Comparative Analysis of Bus Lane Operations in Urban Roads using Microscopic Traffic Simulation

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Abstract: The research focuses on the comparative analysis of three popular types of bus lane operation including roadside exclusive bus lane, bus priority lane and ordinary lane. The analysis is firstly conducted based on simulation tests in Paramics with assumed data about traffic arterial road and input parameters. Then, to evaluate the results, a case study is introduced. This case study is conducted in Nagaoka city at an urban street with a large number of buses going through and a high traffic volume. The results show that with the current traffic situation, once it is deployed, the bus priority lane type can help reduce by 1.2 sec for each passenger traveling on 500m long segment compared with the current ordinary lane type. Choosing the bus lane types in terms of travel time is also investigated in a sensitive relation with the main traffic volume and the number of passengers on the bus.

Key Words: Simulation, bus priority lane, Paramics

1. INTRODUCTION

Deploying public transport system in general as well as bus system in particular is an indispensable trend to relieve traffic congestion and improve traffic quality. However, improving the performance of public transport will usually cause unfavorable conditions for non-bus operations. Therefore, City planners have to decide proper policies to take shape of a harmonious and sustainable traffic system. According to HCM 2000, there are three types of bus lanes. Type 1 bus lanes have no use of adjacent lane; Type 2 bus lanes have partial use of the adjacent lane, which is shared with other traffic; and Type 3 bus lanes provide for exclusive use of two lanes by buses. It can be seen that, this classification was based on the degree of exclusivity of bus lane. The greater the degree of exclusivity of bus lane and the greater the number of lanes available for buses to maneuver, the greater the bus lane capacity.
In Japan, besides the ordinary bus lane type and exclusive bus lane type, another type of bus lane – priority lane – has already been deployed (figure 1) for years. However, there have been very few researches about it. The special thing of this lane type is the complexity of non-buses in choosing lane and changing lane to avoid bus coming. This priority lane type concerns the degree of exclusivity of not only bus, but also other vehicles. This type can improve effectively the bus travel time and minimize negative impacts on non-bus as well.

From three popular bus lane types in Japan, the scope of this paper just focuses on three cases of traffic operation that concerns correspondingly the three mentioned types of bus lane. For a main street with 2 lanes for each direction, the definitions can be expressed:

- **Roadside exclusive bus lane case**: The most left lane is an exclusive bus lane that is used only for bus. The right lane is used mainly for non-buses (cars, big trucks, small trucks) and partly for buses which want to overtake or turn right.

- **Bus priority lane case**: buses, cars, small trucks and big trucks can use both lanes to promote the trips. However, because the most left lane is the priority lane, non-bus vehicles give up their lanes to buses which are reaching into the recognized distance D of these non-bus vehicles on the priority lane. It means non-buses are allowed to use all lanes, provided that they do not obstruct the bus traveling on the priority lane.

- **Ordinary lane case**: Buses and non-buses (cars, small trucks and big trucks) can use two lanes and freely change lanes if necessary.

From the above definitions, it can be imagined that suffering from low speed in the case of ordinary lane with mixed traffic flows, the travel time of buses is improved a lot when exclusive bus lanes are deployed. However, it is really a waste of road space when the number of buses is usually much less than that of passenger cars in the case of exclusive lanes. Thus, non-bus travel time will be affected negatively in this case. To better the situation, a traffic system with priority bus lanes is introduced. The questions are how good the traffic performance in each bus lane type is and what threshold in deciding bus lane type for specific situation is. The research aims at answering the questions.

This paper consists of 7 main parts; each part deals with its relevant aspects. This research’s overview is presented in this section, Section1 – Introduction, and then followed by Section 2 – Literature Review, in which the theoretical background of the research is discussed. The research objectives are presented and elaborated in Section 3. Section 4 describes in detail the methodology used in this paper. Section 5 concerns simulation tests with assumed input data. A case study is scrutinized in Section 6 to evaluate the real improvement when the model is applied to the actual case. And finally, the paper ends with several conclusions and recommendations presented in Section 7.
2. LITERATURE REVIEWS

There have been a number of research papers focusing on bus priority schemes. These bus priority schemes such as reserved bus lanes, bus-only streets, with-flow interior bus lanes, exclusive median bus ways and so on, have been implemented in many urban areas all over the world. With the assignment of special lanes to buses, the level of service of the vehicular traffic was not affected adversely and this assignment created a reduction in the travel time and an increase in the speed of buses (Cox, 1975). However, during off-peak periods or when the traffic is low, the bus lane has little impact on buses (Shalaby and Soberman, 1994). If an exclusive bus lane is provided under highly heterogeneous traffic conditions, the maximum permissible volume to capacity ratio that will ensure a level of service of C for the traffic stream comprising all the motor vehicles, except the buses, is about 0.53 (Venkatachalam Thamizh Arasan et al., 2008). In other words the impacts of exclusive bus lanes are significant and with utilization of the exclusive bus lanes, the operational efficiencies of buses and the general traffic are improved so much (Lin Zhu, 2010). The impacts of reserved bus lanes on both bus and auto performance were also measured by comparing relative speed changes of buses and autos and the average circulation rate of bus trips for a real case in Seoul, Korea (Hyung Jin Kim, 2003). The reserved bus lane can improve bus travels but it may affect the performance of adjacent. Due to the macroscopic simulator TRANSYT-7F, Amer S. Shalaby (1999) concluded several impacts of reserved bus lanes for the study case in downtown Toronto, Canada. The research showed that the performance of the average bus improved and the performance of adjacent through traffic deteriorated.

Some characteristics of bus lanes were also compared with each other. Joy Dahlgren (1997) defined circumstances in which high occupancy lanes are less effective than general purpose lanes in reducing delay. To get this, the authors built a model that combined queuing theory and mode choice theory to compare 4 considered alternatives: add a high occupancy vehicle lane, add a general purpose lane, convert an existing lane to a high occupancy lane and do nothing. They concluded that when applying the model in a wide range of a typical situation, adding a general purpose lane would be even more effective than adding a high occupancy lane. In addition, Huanyu et al. (2003) considered bus-only and high occupancy vehicle lanes two common occupancy-based preferential facilities on highway and used the CORSIM simulation model to develop a decision model for determining whether a freeway preferential bus lane can be justified under prevailed conditions. Furthermore, the advantages of exclusive bus lane were surveyed when SEO, Young Uk et al. (2005) was setting-up a methodology and criterion of exclusive bus lane based on finding a travel equilibrium point. This point is identified by making the travel time between buses and automobiles equal after operating it. Since then, they recognized that the exclusive bus lane is useful only to equilibrium points with specific total traffic volume and bus volume.

Recently, several studies have focused on bus priority lane with different approaches. Kunihiro Sakamoto et al. (2007) analyzed real data to identify the effectiveness of bus-priority lanes as a countermeasure for traffic congestion in Shizuoka, Japan. However, because the approach just derived from the real data comparison between two periods, before and after the implementation of BRT, it lacked a comprehensive investigation into concerned factors as well as a comparative analysis on the effects of each bus lane type. Meanwhile, Minh Tranhhuu et al. (2007) also modeled bus lane priorities in a motorcycle environment using Saturn with the data collected in Hanoi, Vietnam. However, with this mesoscopic simulation, the vehicle individual behaviors modeled were not correct. Therefore, it affected the accuracy of the final results.
It is clear from the review of literature that the choice of bus lane types and their effects on vehicle travel times have received less attention. How the vehicle travel times change in each case of bus lane type has not been analyzed and compared appropriately. Therefore, it is necessary to conduct a research on these issues.

3. RESEARCH OBJECTIVES

The main objectives of this paper are as follows:

• The effectiveness of the three types of bus lane treatment, including exclusive bus lane, ordinary lane and especially bus priority lane in the improvement of traffic conditions.

• The importance and the sensitivity of main traffic volume, the average number of passengers on bus in choosing bus lane treatment.

4. METHODOLOGY

4.1 Ideas for bus priority lane deployments

According to Paramics Technical Report, lane changing model in Paramics is done using two devices, namely gap-acceptance policy and historical record of suitability gap availability. Considering a two lane per direction segment, the gaps are illustrated as in figure 2.

\[
\begin{align*}
g_1 &> d_{\Delta V_1} + h v_1, \quad \text{and} \quad g_2 > d_{\Delta V_2} + h v_2 \\
\text{where} \quad d_{\Delta V_1} &= t_{ro} + \frac{\Delta V_1}{D_1}, \quad d_{\Delta V_2} = t_{ro} + \frac{\Delta V_2}{D_2} \\
\Delta V_1 &= v_1 - v_0, \quad \Delta V_2 = v_0 - v_2 \\
v_N &\quad \text{is the current speed of Dynamic Vehicle Unit N (DVU_N)} \\
D_N &\quad \text{is the maximum deceleration of DVU_N}
\end{align*}
\]

The lane changing behavior depends on not only the above gaps, but also awareness factors \( \alpha^{\text{awareness}} \) to change lane. Occasionally, drivers meet acceptable lead gaps, lad gaps, but they do not want to take a lane changing action. The probability for a vehicle changing lane is:

\[
P_{\text{changing lane}}(t) = \alpha^{\text{awareness}} P(\text{Lead gap accept case}) \times P(\text{Lag gap accept case}) \\
= \alpha^{\text{awareness}} \times P(G_{i}^{\text{Lead}}(t) > G_{i}^{\text{cri Lead}}(t)) \times P(G_{i}^{\text{Lag}}(t) > G_{i}^{\text{cri Lag}}(t))
\]
Comparing the two mentioned types, namely the priority and the ordinary, the awareness factors are quite different because of the recognition of priority lanes for buses. It is easy to see that the awareness factor for changing lane from lane 1 to lane 2 in the priority case is larger than that in the case of ordinary lane. Meanwhile its awareness factor for changing lane from lane 2 to lane 1 is smaller than that in the ordinary case. If assuming that the traffic situations such as lead gaps, lag gaps, the number of vehicles in the road segment, etc are the same in the two above cases, we can see

\[ P_{\text{Increase Lane}_1} = 1 + (\beta_{\text{Awareness}} - \alpha_{\text{Awareness}}) x P(G_{\text{Lead}i}^i(t) > G_{\text{Lead}i}^{\text{priority}}(t)) x P(G_{\text{Lag}i}^i(t) > G_{\text{Lag}i}^{\text{priority}}(t)) \]  

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\[ 1 + (\alpha_{\text{Awareness}} - \beta_{\text{Awareness}}) P_{\text{Repeat Lane}}^i > 1 + (\alpha_{\text{Awareness}} - \beta_{\text{Awareness}}) P_{\text{Repeat Lane}}^i P_{\text{Repeat Lane}}^i \]  

or \[ P_{\text{Increase Lane}_1} < P_{\text{Increase Lane}_1} \]  

or \[ \text{Traffic density on Lane}_1 < \text{Traffic density on Lane}_1 \]  

On a road segment that is long enough for bus not to change lane, the bus travel time on that road segment is directly proportional to the traffic density on that bus lane. Therefore, bus travel time on lane 1 in the priority lane case is usually smaller than that in the case of ordinary lane. The advantages in bus travel time when deploying bus priority lanes instead of ordinary lanes can be seen clearly. But how the reduction is and how impacts on non-bus movement are, the study will try to investigate it.

4.2 Algorithm in Paramics programmer module

Using C++ and Paramics Programmer module, the research creates a bus-priority plugin (a dynamic link library DLL) to simulate the case of priority lane. The detail of the algorithm for this plugin can be seen in figure 4. In this plugin, functions for checking and changing lanes are called for each simulation time step. The distances between the buses and those vehicles are determined with the following formula:

\[ d_{\text{bus}(i)-\text{vehicle}(j)} = \sqrt{(x_{\text{bus}(i)} - x_{\text{vehicle}(j)})^2 + (y_{\text{bus}(i)} - y_{\text{vehicle}(j)})^2} \]  

(8)

where \((x_{\text{bus}(i)}, y_{\text{bus}(i)})\): Co-ordinates of bus i

\((x_{\text{vehicle}(j)}, y_{\text{vehicle}(j)})\): Co-ordinates of vehicle j moving in front of the above bus i, on lane 1.

The paper assumes that, through rear-view mirrors, the visibility of the driver on front vehicles to recognize any bus rearwards is in the range D from 20m to 60m. Therefore, vehicles within the distance of 20m - 60m ahead from the bus will have following responses:

- If the vehicle and the bus travel on the bus priority lane (the vehicle now travels on lane 1), the vehicle, if possible, moves onto lane 2, to give way for the bus coming (as shown in figure 3).

- If the vehicle now travels on lane 2, this vehicle will not be allowed to move onto lane 1 (prioritized lane for buses).

![Figure 3 Vehicle changes lane to give way for bus](image-url)
The above lane changes have two exceptions: one exception for cases in which the vehicle wants to turn left at intersections, and another for cases that the vehicle cannot change lanes concerning with having no acceptable gaps for them to change lanes.

5. SIMULATION TESTS

5.1 Traffic network and assumed data

The paper builds a hypothesis traffic network with the orientation of left hand driver. In this network, zone 1 and zone 2 are main zones, and other zones are on side streets. The lay-out is illustrated as in figure 5:

The main street has 2 lanes for each direction. Meanwhile each direction on the side streets has one lane. At each intersection, the network has slip lanes for vehicles that want to turn right. The length of these slip lanes on the main street are around 90-100m and 30-40m for the...
side streets. Traffic signals at intersections include 3 phases and the split between the main streets and side streets is 75:25. Two bus stops are designed on the main street with the dwell time of 30sec. Vehicle types and the proportions are proposed for cars, small trucks, big trucks as 77%, 13% and 10% respectively.

In Paramics, the process of releasing vehicle is controlled by travel demand. There are two kinds of travel demand mentioned in this paper, one for the main street and the other for the side streets. These travel demand types are specified in the form of origin-destination matrices. The percentages of releasing vehicles in each period are specified in the profile file of the core Paramics. This study assumes that the side street demands are invariable while the main street demand is changeable. The side street traffic volumes are always 300vph in this research. The main street demand is divided into 7 levels corresponding to seven demand patterns. In each pattern, the simulation time is 5 hours from 6AM to 11AM. Each demand pattern has a warming up period (from 6AM to 7AM) with the traffic volume of 500vph, a transition period and a peak hour period with its traffic volume. The warming up period makes the simulation model more realistic and the peak hour periods are used to calculate vehicle travel times, which is considered at 7 levels: 500vph, 750vph, 1000vph, 1250vph, 1500vph, 2000vph, and 2500vph.

5.2 Results from the simulation tests

The relationships between the main traffic volume and vehicle travel times are non-linear curves. Generally, the vehicle travel time increases when the main traffic volume increases.

![Figure 6 The relationship between travel times and main traffic volume.](image)

The effects of the other vehicles on bus operations create changes in the bus travel time among the cases. In figure 6, it is clear that the bus travel time is lowest in the exclusive case and highest in the ordinary lane case. Priority lane case can improve the bus travel time so much compared with the ordinary case. For non-bus travel time, it is straightforward to see that the travel time is lowest in the ordinary lane case and highest in the exclusive bus lane case. That is reasonable because the road surface area for non-bus use is the largest in the ordinary lane case and the smallest in the exclusive lane case.

6. A CASE STUDY

The study site is a main urban street which lies partly on the route No.351 and partly on the segment route No.36 leading to Nagaoka station (figure 9). From field inspections, this urban...
street segment has a large number of buses passing through and a high traffic volume in comparison with other areas in the city. As a gate entering Nagaoka station, this arterial plays an important role in increasing the transport capacity and creating convenience for traffic participants. To collect a comprehensive data of this urban street, 10 cameras were placed as shown in figure 7 to observe the traffic during the period from 7:30AM to 9:30AM. Four cameras were set at 4 intersections to record the traffic volumes on the main street, the side streets and turn traffic volumes. The remaining cameras were used to video at bus stops along this route. To get the accuracy of travel time calculation and the time of bus coming, all cameras started at the same time and they had the same local clocks. The arrangement is as follows:

![Figure 7 The camera’s locations for data collection](image)

After capturing the traffic situation, the captured video was analyzed in Transportation Lab to obtain the traffic proportion (Figure 8), traffic volumes, turning proportion, bus interval, bus dwell time, car travel time, bus travel time, traffic signals at intersections, offset, etc. Based on the data observed, the main traffic volume on the direction to the station is around 514vph and 365vph on the opposite direction during the peak hour. The detailed traffic volumes are displayed in the part of comparison between simulated flows and observed flows at the end of the following calibration process. All the traffic information, control information and geometric information of the study site are the input for Paramics Modeler – a microscopic simulation software. The displays from the map and the interface of Paramics are as follows:

![Figure 8 Traffic proportion](image)

![Figure 9 The study site (left) and Simulation Nodes, Links, Zones built in Paramics (right)](image)
6.1 Model validation

Observed traffic flows at 32 points in the traffic network during the peak hour were divided into 4 intervals, from 8:00 to 8:15, 8:15 to 8:30, 8:30 to 8:45 and 8:45 to 9:00. Meanwhile, the simulated traffic flows were obtained from Paramics by setting period of 15min interval to collect data at 32 points during the peak hour. From the simulated results and observation data, the traffic flows in 4 intervals during the peak hour from 8:00 to 9:00 are plotted around the 45-degree line, as shown in figure 10. The values of simulated traffic flows and observed traffic flows distribute closely along the 45 degree line. The relative errors of traffic flows at all observed points are less than 15 percent.

The vehicle travel times are measured on the road segment A1A2 (as in figure 7) when vehicles traveling from intersection 1 to intersection 4 from recorded video tapes and from Paramics modeler. Vehicles were classified into 2 groups, bus and non-bus. The comparisons for every interval during the peak hour are shown in figure 11.

The travel times of bus and other vehicles for each direction on the main street in the observation case and simulation case are approximately the same. The relative errors of travel times of bus and non-bus are less than 5 percent at each considered interval.
6.2 Comparative analysis

After validating the model for the ordinary lane case, the research investigates 2 cases more, exclusive lane case and priority lane case, based on the available traffic network. These 2 cases utilize the geometric figures, the current traffic volumes, bus schedules, etc. but change the policy for traffic activities. With the same traffic conditions but differences in policy (ordinary lane case, priority lane case and exclusive lane case), the traffic performances during peak hour from 8:00 to 9:00 in 3 cases are different as shown in figure 12. The research will compare bus travel time and non-bus travel time on the direction to the station for each interval and for each bus lane case. The peak hour will be divided into 4 intervals, from 8:00 to 8:15, from 8:15 to 8:30, from 8:30 to 8:45 and from 8:45 to 9:00. To show more clearly the advantages and disadvantages of each treatment, the reductions or increases in travel time among cases will be concretized and illustrated in this figure.

On the studied direction, the bus travel time and non-bus travel time at each interval during the peak hour are displayed as follows:

Figure 12 Vehicle travel time comparisons for each case, each interval

From the above figure, compared with bus travel time in the ordinary lane case, the bus travel times in the case of exclusive bus lane and priority lane reduce significantly. Meanwhile, non-bus travel time does not change so much when comparing the priority lane case and the
ordinary one. Indeed, as for the bus travel time, the reductions for the priority lane case are 2.9%, 5.1%, 3.9% and 2.6% at each interval of the peak hour in comparison with the ordinary lane case. These figures decrease considerably when comparing with the exclusive bus lane, namely 5.6%, 6.3%, 8.0% and 4.0%. On average, the bus travel time in the priority case and exclusive lane case reduce by averagely 3.63% and 5.98% respectively during the peak hour. As for non-bus travel time, at each period during the peak hour, the increases are 1.0% (period from 8:00 to 8:15), 1.6% (period from 8:15 to 8:30), 2.3% (period from 8:30 to 8:45) and 2.2% (period from 8:45 to 9:00) for the priority case compared with the current ordinary lane case. Meanwhile, non-bus travel times in the exclusive lane case increases significantly, by 2.8%, 5.5%, 12.2% and 7.3% at each 15 minute interval. Generally speaking, the non-bus travel times are different insignificantly between the ordinary lane case and the case of priority. Averagely, the non-bus travel times increase by about 1.78% for the priority case and 6.95% for the exclusive lane case during the peak hour from 8:00 to 9:00. In a word, the performances of 3 cases of bus lane in terms of travel time can be seen clearly through this comparison. Although the exclusive bus lane can reduce a lot bus travel time, the non-bus travel time also increases greatly. With the bus priority lane treatment, bus travel time can be reduced considerably while there is a slight increase in non-bus travel time.

6.3 The decision on choosing bus lane type

During the peak hour, there are 28 buses passing segment A1A2 on the studied direction. Based on the observation, the average number of passengers on each bus was 19.4 with the standard deviation of 3.2 for 28 buses and on each non-bus is 1.25 with the standard deviation of 0.4 for 110 passenger cars. Converting all bus travel time and non-bus travel time into passenger travel time, we can estimate the time needed for one passenger going from intersection 1 to intersection 4 with the results illustrated in figure 13.

![Figure 13 Passenger travel time comparisons](image)

It is clear that, compared with the exclusive bus lane and the ordinary lane case, the priority lane case has a very good performance in reducing passenger travel time. Indeed, for this direction, the priority treatment can reduce by 1.2 (s) (or 0.8%) per passenger in comparison with the current ordinary lane case. Meanwhile, the exclusive bus lane treatment makes the passenger travel time increase by 1.3 (s) (equivalent to 0.8%). Although exclusive bus lane can improve bus travel time very much, its negative impacts on non-bus operation are significant in this case. Therefore, bus priority lane is a proper treatment, which can improve bus service and reduce negative impacts on non-bus simultaneously.

6.4 Sensitivity analysis

The traffic volume and the number of passengers change every day, every hour. In addition, it is so difficult to count exactly the number of passengers on all buses and all passenger cars. Thus, the decision on choosing bus lane type would be changed according to the traffic situation. The research preserves the bus schedule in this study site and conducts an analysis.
of choosing bus lane treatment based on ranges of the number of passengers and main traffic volume. The differences in passenger travel time between cases are formularized as follows:

\[
\Delta_{Pr_i}(X_1, X_2) = T_{passenger_{Ordinary}} - T_{passenger_{Priority}}
\]

(9)

\[
\Delta_{Exc}(X_1, X_2) = T_{passenger_{Ordinary}} - T_{passenger_{Exclusive}}
\]

(10)

where

\[
\Delta_{Pr_i}(X_1, X_2) = \text{Difference in passenger travel time between the ordinary case and the priority lane case (sec/passenger)}
\]

\[
T_{passenger_{Priority}} = \text{passenger travel time on A1A2 segment with direction to the station in the priority case (sec/passenger)}
\]

\[
T_{passenger_{Ordinary}} = \text{passenger travel time on A1A2 segment with direction to the station in the priority case (sec/passenger)}
\]

\[
X_1 = \text{The main traffic volume on the main street (vph)}
\]

\[
X_2 = \text{The average number of passengers on buses (passengers)}
\]

\[
\Delta_{Exc}(X_1, X_2) = \text{Difference in passenger travel time between the ordinary case and the exclusive lane case (sec/passenger)}
\]

As being seen in equations (9), (10), the priority treatment or exclusive bus lane case is considered a better case compared with the current ordinary lane case when the value of \(\Delta_{Pr_i}(X_1, X_2)\), or \(\Delta_{Exc}(X_1, X_2)\) is positive. The bigger the values of \(\Delta_{Pr_i}(X_1, X_2)\), \(\Delta_{Exc}(X_1, X_2)\), the better the cases of priority, exclusive lane respectively in comparison with the ordinary lane case. The research investigated the three cases of bus lane with various values of the main traffic volume. The considered values of main traffic volume are 300vph, 400vph, 500vph, 800vph, 1000vph, 1300vph, 1500vph and 1900vph. At each value of main traffic volume, the output travel times were obtained from Paramics after 10 times of running for each case of bus lane. The relationships are illustrated as in figure 14.
From figure 14, the violet Delta lines and blue Delta lines are contours of which values represent for the differences in passenger travel time between the case of ordinary and priority lanes. Similarly, the yellow Delta lines are also contours of which values represent for the differences in passenger travel time between the ordinary case and the exclusive lane case. There are two main points the research would like to bring out in this figure. The first one is the area distribution. It is easy to see that, the area with high number of passengers on bus and low main traffic volume is the most suitable for exclusive bus lane treatment (the area with yellow lines). Meanwhile the area with the low number of passengers on bus and high main traffic volume is good for ordinary lane case (the area with violet lines). The middle area with blue hatch, between the area for exclusive bus lane and the area for priority lane is proper for deploying priority lanes. If the priority lane were deployed in this area, the passenger travel time can be reduced by up to 1.8sec when traveling on a 500m main road segment. The second point the research wants to mention is the slopes of Delta lines. Both the main traffic volume and passenger numbers, in the scope of this research, are very important factors in choosing bus lane types. However, the slopes in the case of exclusive lane are very high compared with that in the other cases. It means that the dependence on passenger numbers in the exclusive lane case is very high, higher than that on the main traffic volume. These slopes decrease gradually from the case of exclusive bus lane to priority lane and finally to the ordinary lane case when the main traffic volume increases. At that moment, the dependence on the main traffic volume becomes more important than that on the passenger numbers.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

- The research comparatively analyzed the impacts of the three popular types of bus lane in Japan by using Paramics as a tool to simulate the bus lane types, especially for the type of bus priority lanes. The results showed that although the exclusive bus lane type can improve bus service so much, its negative impacts on general vehicles are significant. Thus if deployed at the study site, the exclusive bus lane would make the passenger travel time increase by 1.3sec on a 500m long urban street. Meanwhile, because of the flexibility in choosing lane in the priority lane case, developing bus priority lane at this study site can reduce 1.2sec for each passenger traveling the above urban street.

- In addition, the research conducted a sensitivity analysis in choosing bus lane types when the main traffic volume and the number of passengers on bus change. The analysis showed that the exclusive bus lane is proper for conditions in which the main traffic volume is low and the number of passengers on buses is high (the area with yellow lines). In this area, the passenger travel time improvement depends heavily on the passenger numbers. When the main traffic volume increases, the areas suitable for priority lane cases (the blue area) and ordinary lane case (the area with violet lines) are shown as the above figure. Then, the dependence on the number of passengers in improving passenger travel time gradually switches to that on the main traffic volume.

7.2 Recommendations

- The research would like to analyze the advantages of bus priority lane in the aspect of city planning for bus operations. Calibrations of parameters as well as further analyses of the model are beyond the scope of this research. That should be dealt with by further studies. In
addition, the final results for exclusive bus lane in this research are applied only for short periods. For long periods, because of being congested caused by bus lane operation, auto drivers choose other routes or give up driving and take a bus to save travel time with respect to TDM policies. The area distribution in choosing bus lane type should be changed. Therefore, the bus lane policies would be appropriate for the lengthy travelers so that the auto drivers shift their modes or change their routes. Those are important points for next studies.

- To provide city planners with sufficient information for making decisions of what bus lane policy, a lengthy segment with a comprehensive investigation on factors such as bus schedule, tuning flow rate, effective distance between intersections, the awareness of drivers, etc. should be considered. In addition, not only in terms of travel time but also other aspects as specific geometrical conditions, convenience, safety etc are also necessary terms needed to be concerned and completed in future studies.

- Improving bus service and minimizing the negative impacts on other vehicles simultaneously are the essential targets in marking traffic policies. These targets can be obtained from the deployment of not only bus priority lanes, exclusive bus lanes but also bus signal priority system. Thus, focusing on studies about bus signal priority as well as combining the operations of bus priority lane and bus signal priority system is also a promising aspect for future works.

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