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A STUDY ON SETTING-UP A METHODOLOGY AND CRITERION OF EXCLUSIVE BUS LANE IN URBAN AREA

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Abstract: To ease traffic congestion in urban area exclusive bus lane has been operated by means of transportation demand management strategy. However, because criterion of bus-only lane is not defined clearly, this strategy has been used indiscreetly. The purpose of this study is setting-up a methodology and criterion of exclusive bus lane using the point that makes the travel times between bus and automobile equal after operating it. This point is regarded as traveler equilibrium. If we find these criteria and use those effectively, we anticipate improving availability of bus and decreasing traffic congestion ultimately by deploying the exclusive bus lane. To perform this study, we use the traffic simulation package, NETSIM, and review real two areas such as Kangnamdaero, or the Kangnam Road in southern Seoul and Sejongro/Taepyongro in northern Seoul. As a result, it is analyzed that the exclusive bus lane is useful only above particular points that correspond to specific total traffic volume and bus volume. But this study has some limitations that bus lane is operated only on median lane and the number of sample area is small. So this aspect needs to be considered later.

Key Words: Exclusive bus lane, Criterion, User equilibrium, NETSIM, Simulation

1. INTRODUCTION

1.1 Backgrounds and Purposes

The exclusive bus lane that gives a right-of-way to buses out of many supporting policies to public transit has been deployed in many countries. But exclusive bus lane has not always same positive outcomes under diverse realistic circumstances including traffic and road conditions. Because the roads on which exclusive bus lane is constructed have many differences in the aspects of diverse conditions such as signals, volume, number of buses, number of lanes, and so on, it is the time to have a desirable establishment standards for

exclusive bus lanes to operate efficiently.
And also, since Seoul City, Korea, has deployed bus-exclusive median lane system this year (2004), there have been some debates that it is insufficient of standards of deployment and method.
Therefore this study has an object to suggest establishment standards for exclusive bus lanes after analyzing the effectiveness changes of exclusive bus lanes under diverse traffic conditions using the microscopic simulation model, NETSIM.

1.2 Scopes and Methods

Because we want to suggest establishment standards for exclusive bus lanes in the metropolis network, we perform this study after selecting realistic roads on which can be constructed exclusive bus lane and have large volumes, many bus service routes out of networks
For the this purpose, we use the real data(Table 1) in Kangnamdaero, or the Kangnam Road in southern Seoul and Sejongro/Taepyongro in northern Seoul and analyze these data using the microscopic simulation model, NETSIM.
Section 2 deals with the present conditions of exclusive bus lane and reviews the existing theoretical methods on bus priority systems and establishment standards. Section 3 sets the standards and approach methods for establishment standards of exclusive bus lane. Section 4 analyzes the effectiveness changes before and after deployment of exclusive bus lane according to bus volume after describing the collected data and network organization. The average travel time is used as a measure of effectiveness in this analysis. Also, for the analysis of exclusive bus lane and the derivation of establishment standards, we suggest the road sections in which can be improved in average travel time comparing the changes before and after deployment of exclusive bus lane according to the changes of ratio between bus and car volumes. Section 5 summarizes this study and suggests some possible policies, further studies and its applications.

Table 1. Analysis object and Criteria by Scenario

Classification	Volume	Bus Volume	Type of Exclusive Bus Lane	MOE		
				Travel Time	Speed	Congestion Time
Kangnamdaero	Veh/hr	Veh/hr	Median	sec	m/sec	Sec
Sejongro/Taepyongro	Veh/hr	Veh/hr	Median	sec	m/sec	Sec

2. LITERATURE REVIESWS

2.1 Existing Establishment Standards for Exclusive Bus Lane

1) Standards in Korea

(1) General Standards

The domestic establishment standards for exclusive bus lane are present using the bus volumes and number of passengers and these standards are presented below.

Table 2. The Existing Criterion for Exclusive Bus Lane

Classification	Bus Volume	Passenger	Type of Exclusive Lane
3-lane (one way)	Above 60veh/hr	Above 1,800per/hr	Roadside Exclusive Lane
	Above 100veh/hr	Above 3,000per/hr	Roadside Exclusive Lane Backward Exclusive Lane
	Above 150veh/hr	Above 4,500per/hr	Center-Lane Exclusive Lane Provide Passing lane over bus-stop
4-lane (one way)	Above 100veh/hr	Above 3,000per/hr	Roadside Exclusive Lane Provide Passing lane
	Above 150veh/hr	Above 4,500per/hr	Center-Lane Exclusive Lane Provide Passing lane

2) Standards in Foreign Countries

The establishment standards for exclusive bus lane have been suggested considering the bus volumes and number of passengers in foreign countries. In America, the standards require the minimum 30~40 bus vehicles per hour and 1,200~1,600 passengers in the buses per hour. In Baltimore City, the bus-only lane can be deployed only when the bus passengers during peak period is over bus passengers per lane except exclusive bus lane. In Britain, the standards require the minimum 50 bus vehicles per hour and 2,000 passengers in the buses per hour.

Table 3. The Criterion in Foreign countries

Classification	Type	Minimum Criteria	
		Volume	Passenger
USA (UTMA)	Roadside	30~40veh/hr	1,200~1,600 per/hr
	Backward	40~60veh/hr	1,600~2,400 per/hr
	Center-lane	60~90veh/hr	2,400~3,600 per/hr
Britain(TRRL)	-	50veh/hr	2,000 per/hr
USA (Baltimore)	$G_2 \geq \frac{G_1}{N-1} \times X$ G1 : Total volume per hour G2 : Bus volume per hour N : No. of Lanes (one way) X : passenger on vehicle/passenger on bus		

3. SETTING THE METHOD FOR ESTABLISHMENT STANDARDS

3.1 UE in Traffic Networks

The UE (User Equilibrium) can be achieved when the travel cost equals among all the used routes in the networks. This principle on UE can be applied to the assessment of exclusive bus lane. If we consider exclusive bus lane and general lane as two routes having the same OD, we can suppose that the point which makes travel cost of two routes equal can be an optimum state that two routes achieve equilibrium. So, we want to suggest the establishment standards by assessing whether the traffic and road conditions including total volume and bus volume can meet the UE of two routes after deploying exclusive bus lane

This equilibrium state between general lane used by only cars and exclusive bus lane used by only buses is showed below. The following figure represents the relationship between equilibrium travel time and equilibrium travel demand of cars and buses. The monotonic increasing function starting from the left side corresponds to travel cost function of cars and the monotonic increasing function starting from the right side corresponds to travel cost function of buses.

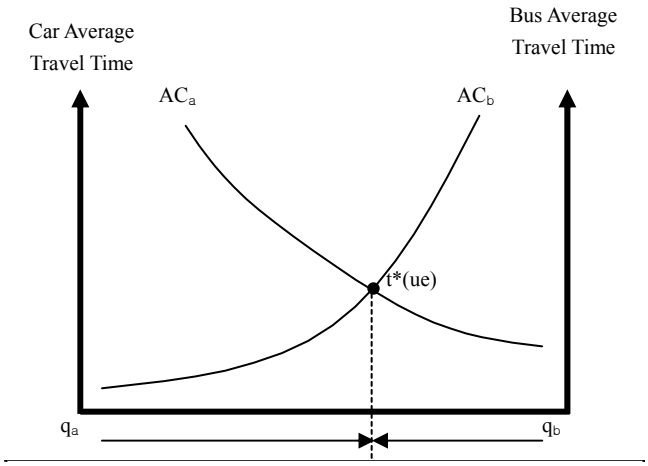

Figure 1. User Equilibrium of Network

The equilibrium travel cost between two modes is determined at the point (t^* (UE)) that the AC curves of bus and car intersect and the equilibrium flow of car and bus is $q_a(ue)$ and $q_b(ue)$ respectively. At this time, we suppose that travel cost consists of travel time only. This study suggests the desirable road section for exclusive bus lane in which the travel time of bus keeps lower to that of car considering the point (t^* (UE)) which makes the travel time of bus and car equal.

3.2 Setting the Method for Establishment Standards

We need to examine the increasing functions of travel time that each mode makes to meet the establishment standards for exclusive bus lane according to the UE. Because the increasing pattern of travel time is different from each other according to the characteristic of two modes, there is an equilibrium point that makes the travel time equal. The difference of travel time between two modes is depicted like following figure. A point of intersection between two graphs can be regard as total volumes in the following graph. And then, the travel time of two modes at this point is equal, which satisfy the UE.

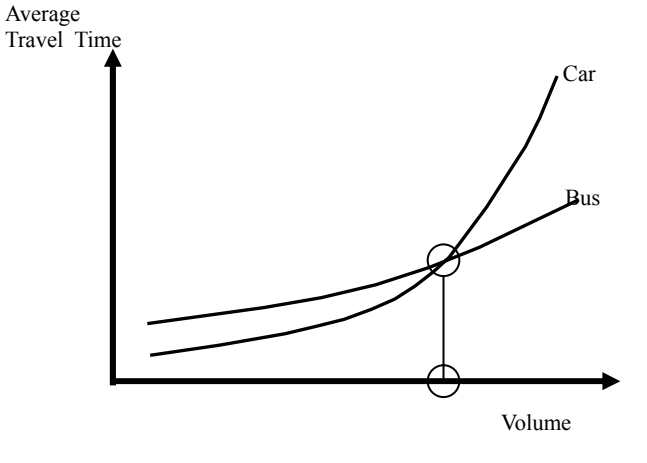

Figure 2. Comparison Travel Time between Car and Bus

We can find a point of intersection at which travel time of two modes is identical from the various scenarios which stand for volume changes of bus out of total volumes according to the assumption above.

$$\begin{aligned} &TT\_bus(t) \leq TT\_auto(t): \text{ The feasible section for Exclusive Lanes} \\ &TT\_bus(t) > TT\_auto(t): \text{The unfeasible section for Exclusive Lanes} \\ &TT\_bus(t): \text{Bus travel time in the specific traffic volume(t)} \\ &TT\_auto(t): \text{Auto travel time in the specific traffic volume(t)} \end{aligned} \quad (1)$$

4. DATA COLLECTION, FIELD TEST AND OUTPUT

This study supposes two categories to suggest the standards for exclusive bus lane. One is the scenario before deploying the exclusive bus lane, the other is the scenario after deploying the exclusive bus lane. We want to inspect the validity and propose the standards for exclusive bus lane after analyzing the changes of travel time, travel speed and delay when bus volumes and total volumes are altered respectively in the each category. This analysis is based on the various real data including traffic, geometric and road conditions in Kangnamdaero in southern Seoul and Sejongro/Taepyongro in northern Seoul. For this study, we set the scope of analysis from 80veh/hour to 300veh/hour in the bus volume during peak time considering the establishment standards (60veh/hour ~ 150veh/hour) for exclusive bus lane as presented <Table 1>.

4.1 Scenarios for Analysis

For this study, we set diverse volume levels from the objective area and analyze those data using the simulation tool, NETSIM. At this time, we make an attempt at synthetic analysis according to various levels of total volumes and bus volumes considering the variation of bus and car volumes. The specific scenarios for analysis are presented in the following figure.

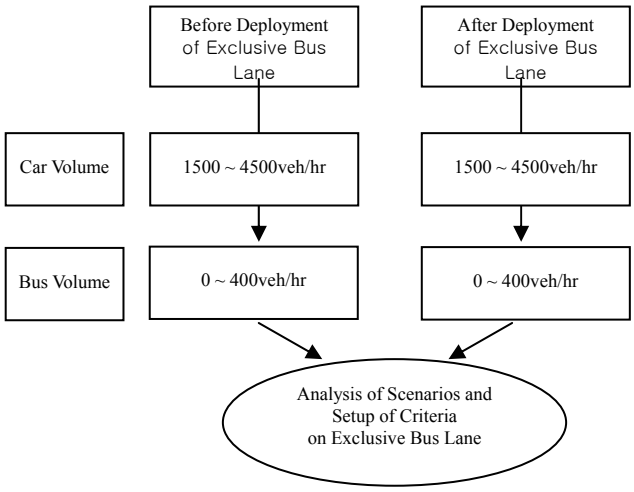

Figure 3. Scenario for analysis

4.2 Network and Traffic Conditions for Analysis

1) Network Organization

This study selects two main arterial roads such as Kangnamdaero in southern Seoul and Sejongro/Taepyongro in northern Seoul and uses traffic simulation tool, NETSIM, for network organization and analysis. The example of network organization for the field in NETSIM is showed like followings.

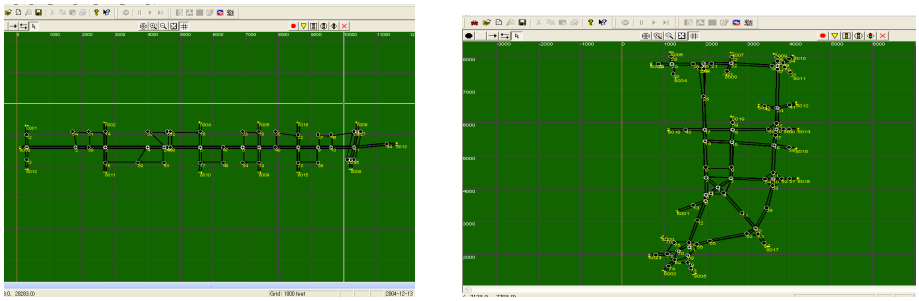

Figure 4. Network of site in NETSIM

2) The Average Volume of Each Section

While the average volumes per hour are distributed diversely from 2,500veh/hour to 3,800vhe/hour, the bus volumes maintain comparatively similar level of about 250veh/hour. These data follow the table below.

Table 4. Traffic Condition in Network

Road	Direction	Total Volume	Bus Volume
Kangnamdaero	South Bound	3,800veh/hr	260veh/hr
Sejongro/Taepyongro	North Bound	3,267veh/hr	250veh/hr

3) Determination of the Simulation Operation Time

When we analyze scenarios throughout the network organization, we should determine the appropriate simulation operation time to lessen the analysis error. In this study, it was analyzed that the output values were not influenced by the estimate values when the operation time was the 3,600 seconds in this analysis using NETSIM as showed following graphs.

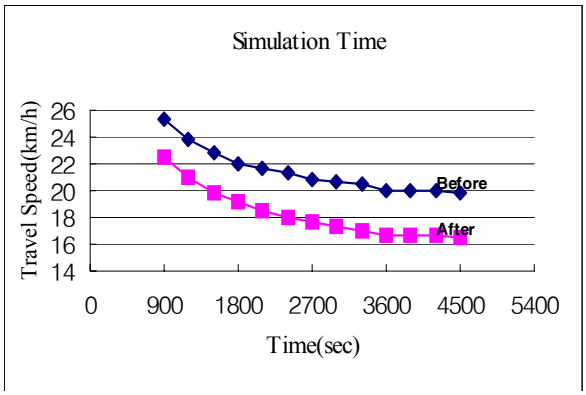

Figure 5-1. Kangnamdaero

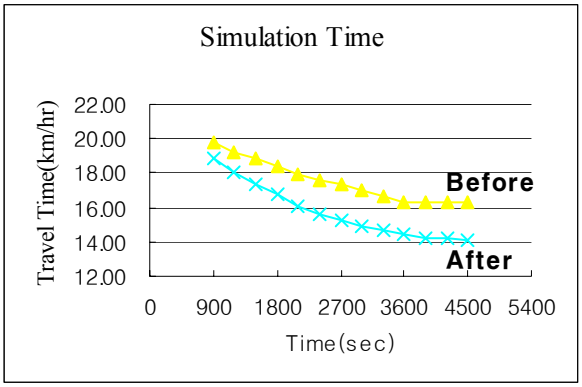

Figure 5-2. Sejongro/Taepyongro

4.3 Analysis Process and Application Results for Exclusive Bus Lane

It was analyzed that the travel time after deploying the bus-only lane was lower than travel time before deploying the bus-only lane irrespective of the changes of bus volumes, when the bus volumes changed from 60vph to 400vph. The differences of travel time between two modes were graphed like <Figure 6> and <Figure 8> to judge the average travel time of two modes from the viewpoint of the benefit of buses, which was derived considering each scenario. The numerical values in the middle of graphs below mean the bus volumes that are set to each scenario.

(1) The Road Section of Kangnamdaero

The transitions of travel time between two modes after deploying the exclusive bus lane is graphed in the figure below and the numerical values in the middle of graphs mean the bus volumes that are set to each scenario.

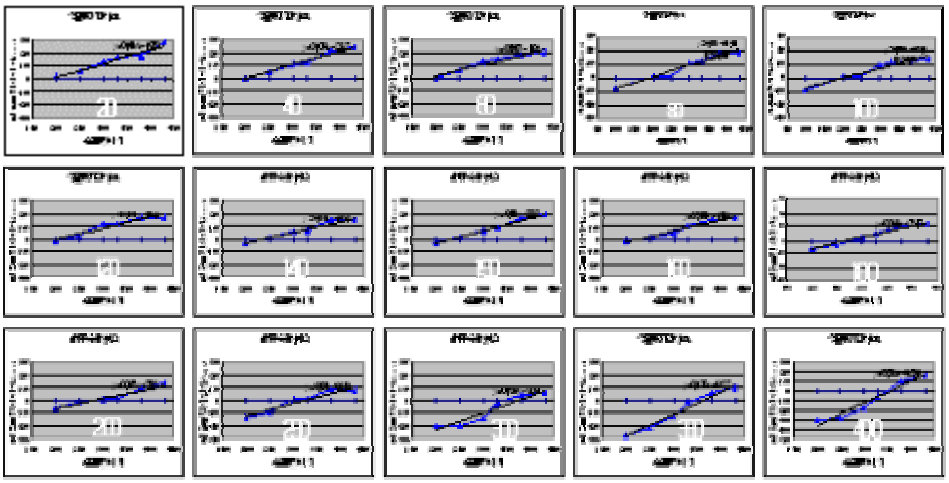

Figure 6. Travel time difference of Auto, Bus(Kangnamdaero)

The two tables below mean the travel time before and after deploying the exclusive bus lane according to the volumes.

Table 5-1 Auto travel time by volume(sec)

Total volume / Bus volume	Before deployment						After deployment					
	2000	2500	3000	3300	3800	4300	2000	2500	3000	3300	3800	4300
20	561.9	578.9	617.6	664.9	667.3	742.7	553.6	581.8	641.3	672	686.8	805.5
40	562.4	590.6	640.6	662.2	692.7	750.7	534.4	588.8	633.2	643.7	733.2	799.4
60	567.1	571.4	653.3	679.6	725	804.6	537.2	574.5	656.3	678.9	687.4	784.2
80	588.4	614.7	640.4	658.2	667.2	729.1	540.5	571.2	645.7	666.8	725.1	805.8
100	606.8	610.4	649.9	658.5	673.3	778.6	545.7	569.6	646.2	660	727.1	793.8
120	603.5	617.1	639.8	648.4	707.3	709.5	547.3	592.1	639.7	651.6	707.5	719.8
140	613.7	621.7	662.9	669.4	683.7	715.1	554.4	576.6	632.5	662.4	732	755.1
150	585	655	660.6	699.6	750.3	783.2	561.2	581.3	629	637.7	763.5	803.4
160	582.3	637.6	654.6	710.8	734.7	743	548.2	582.6	630.9	677.9	738.1	776
180	573	615.3	689.2	707.7	723.2	759.6	540.9	583	632.2	665.3	700.6	715.3
200	598.9	630.8	647.2	686.3	691.5	833.6	544.2	595.9	621	644.4	727.4	761.9
250	657.1	694	701.2	705.2	731.9	853.1	546.3	595.7	648.7	673.1	728.4	778.2
300	677.9	704.6	740.2	764.1	764.9	810	557.9	586.7	670.2	688	731.3	796.3

350	688	693.4	740.6	744.5	818.6	911.8	564.7	594.5	644.6	676.1	712.4	793.3
400	676.9	712.3	730.1	735.8	752.3	918.3	573.1	600.3	647.9	696.5	738.9	790.4

Table 5-2 Bus travel time by volume(sec)

Total volume / Bus volume	Before deployment						After deployment					
	2000	2500	3000	3300	3800	4300	2000	2500	3000	3300	3800	4300
20	738	754.9	792.4	822	818.9	885.2	531.3	521.8	513.5	507.3	512.7	525
40	691	780.5	799	829.9	796.6	906.4	538.4	537.7	524.2	521.2	523.1	555.6
60	763.5	745.3	799	877.6	886.7	840	538.9	522.6	529.6	527.3	514.3	581.2
80	748.8	792.9	801.1	821.9	830.2	898.8	531.7	549.7	525.2	527.7	541.8	610.7
100	799.8	805	820	850	874.1	964.7	533.1	549	547.5	537	598.3	643.5
120	804.8	813.6	821.2	830.1	817	848.4	557.6	559.4	527	534.8	534.8	545.1
140	844.9	821	877.6	902.7	835.5	871.6	581.8	567.4	575.6	594.8	586.7	604.8
150	795.6	842.3	859.5	924.3	871.6	908.1	581.9	564.4	558.2	546.4	600.6	607.9
160	783.3	865.6	833.4	911.9	962.5	903.2	567.9	567.2	585	566	587.1	610.7
180	804.3	821	1074	947.8	897.9	888.9	600.8	618.7	616.4	616.6	592.2	601.2
200	793.8	880.1	852.7	986.1	912.9	1045.	610.5	608.8	608.1	637.5	596.1	678.1
250	995.1	991.5	970.9	911.2	904.1	991.7	678.5	694.3	669.1	664.6	644.8	566.5
300	1066.	1062.	1059.	974.4	1054	1073.	761.4	788.7	811.8	708.9	684.2	732.6
350	960.5	1039.	1146.	1102	1132	1083.	836.9	814	767.3	692.9	657.7	694.5
400	1057.	1227.	1212	1054.	957.3	1112.	882.5	888	826.7	748.7	634.4	620.1

From the above results, we selected the intersection points at which travel times of two modes after deploying the bus-only lane equal and presented those in the following <Table 6> and <Figure 7>.

Table 6. The cross point of travel time by volume

No	Bus volume	Car volume	Total volume
1	20	1733	1753
2	40	1865	1905
3	60	1793	1853
4	80	1908	1988
5	100	1886	1986
6	120	1870	1990
7	140	2205	2345
8	150	2223	2373
9	160	2200	2360
10	180	2592	2772
11	200	2635	2835
12	250	2970	3220
13	300	3301	3601
14	350	3353	3703
15	400	3345	3745

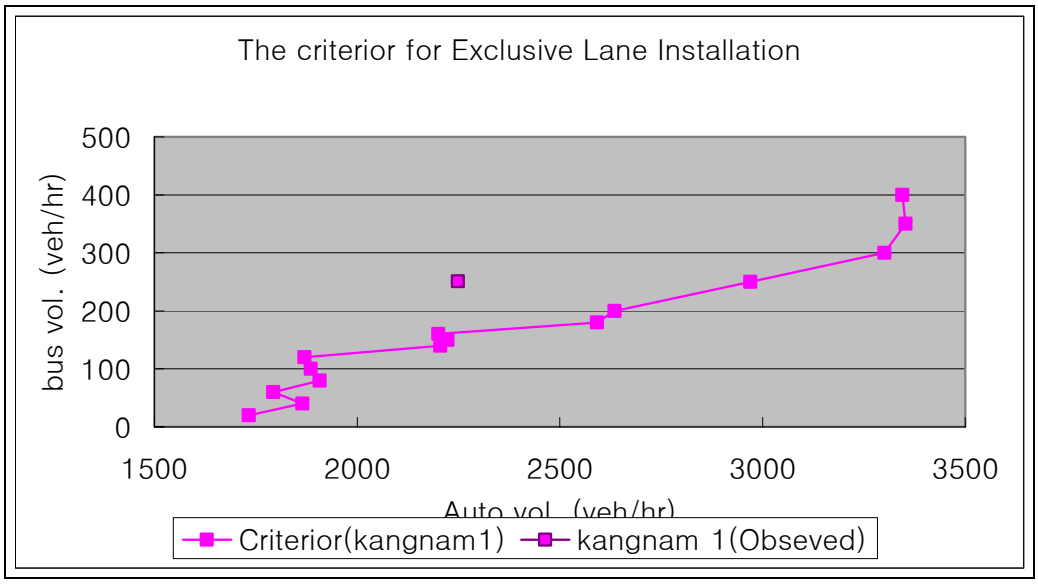

Figure 7. Criterion of Exclusive lane deployment (Kangnamdaero)

(2) The Road Section of Sejongro / Taepyung

The <Figure 8> is showing the transition of travel time between two modes after deploying the exclusive bus lane and the numerical values in the middle of each figure mean the bus volumes divided by each scenarios.

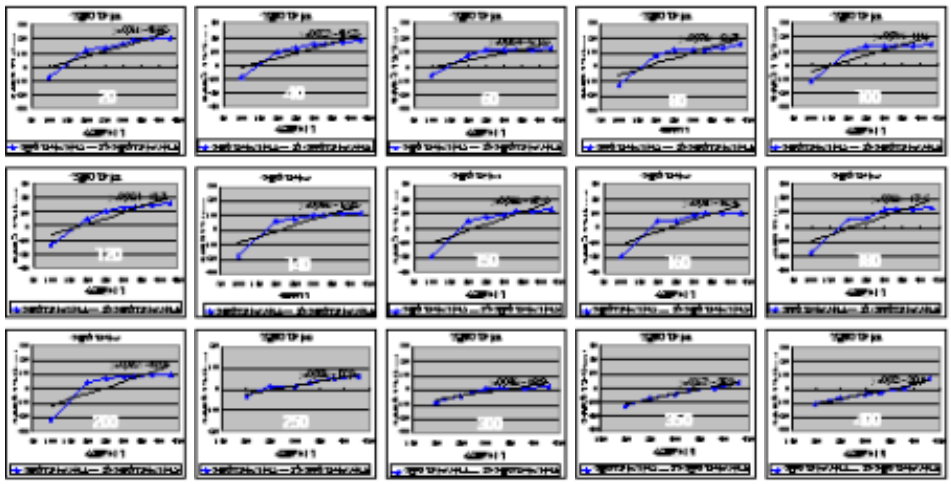

Figure 8. Travel time difference of Auto, Bus(sejongro / taepyung)

The <Table 7-1> and the <Table 7-2> show the travel time before and after deploying the exclusive bus lane according to volumes.

Table 7-1 Auto travel time by volume(sec)

Total volume / Bus volume	Before deployment						After deployment					
	2000	2500	3000	3300	3800	4300	2000	2500	3000	3300	3800	4300
20	530.6	664.4	704.1	721.8	730.3	754.2	679	729.3	742.2	770.1	786.7	801.1

40	537.9	671.5	711.1	712	734.1	764.1	683.9	731.5	765.6	768.9	792.7	794.2
60	562	676.1	711.4	727.8	754.5	754.1	691.3	747.6	749	775.1	780.1	788.3
80	583.4	693.9	725.6	726.6	740.5	759.4	694.2	732.5	770.5	761.4	786.2	820.6
100	599.1	692.4	728.4	746	755.7	760.6	717.6	749	755.8	782.5	793.2	807.7
120	616	717.2	731.3	746	750	751	696.8	753.8	770.5	774.1	779.7	801.7
140	635.4	706.3	725.4	751.7	755.9	764.2	725.5	747	775.4	778	797	797.5
150	661.8	709.9	729.7	734.1	750.7	758.7	715.3	747.6	781.9	785.1	781.6	799.2
160	666.8	715.8	732.4	754.8	754.9	756.1	721	745.7	772	772.9	793.7	799.2
180	683.9	716.7	732.6	742.8	757.9	770.5	728.3	744.6	761.3	775.3	788	794.3
200	691.2	741.2	734.9	768.3	759.8	771.1	730.4	761.6	762.3	762.5	798	799.8
250	728.9	759.9	768.5	769.5	770.3	772.6	742.6	755.4	769.8	776.2	798.6	798.2
300	759.6	765.3	768	774	775.3	786.9	746.5	778.6	797	796.6	804.1	810.8
350	771.4	772.6	773.6	776.9	784.4	792.4	766.1	771.9	777.3	797.9	808.4	815.4
400	773.1	782.7	787.8	791	792.3	814.5	761.3	769.8	775.8	780.9	801.8	812.2

Table 7-2 Bus travel time by volume(sec)

Total volume / Bus volume	Before deployment						After deployment					
	2000	2500	3000	3300	3800	4300	2000	2500	3000	3300	3800	4300
20	657.5	659.6	661.7	676	723	835	555.8	587.8	626.7	586.7	577.8	591.1
40	674.7	731.4	795.6	745.7	880	934.2	586.3	575.5	614.4	614.5	574.1	614.5
60	657.4	725.4	786.2	733.4	834.5	906	614	639.8	636.4	660	662.4	656.8
80	701.6	750	760.1	738.1	799.2	863	614	610.6	646.7	645.3	654.1	656.8
100	713.2	772.3	802	760.5	855.6	804.1	628.4	621.2	624.9	650.7	660.8	655.1
120	738.3	775.9	775	926.3	857.4	913.4	646.2	646.8	641.6	643.7	625	643.8
140	748.8	751.3	860.5	869.1	860	822.2	660.6	669.4	668.3	669.6	682.3	681.2
150	768.5	775.7	839.2	808.6	830.5	892.5	657.6	670.9	685.8	667.8	659.9	668.5
160	754.4	798	797.1	833.9	852.9	840.2	670.8	686	675.7	671.1	687.9	689.3
180	771.8	790.8	819.1	874.5	870.1	837.6	674.2	677.3	639.1	646.4	655.2	659.2
200	801.2	815.3	841	948.7	839.9	916.9	682.2	687.1	681.9	679.7	693.2	693.7
250	851	888.8	916.5	859.5	854.7	951.2	776.5	746	757.4	745.2	744.3	741.9
300	925.6	930.8	934.7	933.8	926	856.6	832.3	811.8	778.8	782.2	779.9	775.8
350	917.7	923.1	937.3	908.6	1000.	993.1	895.8	838.2	815.9	809.5	807.9	778.4
400	953.8	934.9	977.9	936.4	957.6	1015.	863.4	834.8	809.5	806.3	791.1	736.9

From the above results, we selected the intersection points at which travel times of two modes after deploying the bus-only lane equal and presented those in the following <Table 8> and <Figure 9>.

Table 8. The cross point of travel time by volume

NO	Bus volume	Car volume	Total volume
1	20	1139	1159
2	40	1244	1284
3	60	1297	1357
4	80	1583	1663

5	100	1459	1559
6	120	1685	1805
7	140	1958	2098
8	150	2015	2165
9	160	2093	2253
10	180	1882	2062
11	200	2155	2355
12	250	2337	2587
13	300	2980	3280
14	350	3312	3662
15	400	3343	3743

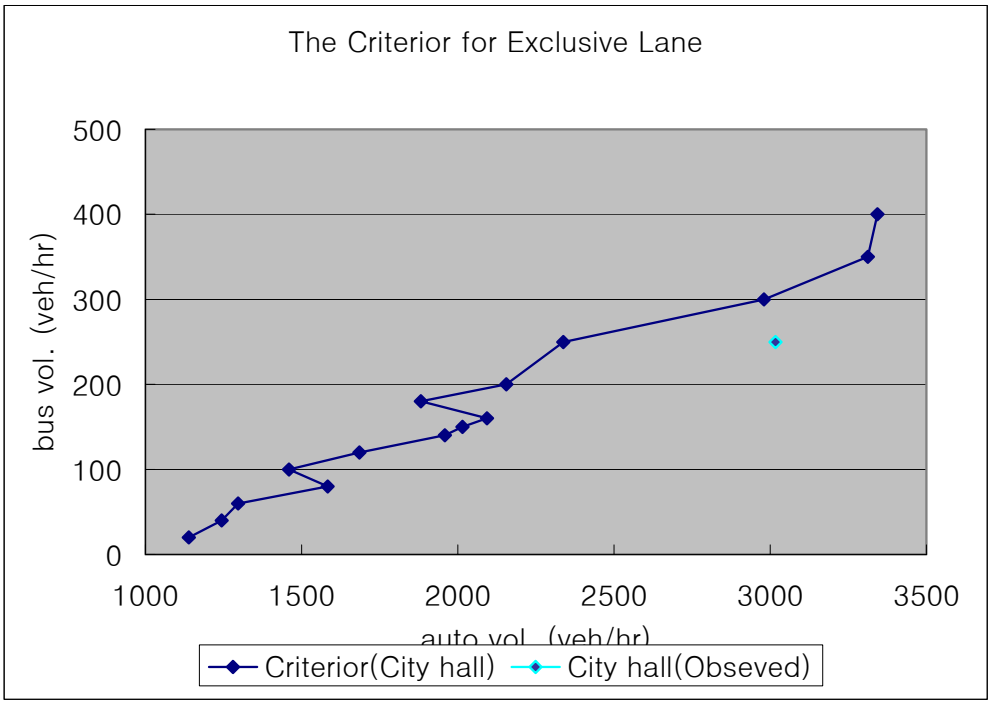

Figure 9. Criterion of Exclusive lane deployment (sejongro / taepyung)

4.5 Outputs

So far, we selected two real areas such as Kangnamdaero and Sejongro/Taepyongro in Seoul for this study and analyzed the validity on deploying of exclusive bus lane with the connection of establishment standards and data obtained from real fields.

The average travel times of bus and car were computed and presented respectively in the <Table 5> and <Table 7> through the simulation outputs in which the bus volumes were fixed and the car volumes were changed. The <Table 6> and <Table 8> were arranged after selecting the intersection points at which the travel times from the outputs of two modes, <Table 5> and <Table 7>, equal. At this time, car volumes can be obtained by subtracting the bus volumes from total volumes. We dotted the points which were extracted from the <Table 6> and <Table 8> considering the interrelation between bus and car volumes and presented

the results in the <Figure 6> and <Figure 8>. In the <Figure 6> and <Figure 8>, we suggest the establishment standards for exclusive bus lane by connecting the points as a line, because the left section of the dotted points means that the travel times of buses are lower to those of cars. In other words, while the left section of dotted points has the validity for bus-only line, the right section doesn't.
Using the results above, we suggest the establishment standards of exclusive bus lane for the areas having above 5-line and summarize the results of validity with the connection of study area and establishment standards like followings.

Table 9. The cross point of travel time between before and after deployment

Kangnamdaero(South-bound)				Sejongro / Taepyung(North-bound)			
NO	Bus volume	Auto volume	Total volume	NO	Bus volume	Auto volume	Total volume
1	20	1404	1424	1	20	1139	1159
2	40	1449	1489	2	40	1244	1284
3	60	1468	1528	3	60	1297	1357
4	80	1531	1611	4	80	1583	1663
5	100	1510	1610	5	100	1459	1559
6	120	1624	1744	6	120	1685	1805
7	140	1633	1773	7	140	1958	2098
8	150	1580	1730	8	150	2015	2165
9	160	1649	1809	9	160	2093	2253
10	180	1778	1958	10	180	1882	2062
11	200	1818	2018	11	200	2155	2355
12	250	1994	2244	12	250	2337	2587
13	300	2104	2404	13	300	2980	3280
14	350	2617	2967	14	350	3312	3662
15	400	3244	3644	15	400	3343	3743

Table 10. The Measured Volume and Result of Evaluation in Analysis Site

Classification	Bus volume	Auto volume	Total volume	Feasibility of Deployment	Deployment
sejongro / taepyung	250	3017	3267	Feasible site	o
Kangnamdaero	251	2249	2500	Infeasible site	x

5. CONCLUSIONS AND FURTHER RESEARCHES

5.1 Conclusions

We analyzed the travel time before and after deploying the exclusive bus lane considering interrelation between buses and total volumes for the real area. We concluded that only the left section of dotted points has validity of exclusive bus lane after analyzing the buses and cars volumes for the section in which the travel times decrease after the exclusive bus lane.
In the case of Kangnamdaero, validity of exclusive bus lane exits when the total volumes distribute from 1,750vhe/hour to 3,750/hour and car volumes distribute from 1,730/hour to

3,350/hour according to bus volumes.
In the case of Sejongro/Taepyongro, validity of exclusive bus lane exits when the total volumes distribute from 1,160vhe/hour to 3,740/hour and car volumes distribute from 1,140/hour to 3,350/hour according to bus volumes.

5.2 Further Researches

There remain several further researches for exclusive bus lane like followings.
- The effectiveness analysis of bus-only lane for less than 4-lane road
- The effectiveness analysis considering the spacing of bus stations

Besides above, but we have analyzed this study based on only peak volumes so far, we need to analyze after dividing the peak and non-peak volumes.

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