_S * (t_S+1)}{2} * D_S + L_{TL} + SFD_S \qquad \text{-----------------Eq(1)}$$

$$X_S - X_{TF} \ge V_S * t_S + \frac{t_S * (t_S+1)}{2} * D_S + V_{TF} * t_{TF} + \frac{t_{TF} * (t_{TF}+1)}{2} * D_{TF} + L_S + SFD_{TF} \qquad \text{-------------Eq(2)}$$

Where:
X, V, t, D, L and SFD are position, speed, time required to stop completely, maximum deceleration, vehicle length and safe distance respectively;
Sub-scripts 'S', 'TL' and 'TF' refer to subject vehicle, target leader vehicle and target follower vehicle in target lane respectively;

If the situation is not feasible to change a lane though the necessity level is must, then courtesy lane change would be applied. In the courtesy lane change model, courtesy giver vehicle would be identified in the target lane and it would be forcibly decelerated till the sufficient gap is created to carry out the lane change process by subject vehicle[2)]. The image of courtesy lane change processes involved in the lane change model has been explained schematically in **Figure 3**.

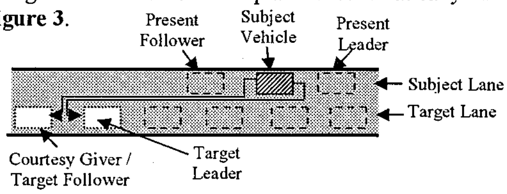


Figure 3: Courtesy Lane Change Process

a) Disadvantages of previous lane change model

A lane changing phenomenon has been considered for the purposes of turn at next intersection, speed advantage and traffic management measures such as bus lane policy in the previous study of the authors[7)]. Though the previous lane change model is predicting the results with adequate accuracy, high lane change rate (events/hr/km) was observed on some links. And also, this model considers only speed of the leader vehicles ahead to make the decision of lane change for speed advantage type. If a vehicle changes lane to improve its speed by considering that its leader is moving slowly, the following vehicle of that vehicle also changes lane by thinking the same. This process continues till the gap is filled in other lane. This process has been explained schematically in **Figure 4** by taking the output from previous simulation model display system in different time intervals. This situation is not realistic and can not be observed in the field. Where as in reality, drivers would be considering the distance to leader vehicle as well. If one vehicle change lane, the preceded vehicle will not change lane immediately as it got some distance to increase its speed unless it is mandatory. It is also proposed to consider parked vehicle on kerb-side in the present study as it is a common phenomenon which can be observed on the urban streets. The previous model is not capable of considering these aspects. There is a need to consider other explanation variables also and other approaches which consider human behaviour as well to make the model more realistic. Therefore, fuzzy logic might be an appropriate technique to consider approximations involved in human behaviour.

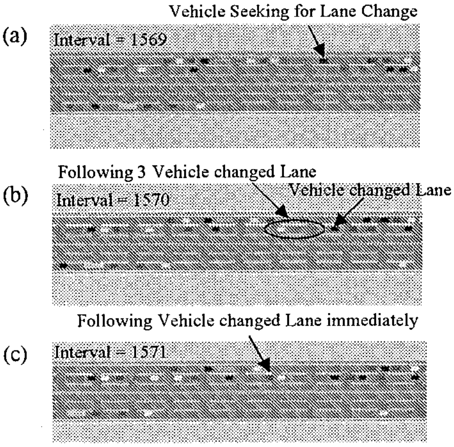


Figure 4: Lane changing behaviour in previous model

b) Necessity of fuzzy reasoning in lane change model

In reality, lane change process is carried out by considering many input parameters such as speed of leader and follower vehicle in the same lane, speed of leader and follower vehicle in the target lane, lead and lag gap in target lane, distance remaining to target lane change, position of leader and follower vehicles etc. Fuzzy reasoning would be considered as appropriate technique in the lane change analysis, because of the following reasons:

- All the above mentioned input parameters are not crisp values and involve with fuzziness.
- Every decision of driver (i.e. intention of driver to change lane or not to change lane), where human element is involved have fuzziness.
- There are no adequate mathematical relationships established between these variables and thus the inference system possesses high non-linear relationships.
- Rule base with fuzzy reasoning (if...then rules) has close resemblance of human knowledge and behaviour as they use linguistic terms and they are capable of handling complicated situations using certain rules.
- Though the standard rule base can be developed to handle this kind of situation, but the rule base would become so large. In case of addition of any input variable, this rule base becomes more complicated. On contrast, rule base with fuzzy reasoning can simplify the rules by making certain variables in to small groups using some linguistic terms.

Hence, by applying fuzzy reasoning with rule base, the above situations can be appropriately dealt and represent the behaviour which can be closer to real human behaviour.

c) Lane change model based on fuzzy reasoning

In the present study, it is proposed to consider total five types of lane changing purposes. They are: Speed advantage, Turn at next intersection, Type of bus lane policy, Presence of bus at bus stop and Presence of parked vehicles along kerb-side. Hence, the motivation for lane changing varies based on the purpose and it is clearly different from each other and considers different input variables. Each purpose has certain input variables which influence the intention of lane change. The input variables considered are Speed Advantage (SPA), Feasibility Level (FSL), and Distance to Leader Vehicle (LVD), Necessity Level (NCL) and Distance to follower vehicle (FVD). The output variable considered here is the intention of lane change (LCN). After consideration of all input variables, a fuzzy rule base has been formulated to determine the output variable for each purpose separately. A total of 54 fuzzy inference rules have been formulated for all purposes and some typical rules have been presented in **Figure 5**.

(i) Speed Advantage Purpose:		
R-1 If SPA is Low	AND FSL is Low AND LVD is Low	Then LCN is Low
R-2 If SPA is Low	AND FSL is Low AND LVD is Medium	Then LCN is Low
⋮	⋮	⋮
R-26 If SPA is High	AND FSL is High AND LVD is Medium	Then LCN is High
R-27 If SPA is High	AND FSL is High AND LVD is High	Then LCN is Medium
(ii) Turn at Next Intersection Purpose:		
R-28 If NCL is Low	AND FSL is Low	Then LCN is High
R-29 If NCL is Low	AND FSL is Medium	Then LCN is High
⋮	⋮	⋮
R-35 If NCL is High	AND FSL is Medium	Then LCN is Low
R-36 If NCL is High	AND FSL is High	Then LCN is Low
(iii) Bus Lane Policy Purpose:		
R-37 If FVD is Low	AND FSL is Low	Then LCN is High
R-38 If FVD is Low	AND FSL is Medium	Then LCN is High
⋮	⋮	⋮
R-44 If FVD is High	AND FSL is Medium	Then LCN is Low
R-45 If FVD is High	AND FSL is High	Then LCN is Low
(iv) Bus Stop / Parked Vehicle Purpose:		
R-46 If FVD is Low	AND FSL is Low	Then LCN is High
R-47 If FVD is Low	AND FSL is Medium	Then LCN is High
⋮	⋮	⋮
R-53 If FVD is High	AND FSL is Medium	Then LCN is Low
R-54 If FVD is High	AND FSL is High	Then LCN is Medium

Figure 5: Fuzzy inference rules for lane changing

The input variable, SPA is the difference between current speed and desired speed of subject vehicle or current speed of subject and leader vehicle. FSL is defined as gap available in the target lane. LVD is the gap between subject and leader vehicle. NCL is the distance remaining to target lane change. And finally, FVD is gap between subject and follower vehicle. As lane changing is a more sophisticated activity only three fuzzy sets are used for each of input and output variables for the sake of simplicity. They are: Low, Medium and High. The triangular membership function is used for all the fuzzy sets in this model.

The most generalized fuzzy inference method is min-max-gravity method. But this method generates undesirable non-linearity. Hence, linear inference methods like product-sum-gravity have been used[12]. The fuzzy rule base of a lane change model describes a driver's intention for a lane change based on their input variables. A lower intention indicates a lower possibility for a lane change and vice versa. The entire process of lane changing maneuver based on the fuzzy reasoning has been depicted in the form of flow chart in **Figure 6**.

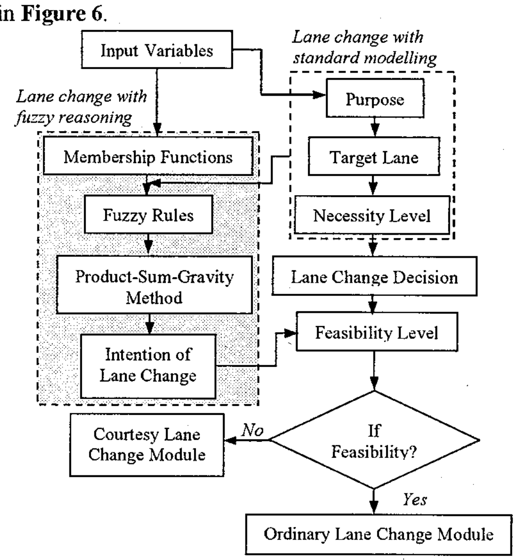


Figure 6: Process involved in lane change model

(5) Display System

A display system has been developed as part of microscopic simulation model to view the vehicular movements simultaneously. For this purpose, MS Visual Basic 6.0 software has been used. This display system mainly developed to understand and appraise the current situation by viewing the vehicular movements. The interested link or intersection has to be specified before starting of the program through the input interface menu. The display for typical link has been showed in Figure 4.

3. Validation of Microscopic Simulation Model

A real network has to be considered along with travel demand data namely OD data, network data (links and nodes) etc to validate the developed simulation model. A part of Gifu city network has been considered for this purpose. This network consists of 60 nodes and 204 links as shown in **Figure 7**. Each link assumed to be having two lanes in both directions. Recently, on Nagara Street (from Node 6 to Node 36), a social experiment has been carried out by implementing bus lane (exclusive) during the morning peak time as shown in figure. Signals have been considered for all the intersections and a constant cycle length (i.e. 120 sec) has been assumed for all types of intersections. In this model, three vehicle types (cars and heavy vehicles as private vehicles and buses) have been considered. Bus generation data has been created from the bus time table available with the concerned bus operating company.

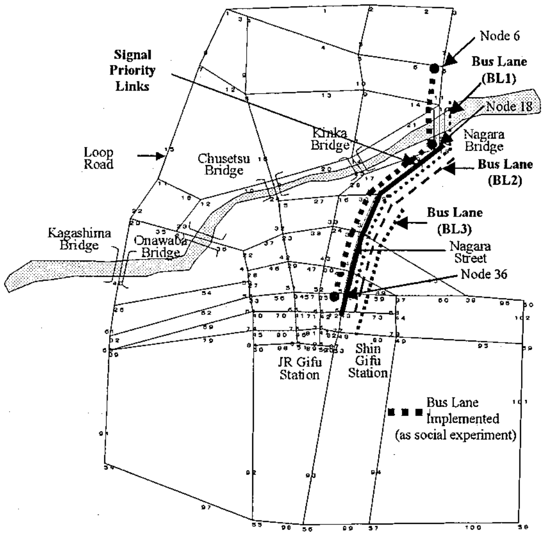


Figure 7: Considered Network of Gifu City

(1) Comparison of Link Flows

The vehicle movements have been estimated for three hours (from 06:00 to 09:00) using the developed microscopic simulation model and calculated peak hour link flows. After the thorough investigation, the observed peak hour link flows in the field for certain links of the Gifu city network have been obtained from the reliable sources. These values have been used here to validate the present simulation model. The comparison between observed and simulated link flows has been plotted as shown in **Figure 8** for about 115 links spreading through out the network. From the statistical analysis, it has been found that R^2 is 0.73 with RMS error value is about 253 Veh/Hr.

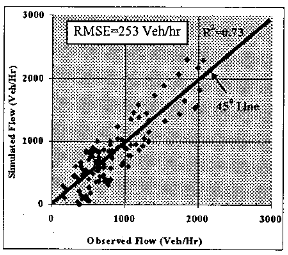


Figure 8: Observed and Simulated Link Flows

(2) Social Experiment

The data related to OD travel time of bus and cars and congestion length observed by Gifu city traffic department as a part of social experiment of implementing bus lane as shown in Figure 7 have also been considered to validate present simulation model. In the present analysis, congestion length is considered as the sum of the length of sections which has density more than critical density and it is measured in kilometers. In **Table 1**, the comparison of observed and estimated travel time and congestion has been given.

Table 1: Observed and Estimated Results

Parameter	Obs*	Est**
Bus OD (Node 6-18) Travel Time (in Min)	7	5
Car OD (Node 3-36) Travel Time(in Min)	14	13
Congestion Length (in Km)***	2.16	2.40

*Note: * Obs - Observed in the field;*
*** Est - Estimated from the present Simulation model*
**** Observed and estimated for specified links*

From the above table, it can be observed that the estimated travel time for bus and car slightly less than the observed values. It may be because of many real problems such as vehicles stopping or parking on the side of the roads and other unexpected delays causing more travel times in case of observed than estimated values. The observed congestion length is also almost matching with estimated value. But, estimated value is slightly more as the present simulation model considers a link with the sections of 100 meters length and measured the congestion length by adding the congested sections. Where as, exact length of congested area has been measured in the field. However, it can be seen from the above table, the consistency between observed and estimated values can be observed from these results.

Therefore, it can be said from the above comparisons and also from R^2 and RMSE values, the developed simulation model is able to predict vehicular movements and other output parameters with a fair amount of accuracy.

(3) Effect of Fuzzy Reasoning in Lane Change

In the present simulation model, fuzzy reasoning has been implemented in lane change model as discussed in Section 2.4. A comparison has been made to assess the effectiveness of fuzzy reasoning in lane change model with the lane change model based on standard modeling. The lane changing behaviour has been carefully observed and it has been found that the adverse behaviour which was explained in Figure 4 has been rectified and vehicles changing their lane more realistically as shown in **Figure 9**. In the present model, the vehicles are considering the distance from the leader vehicle as well to take the decision of lane change. As shown in the figure, the following vehicle of lane changed vehicle is not changing the lane immediately as it observed some free distance, which can be used for accelerating and improve its present speed before approaching closer to the leader vehicle.

The RMS Error value from the comparison analysis of observed and simulated link flows have been considered to use as evaluation index to assess the

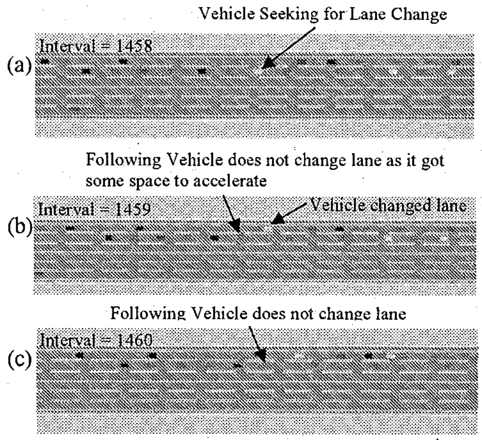


Figure 9: Lane Changing Behaviour with Fuzzy Reasoning

effectiveness of fuzzy reasoning lane change model. Then subsequently, RMS Error value has been estimated for both the cases of lane change with standard modeling and fuzzy reasoning. It has been found that, RMS error value has been reduced to 253veh/hr from 301veh/hr[7)] by implementing fuzzy reasoning in lane change model. It can be said from this analysis that, the present simulation model with the modified fuzzy reasoning in lane change model is able to predict the vehicular movements closer to observed behaviour than before.

4. Bus Priority System

(1) Bus Lane Policy

In the present study, bus lanes have been assumed to be introduced in some of the links on the Nagara Street to ensure high quality of service for buses as shown in Figure 7. Out of the two lanes, left lane has been considered as bus lane. The developed simulation model has been applied by including and excluding bus lanes and compared the different cases to evaluate the policy. This policy is introduced in three different sets of links from north to south directions only (BL1 Set - Link No. 26, 133, 34, 44 and 53; BL2 Set - Link No. 133, 34, 44, 53 and 67; BL3 Set - Link No. 34, 44, 53, 67 and 77) as shown in Figure 7 and estimated the results using developed microscopic simulation model. OD, link travel time for buses and other vehicles and total travel time have been considered as parameters of evaluation. Two types of bus lane policy have been considered in the present study. They are exclusive bus lane policy and priority bus lane policy. The estimated results under these policies have been compared with each other to find out the effectiveness of these policies. The brief description of these policies has been given in the subsequent paragraphs.

a) Exclusive Bus Lane Policy

The definition of exclusive bus lane policy says that only buses are permitted to use bus lane and other vehicles have been prohibited to use it and they have to choose ordinary lane before entering on that link. The buses will stick to bus lane only and they are also not allowed to use other than bus lane.

b) Priority Bus Lane Policy

Under the priority bus lane policy, private vehicles are also permitted to use bus lane provided that they give no hindrance to the traveling buses in the bus lane and give priority to the buses. The buses will stick to bus lane only and they are also not allowed to use other than bus lane at any time. The private vehicles have to change the lane to ordinary lane if they observe any bus coming from their back. Private vehicle which is traveling on a bus lane keep on checking the gap between its' own vehicle and its' follower vehicle and it changes to ordinary lane if the follower vehicle is bus and also if it is close to it. Then it follows lane change model to carry out lane change to ordinary lane.

c) Discussion of Results

The comparison of typical OD and link travel times for existing (without bus lanes) and with bus lane policy (both exclusive and priority) has been presented in **Figure 10 and 11** for different bus lane options.

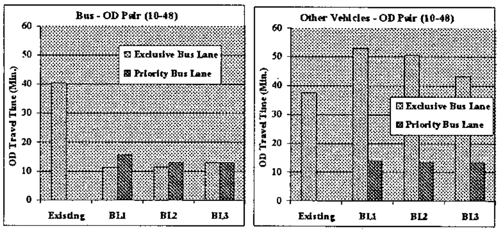


Figure 10: OD Travel Times for Bus Lane Policies

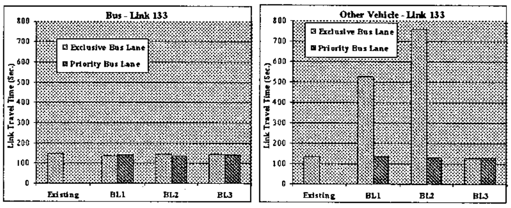


Figure 11: Link Travel Times for Bus Lane Policies

From these figures, it can be observed that a maximum of about 73% reduction in Bus OD travel time and at the same time about 40% increase in other vehicle OD travel time in case of introducing exclusive bus lane. About a 72% reduction can be found in case of priority bus lane policy is implemented. As shown in figure, link travel time for link 133 is almost insignificant change in case of bus travel time under different bus lane policies. In case of other vehicles, travel time increase about 3 times in case of exclusive bus lane of BL1 option and 5 times for BL2 option has been found. The travel times are restored to original positions in case of priority bus lane policy. It can be observed from the figures that the other vehicle OD and link travel time has increased due to the implementation of bus lanes resulting increase in congestion on other than bus lane. Hence the total travel time has increased and vehicles also changed their route to avoid bus lanes in case of implementation of bus lane policy. In case of introducing priority bus lanes, the normal conditions for other vehicles can be restored to some extent by reducing the travel times significantly.

The comparison of total travel time and total number of vehicles using the links having bus lane between 07:00 and 08:00 in all the cases (BL1, BL2 and BL3) have been presented in **Table 2** along with the existing condition.

Table2: Estimated Results for Bus Lane Policies

Option	**Total Travel Time (Hours)**		**Number of Vehicles using Bus Lane Links**	
	Ex. BL	**Pr. BL**	**Ex. BL**	**Pr. BL**
Existing	18769.77		2622	
BL1	18839.58	18813.81	2215	2796
BL2	18820.35	18959.11	2397	2864
BL3	18817.73	18879.89	2365	2866

Note: Ex. BL - Exclusive Bus Lane; Pr. BL - Priority Bus Lane

From the above table, it can be observed that the maximum of about 16% vehicles changed their route and very insignificant amount of total travel time has increased in one hour duration i.e. from 07:00 to 08:00 incase of exclusive bus lane of BL1 option. In case of priority bus lane of BL1 option, total travel time has slightly reduced and number of vehicles using bus lane have increased about 7 %.

The congestion level in case of exclusive and priority bus lane policy of BL1 option have been calculated and presented in **Figure 12**.

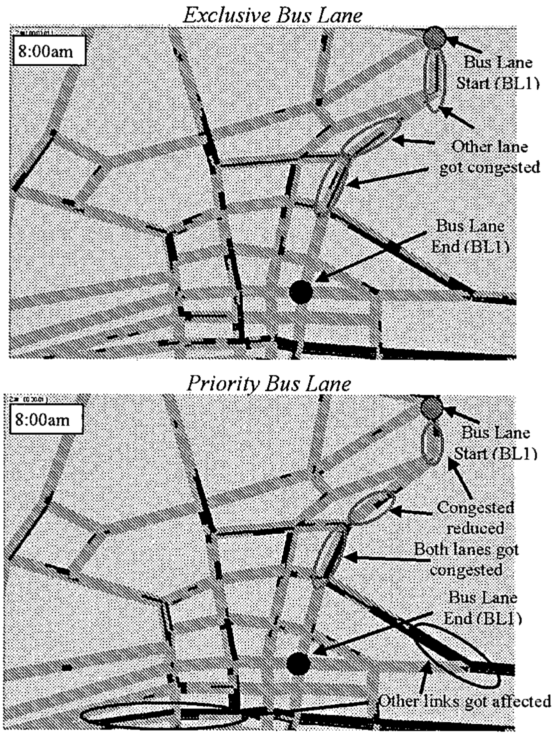


Figure 12: Congested Blocks for Bus Lane Policy (BL1)

From the above figure, it can be seen that the bus lane policy made the drastic reduction in congestion level in the bus lanes thus increase in level of service of buses. At the same time the level of congestion got increased on the adjacent lane as the other vehicles are using only ordinary lane. This can be observed in exclusive bus lane case. This phenomenon has changed in case of priority bus lane and congestion on ordinary lane of some links got reduced tremendously and it has also influenced other links which are far from bus lane. This can be observed from the Figure 12.

From these results it can be said that, the priority bus lane of BL1 option is likely to draw maximum benefits in terms of reducing travel times of buses and judiciously adjusting the other vehicles' travel time, total travel time and number of vehicles changing their route.

(2) Signal Priority for Bus at Intersections

The priority for public transport at intersection can be given by introducing new priority signal phase, which allows a bus to avoid stopping at traffic signal. As mentioned earlier, signal priority has been introduced at about five intersections on Nagara Street as shown in Figure 7. The intersections are Node No. 19, 25, 31, 36 and 43. The priority phase has been assumed in the north to south and south north directions only. The links fall under priority are Link No. 34, 44, 53, 67, 133, 136, 146, 155, 169 and 179. In the present study, priority phase has been introduced whenever the bus comes near to the intersection on these links. While priority phase is introduced on these links, non-priority phase would be initiated on the crossing links at the above mentioned intersections. The links fall under crossing links category are Link No. 30, 39, 48, 58, 72, 147, 151, 161 and 175. Three types of priority options have been considered for the purpose of evaluation to find out the most suitable option in terms of increasing the quality of service of bus and overall network performance. A brief description about the three options considered has been given in **Table 3**.

Table 3: Types of Signal Priority Policy Options

Option	Priority Signal Phase Description
PR1	Restarting signal phase with green
PR2	Signal phase is calculated based on approach volume - restarting priority signal phase with green
PR3	Signal phase is calculated based on approach volume - extending green till priority vehicle cross (or) curtail red and make it green to cross the priority vehicle

Under PR1 option, a constant cycle length of 120 seconds has been assumed. When ever the bus is found near the intersection, the phase is started from green signal to give clearance for that bus. In case of PR2 option, signal phases have been calculated based on the approach volume. The operation of priority phase is just same as PR1 i.e. restarting the signal with green phase. For PR3 option, signal phases have been calculated as PR2 option i.e. based on approach volume. But when ever the bus is found near the intersection, the time required to reach the intersection by that bus is calculated based on the current speed of that bus. If the signal is going to be red at that time, then red would be curtailed and green would be given to that bus. If it is going to be end of green time, green time would be extended till that bus crosses the intersection. The new calculated priority signal phases would be implemented for 2 cycles and after that it would be restored to original signal settings.

For these three options, the results have been estimated using developed microscopic simulation model. The parameters considered to evaluate this policy are same as bus lane policy. They are OD, link travel time for buses and other vehicles and total travel time. The comparison of typical OD and link travel times for existing (without signal priority policy) and with signal priority policy has been presented in the **Figure 13 and 14** respectively.

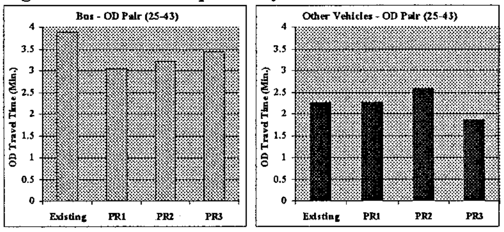


Figure 13: OD Travel Times for Signal Priority Policy

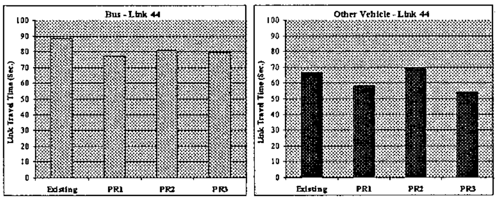


Figure 14: Link Travel Times for Signal Priority Policy

From the figures, it can be observed that about a maximum of 20% reduction in bus OD travel time has been found in case of PR1 option. For other vehicle, about a maximum of 18% reduction in OD travel time has been observed in case of PR3 option. It is also found that about 10% reduction in bus link travel time has been observed for link 44 in case of PR3 options, which is almost same in case of PR1 and PR2 options. For other vehicles, a maximum of about 19% reduction in link travel time for the link 44 has been observed in case of PR3 option.

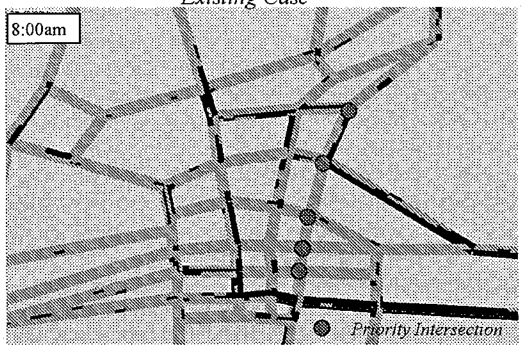
The comparison of total travel time between 07:00 and 08:00 in all the cases (PR1, PR2 and PR3) along with existing case have been calculated and presented in **Table 4**. The total travel time has been reduced about a maximum of 6% in case of PR3 option.

Table 4: Estimated Results for Signal Priority Policies

Option	Total Travel Time (Hours)
Existing	18769.77
PR1	18653.42
PR2	17928.86
PR3	17574.14

The congestion level before and after signal priority policy on these links have been estimated and presented in **Figure 15**.

Existing Case



PR3 Case

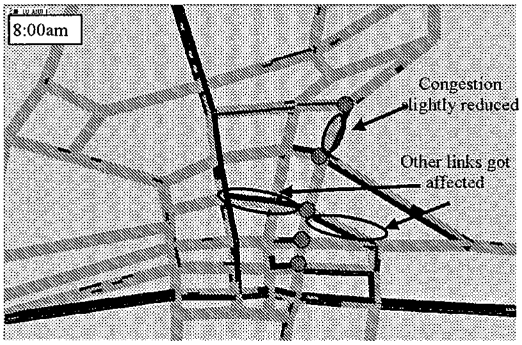


Figure 15: Congested Blocks for Signal Priority Policy

As the volume of buses is very small compared to other vehicles, the priority for buses has a little impact on existing congestion though it has improved level of service of buses. At the same time the level of congestion has increased on the crossing streets which is also representing the fact that the no signal priority has been given to this direction of traffic. From the results it can be said that, the option PR3 is likely to draw maximum benefits in terms of reducing OD and link travel times of buses and judiciously adjusting the other vehicles' OD and link travel times and total travel time.

(3) Sensitivity Analysis for Signal Settings

It has been proposed in the present study that the normal signal would be restored after implementing priority signal phase for certain number of cycles. A sensitivity analysis has been carried out to estimate the optimum number of cycles of priority signal phasing to be implemented and after that normal signal would be started. The total travel time in one hour has been considered as evaluation parameter. The total travel time has been calculated for different options such as signal restoration after one cycle, two cycles and three cycles and compared with each other. It is interesting to observe that normal signal restoration after implementation of priority signal for two cycles is bringing maximum benefits (low total travel time) compared to other two options as shown in **Figure 16**.

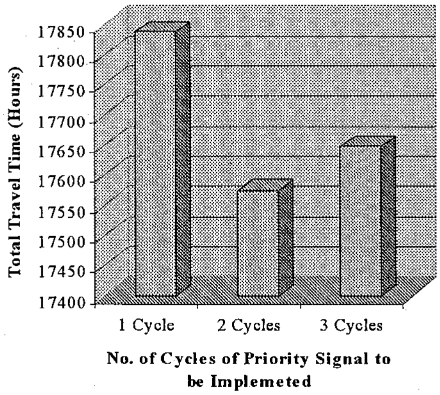


Figure 16: Total travel time for different options of signal restoration from priority to normal

It can be seen from the above figure that the priority signal implementation for two cycles is more beneficial. It may be because the priority signal for priority direction is increasing green time or reducing red time than the existing signal phases. So this increased green time mainly causing to dissipate the queue in priority direction and build the queue in cross street (non-priority direction). After implementing the priority signal for two cycles, almost all the queued vehicles in priority direction might have dispersed where as only some part of the vehicles are able to disperse in case of implementing priority signal for one cycle. By implementing priority signal for three cycles, there may not be any vehicles as such in queue in the priority direction. But there may be long queues and high delays for non-priority direction by that time. That means, the optimum benefits might have observed for two cycle implementation and as such no significant benefits can be expected after that. This phenomenon has been witnessed by closely observing the vehicle movement's display using the present simulation model. The flow and the number of vehicles entering in the intersection are also studied to observe the impact of signal restoration. The flows are little bit high for two cycle option compared to other two options and that means the impact is considerably less for that. Later on, Bus OD travel time also compared among these three options. The priority signal for two cycles is able to reduce about maximum of 55% in bus OD travel time compared to 24% and 49% in one cycle and three cycle options respectively. Based on these observations, it can be concluded that the normal signal restoration after two cycle implementation of priority signal would bring maximum benefits.

5. Concluding Remarks

In this study, a microscopic simulation model has been developed and tried to evaluate different public transport policies particularly bus lane and signal priority policies. The main summary of findings from this study has been given as below:

- Lane change model with fuzzy reasoning seems to be estimating the lane changing behaviour more realistically and overcame the problem faced by standard modelling.

- Priority bus lane option is likely to draw more benefits in terms of reducing other vehicle travel time compared to exclusive bus lanes and judiciously adjusting total travel time.
- It can be observed from the results that option BL1 and option PR3 are likely to draw maximum benefits in terms of reducing OD and link travel times of buses and also adjusting the other vehicles' OD and link travel times, total travel time and number of vehicles using the bus lane / signal priority links.
- Results from the sensitivity analysis of priority signal setting for bus shows that optimum benefits can be drawn if it is lasted for 2 cycles.

From this study, it can be concluded that the developed microscopic simulation model can be applied to evaluate public transport polices particularly bus lane and signal priority at intersections with fair amount of accuracy.

In future scope of this study, it is proposed to consider mode choice behvaiour in the present simulation model explicitly to evaluate the public transport improvement policies. As the PT policies are expected to influence modal split and commuters would be changing their mode, it is essential to consider the mode choice model in the simulation model. And incorporation of departure time model to analyze commuter's characteristics in starting their trip is also proposed. Along with that, it is proposed to consider to model the commuters' behaviour related to information provision in the simulation model.

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マイクロシミュレーションモデルによるバス優先システムの評価*

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地方都市においてはバス交通を中心とした公共交通政策が検討される場合が多い．このとき，バスは都市道路網上で自動車交通と一体的に運行されるため，バス交通に関する政策は，自動車交通との相互の影響により複雑に作用すると考えられる．本研究ではバス優先レーンおよび公共交通優先信号システム(PTPS)についての影響分析のため，都市道路網を対象として個々の車両移動（特に車線変更行動）を表現する交通シミュレーションを構築する．これよりバス優先レーン，PTPSなどのバス交通に関する政策のインパクトについて，広域的な交通流動への影響把握が可能となるとともに，局所的には詳細な交通現象分析が可能となる．

EVALUATION OF BUS PRIORITY SYSTEM WITH MICROSCOPIC SIMULATION MODEL*

by Madhu ERRAMPALLI**, Masashi OKUSHIMA*** and Takamasa AKIYAMA****

The main objective of this study is to provide a basis to evaluate bus priority policies especially bus lane and public transport priority at signal by developing microscopic traffic simulation model. Fuzzy reasoning has been considered in lane change and route choice behaviour. The lane change model with fuzzy reasoning seems to be estimating the lane changing behaviour more realistically. The results show the superiority of priority bus lane option over the exclusive bus lane option. In case of priority at signal options, curtailing red phase and extending green phase has been drawing more benefits compared to other options considered.