PERFORMANCE OF BUS LANES IN SEOUL
– Some Impacts and Suggestions –

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Bus travel in mixed traffic suffers from low speed and unreliability in Seoul. The Seoul Metropolitan Government has implemented a type of bus preferential treatment at most major arterials in Seoul since1996. That is, the reserved bus lane designated for bus use only by land and pavement markings and signs, but not by fixed physical barriers. Until 1996 bus use the most predominant travel mode in Seoul, however the share of bus trips decreased remarkably from 1990 to 1997 due to the fast growing subway supply and the increased number of private vehicles. However, after the regular bus lanes were extended, the bus service improved and thus, the buses again became the predominant travel mode since 1998.

In this paper, the performance impacts of reserved bus lanes in Seoul were evaluated and several suggestions for improving the effectiveness of the bus preferential treatment are proposed. The impacts of reserved bus lanes on both bus and auto performance were primarily measured by the relative speed changes of buses and autos and the average circulation rate of bus trips. Empirical results showed that the bus lanes were successful in improving average bus performance compared with other adjacent traffic. It was confirmed that right turning movement of the buses would cause the deterioration of bus speed in the curbside bus lanes. The average circulation rate of daily bus trips during the bus operation periods was somewhat increased by the bus lane introduction. A current warrant for reserved bus lanes in Korea was reviewed, and average bus speed during peak periods was proposed as a new warrant. In order to improve the effectiveness of the reserved bus lane, the type of lane markings in reserved bus lane, enforcement strategies for illegal parking in the bus lane and FIFO service at bus stops are discussed.

Key Words: Bus lane, Effectiveness, Warrant, Bus service

1. INTRODUCTION

A number of different bus priority schemes have been implemented in many urban areas around the world to offer priority treatment to bus movements along streets. The main objective of their implementation is to enhance bus attractiveness and improve travel time with respect to cars. In addition, bus priority schemes may also provide operating savings to transit operation, improve fuel efficiency, reduce energy consumption, and enhance air quality. Among bus priority schemes such as bus gate, bus malls, bus lanes, bus priority signals, etc., bus lanes are one approach utilized in many areas to deal with concerns related to traffic congestion and mobility. In some areas, bus lanes are serviced within traffic signal controls for providing priority to buses at signalized intersections. In recent years interest has grown for granting priority to buses at signalized intersections, but buses may still be involved in the general traffic flow, sometimes having to suffer heavy time losses when no dedicated bus lanes are reserved in those cases with heavier traffic.

The city of Seoul is over 600 years old and its size is 605 square kilometers, however, only 374.5 square kilometers are available for human activities. Since 10.6 million people reside in this small area, the population density is very high. Car-ownership in Seoul amounts to about 2.5 million in 2002; over 65% are private passenger cars. Private vehicles make up 27% of all the daily trips in Seoul. Furthermore, the inter-city private vehicle volume traveling between neighboring cities and Seoul has remarkably increased from 420,000 vehicles/day in 1996 to 2.45 million vehicle/day in 2002. Among the traffic volume, about 25% just pass through the city of Seoul. The current roadway network in Seoul is insufficient to sustain massive amounts of traffic volume and most arterial roads in Seoul are heavily congested throughout the day. It is, however, financially not feasible to build new roadways to an extent that will mitigate the traffic conditions in Seoul. All the above-mentioned causes aggravate traffic conditions all over Seoul.

Bus travel in mixed traffic suffers from low speed and the reliability in Seoul. The Seoul Metropolitan Government has implemented a type of bus preferential treatment first at an arterial in 1986 and at most major arterials in Seoul since 1996. That is, the Right Side Bus Lanes and Left Side Bus Lane designated for bus use only by pavement markings and signs, but not by fixed physical barriers. Currently, a total length of 218.4km of reserved bus lane is in service.

The impacts of bus lanes on performance of buses have been reported in several papers[1, 2, 3]. The performance of buses in conjunction with bus lane introduction are typically measured by the changes in bus speed, bus ridership, bus dwell time, journey time, fuel consumption and so forth. In general, bus speed was measured directly from a field survey, but other performance measures (e.g., delay) were obtained from simulations for base cases (i.e., before and after) and other scenarios such as parking and turning prohibition, changes in traffic signal timing, and vehicle types allowed to use bus lanes. TRANSYT-7F, a macroscopic simulation and signal-optimization model, has been used most popularly for the purpose of operational analysis of bus lanes on arterials, but the model has an inherent weakness to produce unreliable results when the degree of saturation approaches 100%[3]. In addition, previous studies have mainly analyzed the bus lanes in downtown areas. Rightly or wrongly, for the traffic analysts who know the limitations of simulation analysis, these results obtained from the simulator and the downtown areas may not be adequate to their needs.

The purpose of this paper is twofold. The first is to report the impact of reserved bus lanes implemented in arterials in Seoul. Changes in the performance of buses and other adjacent traffic in the same arterials were evaluated by using the data directly obtained from a field survey. The second is to discuss some suggestions for improving the effectiveness of preferential treatment for buses. This paper also presents new concepts for designing the bus lane warrant on arterial roads.

2. BACKGROUND OF BUS LANE INTRODUCTION IN SEOUL

Figure 1 shows arterials and bus lanes in Seoul. Most major arterials run radially toward the center of Seoul, so that over 25% of all vehicle trips are concentrated at the center of Seoul. Table 1 summarizes the changes of the reserved bus lanes implemented on the arterial roads in Seoul from the year 1993 to 2000. Bus lanes have been implemented on a massive scale since the middle of the1990s. Currently, the reserved bus lanes are operated at a total of 60 roadway sections and the average length of reserved bus lanes is about 3.64km/section. The bus lanes, with the exception of one roadway section, are located at the most right (i.e., curb side) lane. It should be noted that the average length of reserved bus lanes has decreased, while both the number of roadway sections hosting a bus lane and the total length of reserved bus lanes have increased.

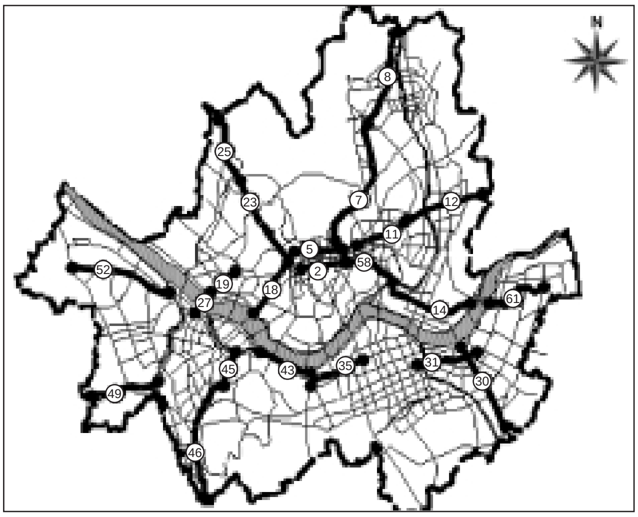

Fig. 1 Arterials and reserved bus lanes in Seoul

The reserved bus lanes are operated by a variety of service forms with respect to type of lane and service duration. The bus lanes are designated for bus use only by lane and pavement markings and signs, but not by fixed physical barriers. The bus lanes are marked by the color blue and there are two types, one is a solid line and another is a dashed line. The solid line is used for marking the roadway section where other vehicles are strictly prohibited from traveling in reserved bus lanes. The dashed line is used for the roadway section where other vehicles are allowed to travel in bus lanes. The dashed line marks the bus lanes located near signalized intersections and access to local roads and streets. Depending upon the hourly volume of buses, the bus lanes are in service during different times. The service duration will be explained

Table 1 Changes in the number of roadway sections and the total length of reserved bus lanes in Seoul

Categories	1993	1994	1995	1996	1997	1998	1999	2000	2001
Number of sections (Length, km)	10 (52)	24 (116)	39 (164)	59 (219)	63 (226)	62 (225)	61 (225)	60 (219)	60 (218)

Source: Seoul Metropolitan Government, 2002[4]

Table 2 Changes in overall average speeds of buses and cars on the major arterial roads in Seoul (unit: km/h)

Classification	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Cars	24.2	24.6	22.6	23.5	23.2	21.7	20.9	21.1	25.4	25.4	22.9
Buses	18.8	18.2	16.9	17.0	18.4	18.8	18.4	18.7	20.1	19.2	19.0

Source: Seoul Metropolitan Government, 2000[5]

in the next section.

Table 2 shows the changes in the average travel speeds of buses and cars on the major arterial roads in Seoul between the years of 1990 and 2000. It is noteworthy for understanding the results in the table that the speed values are the average of all arterials in Seoul, so if the speed measured from the roadway sections hosting the reserved bus lane were not counted, then the bus speed would be somewhat decreased, while the speed of motor vehicles increased. The results of Table 2 were obtained from the annual speed report published by the Seoul Metropolitan Government (2000). However, the speed data on individual arterial was not readily available for corresponding periods, so the average speeds of the two travel modes on roadway sections where the bus lanes were not implemented could not be estimated separately in this study. The average speed of buses decreased until 1992 and started to bounce back from 1993 when the Seoul Metropolitan Government extended the bus lanes to most major arterials in Seoul. The average speed of a bus was consistently lower than that of a car.

Table 3 summarizes the number of bus routes and the number of buses registered in Seoul. The number of buses has not changed much during the last 10 years. However, the number of bus routes was remarkably reduced between 1997 and 2002. The bus routes that were overlapped with other bus routes and subway lines have been deleted. Thus, the reduction of bus routes does not have a negative impact on the bus service, rather improves the overall economy of bus companies.

Table 3 Numbers of bus routes and buses registered in Seoul

Categories	1990	1997	2002
Number of bus routes	379	425	376
Number of buses registered	8,293	8,228	8,228

Source: Seoul Metropolitan Government, 2002[4]

Figure 2 shows the changes in the share of travel modes in Seoul[6]. In case of subway trips, a transfer among different subway lines was counted as an independent trip. Buses have been the most predominant travel mode in Seoul until 1996, however the share of bus trips was remarkably decreased from 1990 to 1997 due to the fast growing subway supply and the share of private vehicles. In 1997, the subway carried 30.8% of the daily trips and then it became, temporarily, the most predominant travel mode. However, after the bus lanes were implemented, the average bus travel speed increased 16% for inbound journeys and 23% for outbound journeys and thus, the buses again became the predominant travel mode since 1998 in Seoul.

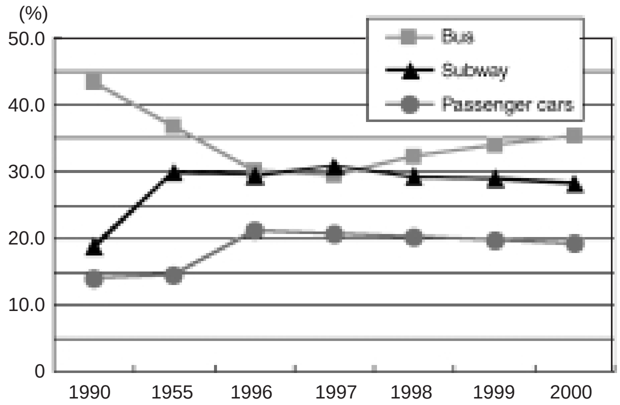

Fig. 2 Changes in the share of travel modes for the daily trips in Seoul (unit: %)

3. NEW CONCEPT FOR BUS LANE WARRANT

The main purpose of preferential treatment of buses in Seoul is to increase the reliability of the bus service. To do this, the curbside lane is designated for bus use on the roadway sections that have at least 3 lanes in each direction. Currently, the bus lane is justified when the hourly bus volume is between 60 and 120 for the time periods from 7 a.m. to 10 a.m. and 5 p.m. to 9 p.m. during weekdays and the time period from 7 a.m. to 10 a.m. on Saturday. When the hourly bus volume exceeds 120, the bus lane will be warranted for the time period from 7 a.m. to 9 p.m. However, the bus lane cannot be maintained if the hourly bus volume is less than 60.

Previously, the Seoul Metropolitan Government had required at least 1,800 passengers per hour for the bus lanes at Right Side Bus Lanes and 4,500 passengers per hour for an exclusive Left Side Bus Lane. However, these requirements had not been actually applied for reserving the bus lane in Seoul, since it was extremely hard to measure the number of persons carried by buses in the field. Due to this, the Seoul Metropolitan Government has required the bus lane warrant that is developed based on hourly volume of buses traveling on the roadway sections of intent. However, this warrant is not reasonable. The main reason for this is that if roadway traffic conditions are getting worse, the travel speed of buses will be decreased so that the hourly bus volume will be decreased. Consequently, it seems that the worse the roadway traffic conditions the lower the bus volumes and the fewer the bus lanes. As shown in Table 2, the average bus speed decreased between 1998 and 2000. During the same period, as can be seen from Table 1, the reserved bus lanes on two roadway sections were actually deleted according to such a warrant.

In order to improve the reliability of the bus service, the preferential treatment of buses must be maintained. When buses carry as many people as motor vehicles, a lane should be reserved for bus use only, since the buses have a much higher occupancy than private motor vehicles. In this light, the warrant of bus lanes can be strengthened by taking into account the relationship of the number of persons carried by buses versus those carried by motor vehicles. The warrant is obviously more conservative than the current warrant.

To fulfill two requirements, one for the hourly bus volume and another for the number of persons carried by buses, the following warrant has been proposed by previous research[7]:

$$V_b \geq \frac{V_a}{N-1} X \tag{1}$$

where V_a and V_b are hourly volumes of motor vehicles and buses, respectively; N is the total number of lanes in each direction; and X is the ratio of average motor-vehicle-passenger to bus-passenger occupancies. However, as mentioned above, this warrant is not appropriate for practical purposes since it was extremely hard to check the number of persons carried by buses and motor vehicles in the field.

It is desirable to favor public transit over car travel due to the basic role of public transport in the city. Considering the limitations of the existing warrants for the bus lane, a reasonable level of average bus speed is proposed as the warrant in this study. The rationale of this warrant is that it is necessary for improving the reliability of the bus service to maintain the bus speed at a reasonable level. Under traffic conditions where the bus speed is lower than a certain level, for example 10km/h, it may be impossible to induce private transit to use public transport.

This paper suggests that the reasonable level of bus speed should be higher than the speed of motor vehicles during peak periods, but not necessarily higher than that during non-peak periods. To determine the bus speed level, the arterial's level of service concept was used in this study. Arterial's level of service is determined based on the average travel speed for the segment, section, or entire arterial under consideration. The average travel speed is strongly influenced by the number of traffic signals per kilometer and the average intersection delay. In urban areas, arterial's level of service can be substantially degraded by inappropriate signal timing, poor progression, local-access traffic, vehicle's turning movements, and increasing traffic flows. It should be noted that arterial's level-of-service D will probably be observed even before substantial intersection problems, and even poor arterial level-of-service values are not far behind arterial level-of-service D[8]. Therefore, in order to enhance bus attractiveness and improve its competitiveness with respect to the auto, it seems to be desirable to maintain the bus speed being higher than the average travel speed at arterial level-of-service D.

In both the US and Korean *Highway Capacity Manuals* (*HCM*), there are three arterial "classes" that are described in terms of the street's function and its design. The average travel speed for a specific arterial at level-of-service D can be obtained from the HCM procedure. In this paper, average bus speed during peak periods is proposed as a new warrant for reserved bus lanes. Thus, if the bus speed is lower than the average travel speed on the arterial interested at level-of-service D during the peak periods, then the reserved bus lane will be introduced. It is noteworthy that the bus speed can be obtained from a number of sources, including local data and validated simulations.

4. EMPIRICAL ANALYSIS OF BUS PERFORMANCE

The reserved bus lane is a type of bus preferential treatment. In this paper, the bus preferential treatment is focused on the purpose of improving bus travel by reducing conflicts between buses and other vehicles. Thus, the impacts of reserved bus lanes were measured by the changes in the following two parts: 1) average travel speeds of bus and cars and 2) average circulation rate of daily bus trips.

Someone may be interested in the changes in the total number of passengers carried by buses and the revenue of bus companies. The changes in the share of buses, passenger cars, and subways in Seoul can explain the change in the total number of passengers carried by buses. The changes in the share of travel modes in Seoul are presented in Figure 2. The change in the revenue of bus companies is highly related to the bus fare and the number of bus passengers. The bus fare has been changed several times for the last 10 years. Furthermore, passengers who transferred between bus and subway within the specific time period (e.g., 30 minutes) have an advantage in discounting the fares of the two travel modes, so it is extremely difficult to estimate bus revenue reasonably well. Due to these reasons, the changes in the total number of passengers carried by buses and the revenue of bus companies were not analyzed in this study. It should be noted that the investigation for mode and route shifts was beyond the scope of this study.

4.1 Average travel speed of buses

In order to check whether the bus speed improved by implementing bus lanes, the travel speeds of buses and motor vehicles was measured. To do this, two methods were used. The first method compared the average speeds of buses and motor vehicles traveling on the roadway sections hosting the bus lanes with those of buses and motor vehicles on a total of 21 arterials in Seoul. The second method compared the average speed of motor vehicles traveling in the bus lane with that of motor vehicles traveling in adjacent lanes on the same roadway section during the same time period on two arterials. Motor vehicles may be appropriate for checking the traffic condition in reserved bus lanes rather than the bus itself, since a motor vehicle does not necessarily experience a delay at every bus stop for boarding services. Therefore, the results emanating from the second method may be useful for analysts to check whether travel conditions in bus lanes are really far more improved than adjacent lanes on the same roadway section.

The average speeds of buses and motor vehicles traveling on 21 roadway sections implemented by the reserved bus lanes were measured by a floating car method during the service time periods of bus lanes for the three weekdays from June 20 to June 23 in 2000. The results are summarized in Table 4. It should be noted that the results in the table were measured for only one travel direction (i.e., outbound from downtown). In the table, Section 61 has Left Side Bus-Only Lane and the other sections have Right Side Bus Lane.

In Table 4, if the ratio of bus speed to car speed is greater than 1.0, the average speed of buses will be higher than that of motor vehicles and vice versa. It should be noted that dwell time of buses at bus stops, time lost in acceleration/deceleration, travel times at cruise speed, and delay at traffic signals were taken into account for estimating the bus and car speeds in the table. It is reasonable to assume that both buses and cars would experience the same amount of delay due to traffic signals, but would not take the same amounts for other times. Since buses are delayed at every bus stop for passengers' boarding, the cruising speed of buses is not always lower than that of cars, even though the ratio of the bus speed to car speed is less than 1.0. In other words, the bus speed on the reserved bus lane should not be always higher than the car speed, and the bus lane does not necessarily guarantee the average bus to maintain a higher speed than the car speed. In this light, we have to understand that the average bus speed could be lower than the average car speed on the reserved bus lanes.

The bus speed is greater than the car speed on 8 sections among a total of 21 sections. Most of the bus speeds on the eight sections are greater than 20km/h, and the bus speeds of Sections 2, 43, and 46 are much greater than the car speeds. More specifically, the car speeds on Sections 2, 43, 45, 46, and 58 are in the range of 15.9 – 17.5km/h, while the bus speeds are between 20.4 and 25.6km/h. These results do provide evidence that the bus lane was successful in improving average bus performance compared with the adjacent traffic.

The average speed of buses is lower than that of motor vehicles on 13 sections. In fact, there are many factors to reduce the average bus speed. These include dwell time at bus stops, time lost in acceleration/deceleration, delay at traffic signals, vehicles' turning movements, local access traffic, illegal on-street parking, mixed traffic in the reserved bus lane marked by the dashed line, and so forth. However, some factors are not controllable and may produce adverse consequences. For example, the dwell time at the bus stop is absolutely dependent upon the bus ridership, but it can be increased by the bus lane introduction, so that the dwell time will be increased. Due to the limitation of data available for analysis, this study has intensively investigated the influence of two relevant factors. The first is associated with bus turning move-

Table 4 Average travel speeds of bus and cars, number of turning bus routes, and hourly bus volume on the reserved bus lanes

Section Number	Length (km)	Number of Lanes (each direction)	Average Speed (km/h)		Ratio of Bus/Car	Number of Turning Bus Routes		Number of Turning Bus Routes Per km		Bus Volume (buses/hr)
			Bus	Car		Right	Left	Right	Left	
2	3.2	3	24.9	16.1	1.55	0	11	0	3.4	166
5	4.5	4	14.3	16.3	0.88	20	7	4.4	1.6	359
7	10.8	3~4	20.1	25.0	0.80	6	24	0.6	2.2	254
8	4.0	3~4	25.9	33.1	0.78	2	0	0.5	0	189
11	4.1	3	12.4	26.1	0.48	16	15	3.9	3.7	342
12	5.6	3	19.2	28.4	0.68	12	17	2.1	3.0	286
14	4.1	3	18.8	20.2	0.93	5	6	1.2	1.5	109
18	3.7	3~4	9.9	20.0	0.50	16	4	4.3	1.1	251
19	2.6	3~4	15.6	18.5	0.84	12	12	4.6	4.6	263
25	3.8	3	19.0	19.8	0.96	1	1	0.3	0.3	126
27	1.1	3	29.0	25.1	1.16	0	0	0	0	122
30	6.3	4~5	19.4	22.4	0.87	7	14	1.1	2.2	245
31	5.2	4~5	26.0	34.2	0.76	6	0	1.2	0	211
39	3.6	3	10.6	12.8	0.83	14	9	3.9	2.5	285
43	9.0	3~4	25.6	17.5	1.46	10	20	1.1	2.2	303
45	4.5	3~4	20.4	15.9	1.28	9	7	2	1.6	N.A
46	6.8	5	24.3	17.2	1.41	11	13	1.6	1.9	186
49	12.6	3~4	22.9	21.7	1.06	9	8	0.7	0.6	198
52	3.8	4	25.3	29.1	0.87	2	0	0.5	0	224
58	3.9	3	17.5	13.2	1.33	5	12	1.3	3.1	127
61	4.5	5~6	31.8	29.7	1.07	9	0	2	0	193

ments on the reserved bus lane. The second is related to two types of bus lane markings (i.e., solid and dashed lines). For the other factors, a brief discussion will be provided in the next section.

With respect to the impact of turning movements on traffic performance, it has been reported that modifications to left-turn movements (introduction of exclusive left-turn lanes and prohibition of left-turn movement) in Bay Street in downtown Toronto would have a minor impact on both bus adjacent through traffic performance[3]. However, it should be noted that there are two lanes in each direction and two over-lapping bus routes, a main route supplemented by a short turn route during morning and evening peak periods, in Bay Street. In addition, the traffic and roadway conditions in Bay Street are quite different from the arterials in Seoul, so it is necessary to check the impact of vehicles' turning movements on both bus and adjacent traffic performance on arterials in Seoul. To do this, this study has examined the impact of only bus turning movements on both bus and adjacent traffic performances, since the data on turning movements of the adjacent traffic were not readily available for the corresponding period of other available data used in this study.

Table 4 shows the number of bus routes, which have right-turn and left-turn movements at signalized intersections along each bus-lane section. By dividing the numbers of right- and left-turn bus routes by the length of each section, the average numbers of turning bus routes per km of each section were calculated. The results are provided in the same table. In addition, the average hourly bus volumes are also presented in the table. It is noteworthy that all bus-lane sections in Seoul have reserved one lane for bus use, but motor vehicles are allowed for traveling in the reserved bus lane marked by a dashed line.

Among the thirteen sections where the ratio of bus speed to car speed was lower than 1.0, Sections 5, 11, 18, 19, and 39 have more than three bus routes pertaining to right turning movements per km and have more than 250 buses per hour. Again in Table 4, the bus speeds of sections 18 and 39 are around 10km/h and those of Sections 5, 11, and 19 are lower than 16km/h, while the bus speeds of the other eight sections (i.e., sections 7, 8, 12, 14, 25, 30, 31, and 52) are in the range of 17.5 – 26km/h. On Sections 2 and 27 where there is no right-turn bus route, the bus speeds are 24.9 and 29km/h, respectively. Overall, right-turn movements of buses would cause the deterioration of bus speed.

Most of the arterials in Seoul consist of 3 to 4 lanes in each direction, so left-turn movements of bus routes would have strong impacts on adjacent traffic. Again in Table 5, sections 2, 11, 19, and 58 have more than three bus routes pertaining to left turning movements per km. With the exception of section 11, the car speeds of these sections are below 20km/h as shown in Table 4. In contrast, the bus speeds on Sections 8, 27, 31, and 52 where there is no right-turn bus route are in the range of 25.1 – 34.2km/h. It is very clear that the car speed in the adjacent lanes tends to decrease when the left-turn movements of buses are involved. Therefore, based on the above-mentioned results, it can be said that turning movements of buses on the arterials hosting the reserved bus lane in Seoul would cause the deterioration of the performance of both buses and adjacent through traffic.

According to the second method for measuring the bus and car speeds, the average speed of motor vehicles traveling along the bus lane were measured on two consecutive roadway sections, 18 and 49 in Table 4. Section 18 is the 3 to 4-lane (each direction) roadway section and consists of a street and a bridge over the Han River, and Section 49 is the 3 to 4-lane (each direction) roadway connecting Section 18 toward a neighboring city. The total length of the two sections is 16.3km. In Section 18, the motor vehicles, testing cars, traveled along the entire length of the reserved bus lane at an average speed of 19.3km/h, while the other motor vehicles traveled at 20.0km/h in the adjacent lanes. The difference between the two speeds is very small, but it is interesting that the car in the bus lane did travel at the same speed level. Frankly speaking, it was expected that the car in the bus lane would travel somewhat faster than the car in adjacent lanes. There is a possible reason for explaining this. In Section 18, there are only two bus stops, so the test cars could not enjoy the bus preferential treatment, although they traveled in the bus lane. In contrast, the testing cars traveled in Section 49 at an average speed of 35.5km/h in the bus lane, while the other motor vehicles traveled at 21.7km/h in the adjacent lanes. It is noteworthy that a bus traveled in the same section at an average speed of 22.9km/h as shown in Table 4. In fact, due to the relatively low cruise speeds and low acceleration/deceleration rates of the buses compared with motor vehicles and because buses experienced longer dwell times, the buses took more time to travel the same distance than the cars in the bus lane. The above observations of car speeds in the reserved bus lane are very encouraging.

Table 5 presents the field survey results for the reserved bus lanes introduced in major arterials in Seoul by the type of line markings. As noted earlier, there are two types of bus lane markings (i.e., solid and dashed lines) in Seoul. Cars are permitted to use the bus lane marked by the dashed line, but they are strictly prohibited from traveling in the bus lane marked by the solid line. There, it can be expected that the bus performance could not be improved in the bus lanes marked by the dashed line as much as another type of bus lane.

In Table 5, Section 27 has Right-Side Bus-Only lane and Section 61 has Left- Side Bus-Only Lane. The reserved bus lanes of the two sections were entirely marked by the solid line. Section 27 is 3-lane (each direction) bridge over the Han River, and Section 61 is 5 to 6-lane (each direction) arterial that directly connects the downtown and the eastern region in Seoul. The left turning movements of both buses and cars were not permitted on these sections, but the right turning movements of buses were allowed in Section 61. The average bus speeds of the two sections are relatively greater than those of the other sections.

The bus lanes along Sections 2, 5, 43, 45, 49, and 58 were intermittent, while the bus lanes along the other sections were continuous. Sections 5 and 58 did not reserve the bus lane for the section length of 0.1 and 0.2km, respectively. Notwithstanding these values are relatively very small compared with the other intermittent bus lane sections, the bus speeds of the two sections are much lower than those of Sections 2, 43, 45, and 49. However, the bus speeds of all intermittent bus lane sections are higher than the car speed, with the exception of Section 5. As noted earlier, heavy right-turn movements of buses would cause the decrease of bus speed on Section 5. The above results indicate that the intermittent bus lane would not cause the decrease of the bus lane effect.

With the exception of Sections 27 and 61, the solid line and the dashed line were not continuous. In other words, the two types of line markings were intermittent along the sections where the reserved bus lanes were both continuous and intermittent. In addition, the lengths of solid lines and dashed lines were not constant. Due to these facts, the impacts of two types of bus lane markings and the ratio of the two lines on bus performance could not be identified in this study. However, Table 5 shows that the bus speed is greater than car speed on the

Table 5 Survey results for the bus lanes by the type of line markings and average speeds of bus and cars

Section Number	Length (km)	Number of Lanes (each direction)	Average Speed (km/h)		Solid Line Marking		Dashed Line Marking		No Line Marking	
			Bus	Car	%	km	%	km	%	km
2	3.2	3	24.9	16.1	12	0.4	62	2.0	26	0.8
5	4.5	4	14.3	16.3	43	1.9	54	2.4	3	0.1
7	10.8	3~4	20.1	25.0	52.3	5.6	47.7	5.2	-	-
8	4.0	3~4	25.9	33.1	10	0.4	90	3.6	-	-
11	4.1	3	12.4	26.1	39.6	1.6	60.4	2.5	-	-
12	5.6	3	19.2	28.4	21	1.2	79	4.4	-	-
14	4.1	3	18.8	20.2	16	0.7	84	3.4	-	-
18	3.7	3~4	9.9	20.0	41.8	1.5	58.2	2.2	-	-
19	2.6	3~4	15.6	18.5	9.5	0.2	90.5	2.4	-	-
25	3.8	3	19.0	19.8	6.3	0.2	93.7	3.6	-	-
27	1.1	3	29.0	25.1	100	1.1	-	-	-	-
30	6.3	4~5	19.4	22.4	51.3	3.2	48.7	3.1	-	-
31	5.2	4~5	26.0	34.2	80	4.2	20	1.0	-	-
39	3.6	3	10.6	12.8	15	0.5	85	3.1	-	-
43	9.0	3~4	25.6	17.5	20	1.8	55	5.0	25	2.3
45	4.5	3~4	20.4	15.9	13	0.6	57	2.6	30	1.4
46	6.8	5	24.3	17.2	32	2.2	68	4.6	-	-
49	12.6	3~4	22.9	21.7	10	1.3	72	9.1	18	2.3
52	3.8	4	25.3	29.1	44.9	1.7	55.1	2.1	-	-
58	3.9	3	17.5	13.2	17	0.7	78	3.0	5	0.2
61	4.5	5~6	31.8	29.7	100	4.5	-	-	-	-

sections where the proportion of dashed lines is much greater than that of solid lines. From this observation, we can presume that car drivers tend to use adjacent lanes rather than the bus lanes regardless of the type of bus line markings where they travel the roadway sections hosting the reserved bus lanes. Interestingly enough, most car drivers are not willing to travel along with the buses along the bus lane although they can save a little on their travel time if they use the bus lane.

4.2 Average circulation rate of bus trips

In order to assess the impact on bus operation, the average circulation rate of bus trips was surveyed for the buses traveling on Sections 8, 25, 27, 45, and 52. The average circulation rate of a bus trip is defined as the number of round trips that each bus has traveled along its route during the period of daily operation. Here, the bus will complete one circulation when the bus starts from the origin of its bus route and returns to the origin. This can be calculated by the total number of bus trips, summed over all buses of each bus route traveled, divided by the total number of buses on the bus route. The results are presented in Table 6. A total of 20 bus routes were surveyed. Among the five sections, the average circulation rates of the buses traveling on the roadway sections 25 and 52 were reduced by 2.8% and 4.1%, respectively, compared with those of the year 1995. In contrast, the average circulation rates of the buses on the other three roadway sections increased by 5.3%. It is noteworthy that the average circulation rate of overall bus trips in Seoul has increased by about 8% in the year 2000.

Again in Table 6, it can be seen that the average bus speeds of Sections 25 and 52 decreased between 1995 and 2000. Contrasting with these two sections, the average bus speeds of Sections 8, 27, and 45 increased during the same period. It seems that the circulation rate of bus trips is closely related to the bus speed. In this light, it can be assumed that if the bus lanes were not implemented on Section 25 and 52, the bus speeds of these two sections would be further decreased. Therefore, consequently, the circulation rates of buses traveled on the sections would be less than those of Table 6. Although the results in the table may not be enough to strongly support the conclusion such that the bus lane does definitely improve the bus operation, it can be accepted that the bus

Table 6 Changes in the average circulation rates of bus trips traveling in the bus lanes

Section Number	1995			2000		
	Bus speed	Car speed	Circulation rate	Bus speed	Car speed	Crculation rate
8	20.9km/h	29.4km/h	7.10	25.9km/h	33.1km/h	7.45
25	21.2	21.4	6.45	19.0	19.8	6.20
27	25.3	27.2	5.48	29.0	25.1	5.78
45	17.1	14.5	4.83	20.4	15.9	5.11
52	26.3	30.5	6.40	25.3	29.1	6.20

lane has a positive role of improving bus frequency.

5. SOME SUGGESTIONS FOR IMPROVING BUS LANES

5.1 Increase bus only lanes and reduce bus lanes allowing other vehicles

As reviewed in the preceeding section, the reserved bus lanes in Seoul are two types, one is a solid line and another is a dashed line. In the bus lane marked by the solid line, private vehicles are strictly prohibited from traveling in the regular bus lane. The private vehicles are allowed for traveling in the regular bus lanes marked by the dashed line only. Therefore, it can be expected that the cruise speed of buses in the solid line is greater than that of the dashed line. Consequently, the regular bus lane marked by the solid line should increase in order to improve the bus speed.

As reviewed earlier, due to the fact that each bus lane is in service under different traffic and roadway conditions, it is not reasonable to simply compare the bus speed to the ratio of the length of solid line to that of dashed line in each bus lane. However, based on the results of Table 5, it can be said that the proportion of solid lines in reserved bus lanes in Seoul is too low. Currently, the overall proportion of solid lines in the reserved bus lanes in Seoul is less than 40%. It is, therefore, necessary for improving the bus speed to establish the basic requirements for marking the dashed line in the reserved bus lane.

For practical purposes, how long the solid line is continuously maintained in the reserved bus lane may be more important than the ratio of the length of the solid line to that of dashed lines. However, there are many restrictions to prolong the solid line, since the bus lanes are located near signalized intersections and access to local roads and streets should be allowed for use by other vehicles. One possible way to mitigate this problem is to control the access traffic in the reserved bus lane. To do this, locations of bus stops and accessibility of local traffic would be rearranged. Depending on the location of bus stops, the feasibility of the access control of local traffic in the reserved bus lane would be determined.

5.2 Strong enforcement of illegal on-street parking in bus lanes

The illegal on-street parking in the reserved bus lane may be the most serious problem that needs to be solved for improving the bus service. There are two reasons for the occurrence of illegal parking in the bus lane. The first reason is associated with the width of the bus lane. Usually, the bus lane at bus stops is relatively wider than the adjacent lanes. This is to provide convenient maneuvering for buses. However, private vehicles have often abused the space for illegal parking.

The second reason is that enforcement has mainly focused on vehicles illegally traveling in the bus lane marked by the solid line rather than vehicles illegally parking within the bus lane. The Seoul Metropolitan Government has implemented automatic vehicle enforcement facilities at many locations in the reserved bus lanes marked by the solid line. Besides, manual enforcement is performed in the field. However, these efforts seem to be inefficient for improving the bus service, since such enforcements have always been performed at the same locations during the same time periods so that car drivers are able to avoid the enforcements. In fact, the number of illegal vehicles detected by the enforcement has steadily decreased, while the illegal on-street parking in the regular bus lane is significant in Seoul. Therefore, in order to improve the effectiveness of reserved bus lanes, strong enforcement for vehicles illegally parking within the bus lane is essentially required, especially during the high peak use period of the bus lane service.

5.3 First-In-First-Out service at the bus stop

Another problem that should be considered for improving the bus service in Seoul is traffic weaving in the bus lane. Whenever there is a queue of more than four buses at the bus stop, the buses do not properly service at the location designated for passengers' boarding, so that boarding service often occurs at several locations in the bus lane. As a consequence, bus travel suffers from severe weaving in mixed bus traffic during the peak period.

If the buses do service in order of their arrival, usually called "first in, first out" or FIFO, then the weaving problem in the bus lane will disappear. Therefore, in order to apply the FIFO discipline for passengers' boarding service, we have to make the bus stop such that a newly arrived bus cannot leave before other buses. To do this, the newly arrived bus should only be allowed to open the rear door to let off passengers until the bus is the first in the queue. Then the bus will be allowed to open the front door to board passengers when the bus is the first in queue. This queue discipline would be inconvenient for passengers, since passengers waiting to board a bus might appear to board in an order which has no relation to the order in which they arrive so that their waiting time to board would be somewhat increased. However, if the buses are to be operated according to the FIFO queue discipline, the level of congestion at the bus stop can be greatly improved.

6. CONCLUDING REMARKS

The impacts of reserved bus lanes were evaluated and several suggestions for improving the effectiveness of the bus preferential treatment were proposed. The bus lane is a type of bus preferential treatment. In this paper, the bus preferential treatment is focused on the purpose of improving bus travel by reducing conflicts between buses and other vehicles. Thus, the effectiveness of the reserved bus lane was primarily measured by the relative speed changes of buses and cars and the average circulation rate of bus trips. Besides, the change in the daily trip share of various travel modes was reviewed.

The reserved bus lane has positive impacts on the bus performance in terms of average travel speed, and the significance of performance improvement was dependent upon right turning movements of the buses and the type of bus lane markings in reserved bus lanes. Furthermore, if we consider the fact that buses are delayed at every bus stop for passengers' boarding service, the results for bus speeds presented in this paper are very promising for justifying the reserved bus lane as a public transportation strategy to balance public and private transport.

It was confirmed that the circulation rate of bus trips is closely related to bus speed. Although the results presented in this paper may not be enough to strongly support the conclusion that the bus lane does definitely improve bus operation, it can be accepted that the bus lane has a positive role for improving the bus service.

The warrant for the reserved bus lane in Korea was reviewed. It is desirable to favor public transit over car travel due to the basic role of public transport in the city. Considering the limitations of the existing warrants for the bus lanes, this paper has recommended the use of a reasonable level of average bus speed during the peak periods for the bus lane warrant. The rationale of this warrant is to maintain the bus speed at a reasonable level in order to improve the reliability of the bus service.

In order to improve the effectiveness of the reserved bus lane, the type of lane markings in the bus lane, the enforcement strategies for illegal parking in the bus lanes, and FIFO service at the bus stop were discussed. Firstly, the bus lane marked by the solid line should increase in order to improve the bus speed. Secondly, strong enforcement for vehicles illegally parking in reserved bus lanes is required, especially during the peak period of the bus lane service. Finally, buses should be served in order of their arrival, usually called "first in, first out" or FIFO, in order to avoid a weaving problem in the bus lane.

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