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Ex-post Evaluation of Bus Rapid Transit System in Nagoya city

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Abstract

This paper elaborately explores mid- and long-term effects of "Key Route Bus System" an exclusive median bus lane system in Nagoya, the third largest city in Japan, which was one of the initial BRT system implementations in the world initiated in 1985. The results suggest that: 1) Higher operation speed and the more punctuality can be attained 2) Compared to the ordinary bus system, catches bigger patronage. 3) Real total capacity of transport in terms of passengers does not decline in the corridor 4) Total travel time for bus passengers decreases because of shortened in-vehicle time in exclusive lanes.

1. Introduction

Excessive dependence on car mobility evidently causes various environmental problems and even more severe urban problems with worsening congestion on the roads. Therefore it is necessary to provide better public transportation infrastructures and services within the urban transport system, which is and sooner or later will be suffering from private automobile dependent transport.

There are many examples of the cities in the developed countries that have developed noteworthy public transport systems even before the rapid motorization progress began. However, in many other cities from the developing world, the road network has been improved earlier than the development of public transport and hence has contributed more to the accelerated motorization during the urbanization. Public transport in such cities is often provided by the buses, although huge car traffic causes a remarkable decrease in punctuality and service speeds of the buses, which is followed by a likely decline of the passenger demand. The construction of railroads, although constitutes a real alternative to private automobile transport, requires both unaffordable investment in some cases and construction time and therefore fails to provide short term solutions especially in cases where there is lack of financial resources. On the other hand, even after the introduction of the new rail systems, in many cases the bus network was not re-organized accordingly and competition among buses and railroads emerges as they serve along the same corridor although the ideal will be the buses rather serving as feeder routes.

BRT System has been recently favored also in developing countries as a new mode of public transportation, therefore it is no wrong to claim that buses have been gaining more interest, and BRT systems operating at higher speeds on the exclusive lanes are often regarded as an alternative to railway systems as they hold the advantages of lower construction costs and greater flexibility in route selection over the railways. In the world of rapid motorization and economic growth that the public transport looses its competitiveness, hence BRT is accepted as an effective public transport mode in many aspects.

However, review of the relevant work on BRT systems has revealed that a detailed ex-post evaluation of BRT systems in terms of their impacts on road traffic, modal shift and induced demand and also the environment is still poor. Therefore the purpose of this study is to disseminate know-how and experiences about Japanese BRT System in Nagoya particularly considering the operation efficiency of operation and the passenger demand. Nagoya BRT System so called “Key Route Bus System” (Figure-1) is the first Japanese BRT system, and has been serving the central area of Nagoya since 1985. Although Key Route Bus System proves its advantages of higher speed and capacity as it runs on the central lane, unfortunately it could not have found any another applications so far.

<Figure-1>

2. BRT System in Nagoya

FTA (Federal Transit Administration) defines the BRT system as "rapid mode of transportation that can combine the quality of rail transit and the flexibly of buses". And TCPR A-23 project provides a more detailed definition. It briefly explains BRT system as: "BRT is a permanently integrated system of facilities, services, and amenities that collectively improve the speed, reliability, and identity of bus transit". BRT systems have a number of advantageous features like: improvement of running environment; rapid boarding and alighting, fast and efficient fare collection, use of ITS (Intelligence Transport System), and integration with other modes. Many of the BRT systems are operated on the exclusive lanes- physically separated right-of-way allowing the buses keeping their schedules. Famous BRT systems in Curitiba, Bogota, and Seoul have the exclusive lanes in the central part of the road. Notably, merit of the median bus lane comes from eliminating the effects of -street parking and left (or right)-turning cars on the transit system. Another type is to provide separate road systems constructed only for the operation of buses (for example Ottawa, Los Angeles etc.), or separate specific systems necessary to run the specific vehicles for some of the BRT systems so called "Guideway Bus" (Essen, Adelaide, Nagoya -Yutorito Line). Table-1 summarizes some examples of BRT systems which have median bus lane.

<Table-1>

2.1 The city of Nagoya

The city of Nagoya is the third largest populated major region in Japan. The total population in 2006 is 2.22 million over an area of 326 km^2. The population is almost the same as in Paris (2.14 million in 2004), but the urban area is three times larger (105km^2), proving relatively lower population density in the city of Nagoya.

The main characteristic of transportation in Nagoya is the extreme provision of roads, substantially improved after the 2nd world war. The total area occupied by roads is 16% of the urban area, a similar figure compared with 16% in central Tokyo, or 19% in Osaka first and second largest cities in Japan. But the share of road surface in the central city is approximately 40%, making the city of Nagoya the “the city of wide highways” in Japan. Consequently, low population density and extensive road network with high capacity promoted the car traffic and the share of the trips made by private automobiles which is as much high as 70% higher than those of Tokyo or Osaka.

The public transport service in the city is provided by suburban railways, subways and busses (including Key Route Bus and Guideway Bus) and operated by “Transportation Bureau of the city of Nagoya” and “Japan Railways”. The total length of subway is 89.1 km and buses are operated on 700km bus network.

2.2 Key Route Bus System of Nagoya

Nagoya Key Route Bus System has been planned to supplement the subway system and its characteristics have been defined as below:

1) Exclusive bus lanes in the middle/ center of the road
2) Higher operational speed (25km/h) by introducing bus prior signal system and expanding the bus stop intervals (800-1000m)
3) Introduction of new vehicles better than conventional buses
4) Minimizing the physical and monetary (fee) impedances of mode transfers (from and to subway)

Some of the given consistent concepts of the BRT in the earlier planning stage have not yet been installed. Figure-2 shows the proposed routes of the Key Route Bus System of which only two of the routes were selected and are currently in operation.

<Figure-2>

In 1982, the first section of the Key Route Bus No. 1 named as “Toko Line”, was opened with its exclusive lanes as curbside bus lane not in the central because the central part of the road is occupied by pillars of the elevated motorway. The Key Route Bus No.2, called “Shin-dekimachi Line”, was opened three years after in 1985 as the first implication of central lane in Japan. The total construction cost is approximately 2.5 million US$ per one kilometer, which is only one percent of the cost for subway. After the implementation of the median bus lanes, the operation speed of the bus during daytime raised by 37% from 14.6 km/h to 19.9 km/h). In addition, the system allowed higher frequency of as much as 2 minutes headways in the morning rush hours. Therefore, the Key Route Bus System is now an important rapid transit system serving in the city of Nagoya.

Table-2 gives service level of Key Route Bus No.2 and Figure-3 shows its route. The intervals of bus stops are approximately 600m, as twice as the ordinary bus stops’ in the city. At the moment, bus priority signal has not been installed because the frequency of Key route bus No.2 in the rush hour is shorter than the cycle of signals.

However, the exclusive median bus lane is limited to only one route. The major reason why median bus lanes have not much been implemented is the road traffic law in Japan. For the construction of the Key Route Bus No.2 it was required to introduce many case-specific treatments, which have not been justified by the existing the law and regulations that are not allowing the buses to run in the central lanes. Therefore, special to the only Nagoya BRT system, it has been deregulated to allow the buses registered as “Key Route Buses” use such exclusive median bus lanes.

<Table-2>
<Figure-3>

3. Ex-post evaluation of the median bus lane

There are several studies exploring the effects of BRT systems using median exclusive bus lanes (for example see Levinson et al., 2002 defining BRT system by its seven components). Yabe et al., (2005) defines performance indices to assess the likely effects of BRT on the whole transport system. We follow a Similar approach and the below sub-sections explore the impacts of the Nagoya Key Route Bus System as an ex-post evaluation of the first and the only BRT system in Japan (Figure-4).

<Figure-4>

3.1 Improvement in operation speed and punctuality

Noted earlier, the operating speed was improved by 37% (up to 19.9 km/h) and has stabilized around 19 km/h, which is 1.5 times higher than compared to ordinary buses. Table-3 shows the results of one very recent traffic survey carried out to observe the delays and the extent of deviations from the scheduled time of the bus routes in the city. Table-3 compares the median lane and curbside lane exclusive bus systems with the ordinary buses to explore potential of the two types of Key Route Bus System to increase the punctuality. The average delays and the standard deviations from the schedule evidently proves better and improved reliability and punctuality for the median lane system that is followed by the ordinary, and the buses operating on the curbside type of exclusive lanes have yielded the worst punctuality among the three.

<Table-3>

Figure-5 presents the reasons of the increases in the average operation speed after upgrading the ordinary bus system to median lane exclusive bus system, using the results of the speed survey conducted by the Nagoya City Office. 60 % of the speed improvements are attributed to the reduction in the running time provided by the median bus lane. The second largest reduction of 25.7% is the result of the decreased number of bus stops (from 23 to 17) on the total route.

<Figure-5>

Other reasons for the higher average speeds are the restrictions of on-street parking, left-turns (Japan has left-side traffic). These effects are not separately reported here, but included in the following factors of time saving: stops at signals (13.3%); and traffic jam (4.0%).

In order to examine the impacts of on-street parking, we used the Traffic Census, 1999 for "rush hours on-the-street parking car statistics" and the parking time model suggested by Nakamura et al., (2004) and estimated 9.19 parked vehicles per kilometer, simply, and approximately in every 110m one bus passes by a vehicle parked on the street. Besides, the performance of the curbside lane is easily affected by the left turn movement of the vehicles. Therefore we conclude that the worst punctuality is attributable to the traffic and parking condition on the road.

However, the ordinary vehicles can easily intrude into the exclusive median lane since it is not a system of exclusive lane separated physically from the other lanes. We estimated that 1.07 vehicles enter the median bus lane per kilometer at the average with less impact by the left turns since they move in the same direction with the buses.

The average stop time at the signals constitutes the 27% of the total service time on the road or ,that is If the Key Route Bus would not have stopped at signals, the operation speed could have been improved from 19 km/h to 26 km/h.

One appropriate solution to overcome this problem would be the introduction of a Public

Transportation Priority System (PTPS), which have not yet been implemented because the headway time does not fit with the signal cycle on the road in the rush hours. Instead, line control signal system considering the bus operating speed has been installed. However, although the PTPS is ineffective in the rush hours, it would have absolutely increased the speed in the off-peak hours.

3.2 Number of passengers

Key Route Bus system characterized by higher operation speed and better punctuality offers convenience over an ordinary bus and is expected to attract more passengers. The survey results confirm this likely result and also prove a shift from the car users by 3% which a notable shift when considering the bus and the private car modal shares.

Figure 6 shows the changes in passenger demand for the Key Route Bus No.2 taking the demand in 1988 as index, 100. The number of passengers for the Key Route Bus decreased to 85.6 in 2003 but this was a smaller decline compared to that of total bus passenger demand of decreasing to 69.8 and Key Route Bus No.1 also decreasing to 79.4 in the same term. It can be concluded that the median bus lane has any effect to prevent the decrease rate in bus passengers. Therefore we reach the important conclusion that better service level of the exclusive median lane bus as discussed above was able to maintain the demand on the system better than the other two types of ordinary and exclusive curbside lane bus services in Nagoya.

<Figure-6>

Using the data available to the authors over the 46 sample bus lines, a simple demand model of bus passengers was estimated by the below equation and the model estimation results are represented in table-4.

$$Y = b_0 + b_1 X_i + b_2 X_{ii} + b_3 Z + b_4 \ln(S_i) \qquad (1)$$

Where:

Y: Number of passengers [person / day]

X_i: Population in the catchment area [person]

X_{ii}: Number of students in the catchment area [person]

Z: Average distance of bus service [km/service]

S_i: Number of annual bus services per population in the catchment area [services/person]

The catchment area was defined by a circular area within a 500 m radius from the bus stop. The given variables proved statistically significant relations to explain the demand on the buses but better for the ordinary buses than the Key Route Bus Routes. Figure-7 shows the observed and estimated demand for the two Key Routes Lines and three selected ordinary bus lines (A-Line, B-Line and C-Line). The most likely reasons for the underestimation of the Key Route Lines No. 1 and No. 2 are because the number of the ordinary bus lines was more in the total sample and obviously the Key Route Bus system has higher capacity and potential to carry more passengers.

<Table-4>
<Figure-7>

3.3 Changes in bus stop access/egress and total trip time

Because the bus stops of median lane bus lines are designed in the central part of the road with longer interval, this might have an adverse effect of increasing the access/egress time of the bus stops and increase the door to door total trip time although higher speed on the exclusive lanes contribute to the shorter trip time. To investigate such an impact, we defined a belt-shaped area with 500m width and 10km. long as depicted in Figure-8. We considered three alternatives of an ordinary bus, a median bus lane Key Route Bus and a subway and calculated the access / egress time by the given equation 2 from each 50m x 50m mesh to point A at the city center. The bus stop intervals and the operation speed and standard deviation of delay time are the actual values derived from the Nagoya City Office observations (Table-5) and the headways of the each transport mode was accepted to be identical to avoid any biased results arising from the operation schedules.

<Figure-8>

$$t_{ij} = \frac{l_{ai}}{60V_a} + t_{bj} + \frac{t_{cj}}{2} + \frac{60 l_{di}}{1000 V_{dj}} + 10 t_{ej} \quad (2)$$

where;

t_{ij}: Access time from mesh i to point A [min]

t_{bj}: Waiting time at signals on the way to access bus stops (Key Route Bus) or platform entrance (Subway) [min]
t_{cj} : Frequency of each transport mode j [min]
t_{ej} : Standard deviation of delay time per kilometer [s/km]
l_{ai} : Distance from mesh i to bus stop or platform station [m]
l_{di} : Distance from bus stop or station to point A [m]
V_a : Walking speed [m/s]
V_d :Operation speed of each transport mode j $[m]_j$

<Table-5>

The results imply that longer intervals between the bus stops increased the access /egress time, but was not large enough to overwhelm the improved running time of the Key Route Bus and therefore the total trip time was found to be fairly shorter than an ordinary bus on the network.

Comparing with any subway improvement, median lane proved its cost-effectiveness as the construction cost is only one hundredth of the subway but the total trip time is improved by 42 %.

3.4 Changes in the road capacity

Traffic capacity on the road network evidently decreases after assignment of one lane as the exclusive bus lane. Particularly, the median exclusive bus lane exerts negative effect on the traffic making right turns at the signalized junctions and is the main reason for the difficulty of implementing a median bus lane or Light Rail Transit in Japan. To investigate the extent of reduction in road capacity after the installment of the median lane, we examined three cases; 1) only passenger car traffic, 2) combined passenger car and ordinary bus traffic and 3) car traffic with exclusive median bus lane Key Route (assigned from the ordinary existing lanes on the road) by calculating the number of people as a simple performance indicator.

In the first case with the typical signalization pattern, we simply multiply the total traffic capacity by the average vehicle occupancy (1.3 people/car) and the average peak hour trip speed. For the cases two and three the average speed of the buses in the peak hour they were taken as 12.2 km/hr and 17.9 km/hr, respectively.

Figure-9 shows the capacity changes, separately for two and three lanes. The total capacity was found to be the highest for the combined passenger car and ordinary bus case but the share of the bus was the highest for the third case with an exclusive median bus lane that is obviously the consequence of the improved service level by the Key Route Bus System.

<Figure-9>

3.5 Reduction of the environmental load

Since the fuel consumption and environmental load from the buses can be improved by increased average operation speed, we estimated such effects of the median bus lane by employing the fuel consumption model suggested by Oshiro et al. (2001). Implementation of a curbside bus lane reduces energy consumption by 8% and a median bus lane reduces it by 13% comparing with ordinary bus (see Table-6). Additionally, an actual 3 % shift from car trips to buses, mentioned earlier, also contributed to the reduction of environmental load by the amount of 370 t CO_2/year. Therefore we estimated that the median bus lane totally reduces the carbon dioxide emission by 607t/year.

<Table-6>

3.6 Effects of housing location changes

As the consequence of very well known interaction between the transport and the land use it is likely to prove an interrelation between housing and commercial location patterns and the Key Route bus line with potential to attract more facilities as the principle of Transit Oriented Development along its corridor.

Table-7 presents the population changes since the 1980 separately for the areas within 500m far and the area 500 to 1000m far from each bus stop, and the other accessible along the line. It should be noted that the area has already been developed before introducing median bus lane, and recently facing population decline that is common to many and recent phenomena in Japan. However the Key Route Bus of Nagoya hardly puts any evidence of transit oriented development along its line or nearby the bus stations. The population decline within 500 m zones was less than the zones 500m to

1000 m. but higher than the other zones.

<Table-7>

4. Conclusions

Bus Rapid Transit Systems are regarded as good options of public transport as they provide better services with higher speed and meet higher capacity compared with the traditional buses. BRT systems demonstrate evidently low capital and operation costs per km compared to the railways. They also generate less environmental load because of likely shift from car users and improved speed on the bus network. Therefore BRT has also been acknowledged as one of the best solutions in the developing countries with growing demand and limited financial resources especially in the cases requiring immediate transport network improvements.

Implementations of Bus Rapid Transit Systems have been increasing with a variety of applications of running ways, vehicles, stations and operation systems. However, BRT implementations has been quite rare in Japan and one typical example is the Nagoya Bus Rapid Transit so called here Key Route Bus, our focus in this study, has been operating more than twenty years. The central concern of this paper, to conduct an ex-post evaluation for assessing its performance by a number of indicators has revealed six important results that can be summarized as below:

1) Operation speed and punctuality is much improved. The main contribution is the reduction in the number of passenger cars intruding in to the exclusive bus lane. However, long waiting time and stops at the signals especially in the rush hours still remains to be problematic.

2) The passenger demand was found to be increased by 74% compared with the total number of ordinary bus passengers unless the Key Route Bus system would have been implemented.

3) Although intervals among the bus stops were expanded after the installation of by median bus lane, the overall trip time was reduced because of the improved headway and speed by the Nagoya BRT system.

4) The total road capacity in terms of the total number of passengers declined only slightly although one lane was reallocated as an exclusive bus lane because of the increased number of passengers carried by buses.

5) Research about the impacts of the BRT systems on environment has been rather rare. Here, by employing the bus demand and bus emission models, Nagoya Key Route Bus was found to contribute to environmental load reduction by producing less Carbon dioxide emissions by the amount of 607 t/ year.

6) Unfortunately, Nagoya BRT could not demonstrate any positive impact of Transit Oriented Development that the change of population and other urban facilities was not favoring the idea of BRT supportive land use development.

The authors think that this paper contributes to the literature by its elaborate ex-post analysis on the Japanese BRT experience and by further guiding similar attempts especially those in developing countries.

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Figure-1 Key Route Bus System

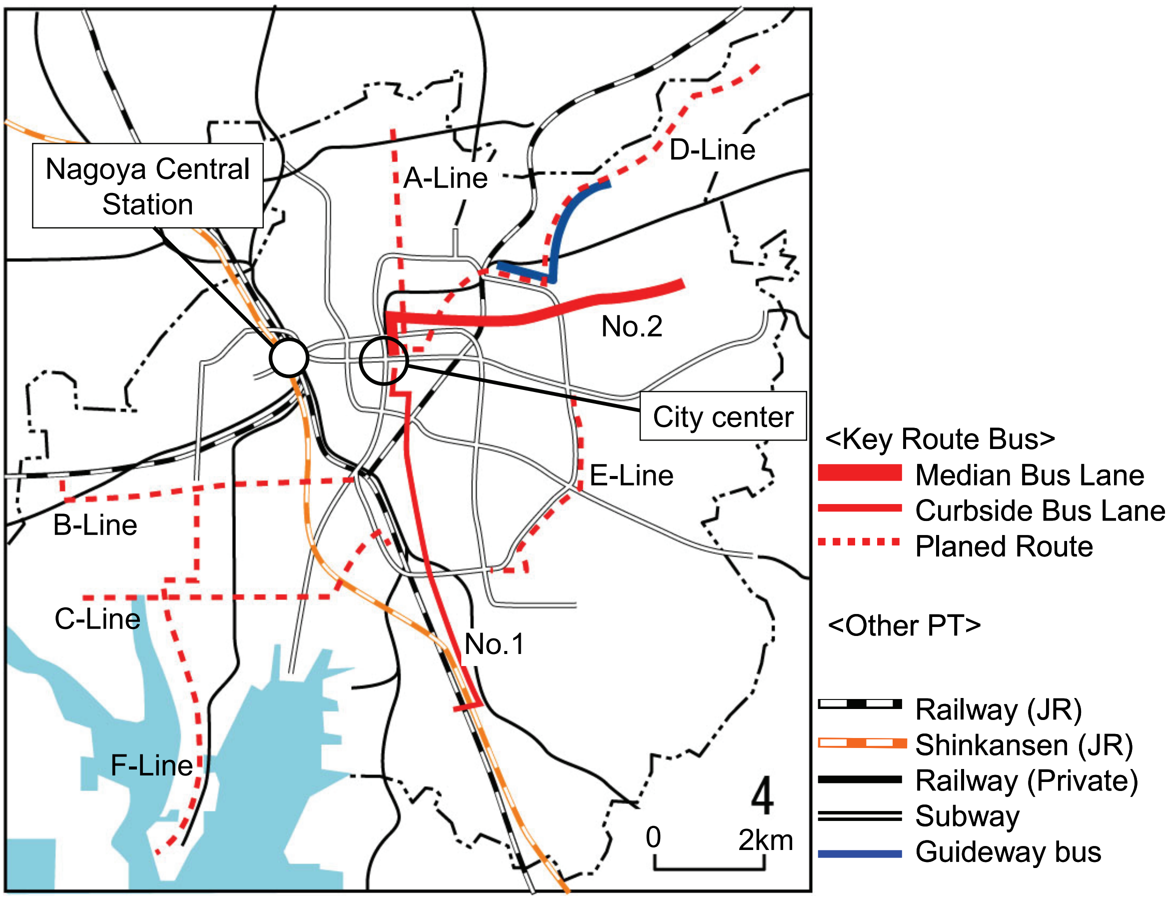

Figure-2 Key Route Bus Plan in the City of Nagoya

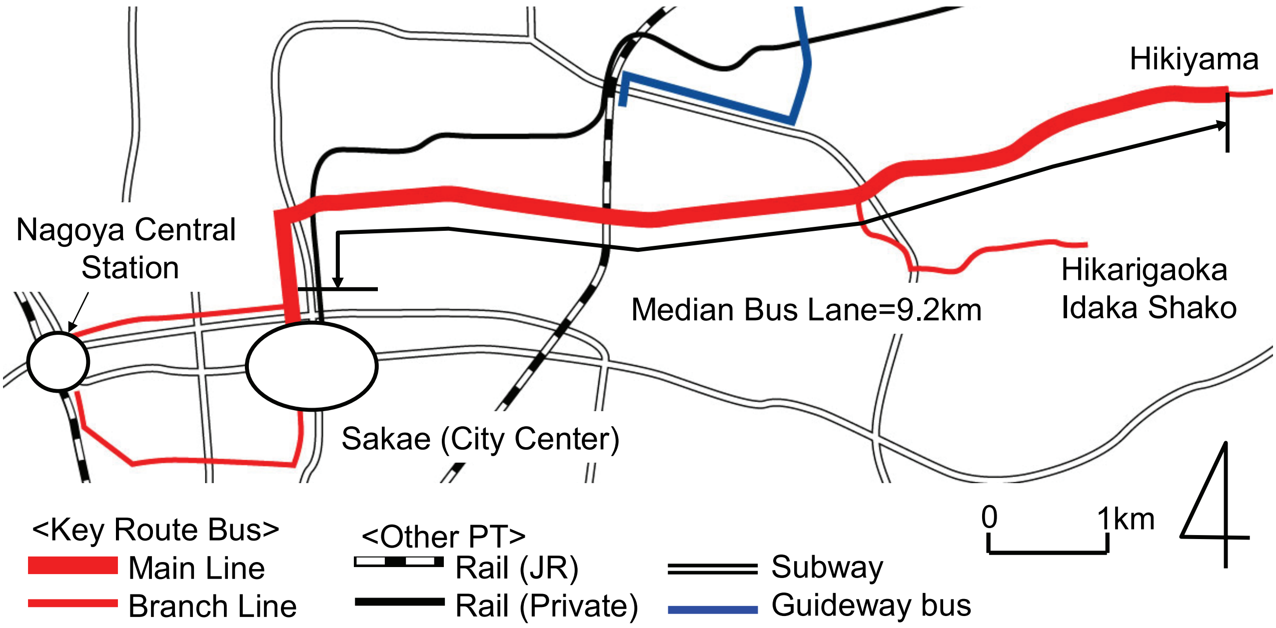

Figure-3 Route of Key Route Bus No.2

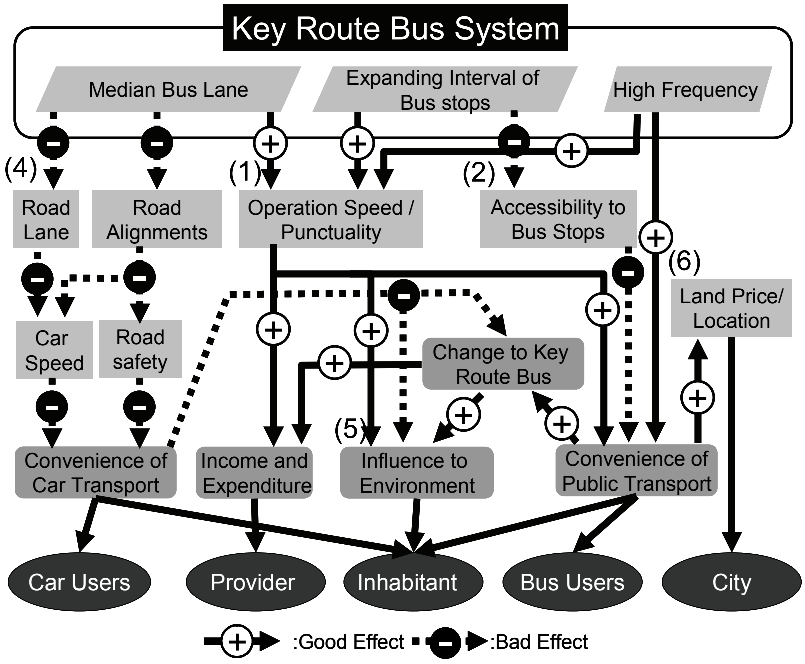

Figure-4 Effects of introduction of median bus lane

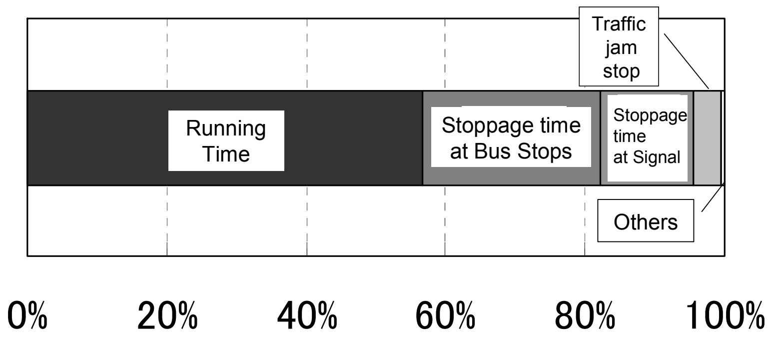

Figure-5 The speed-improvement and punctuality effects

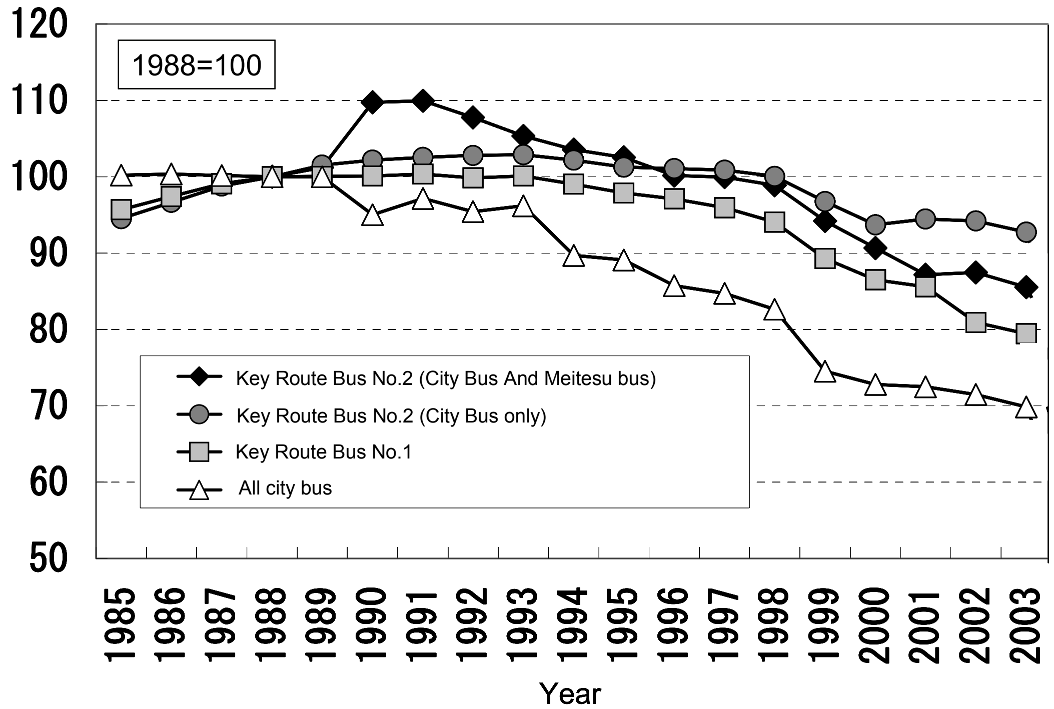

Figure-6 Changes in passenger demand since Key Route Bus No.2 has been operated

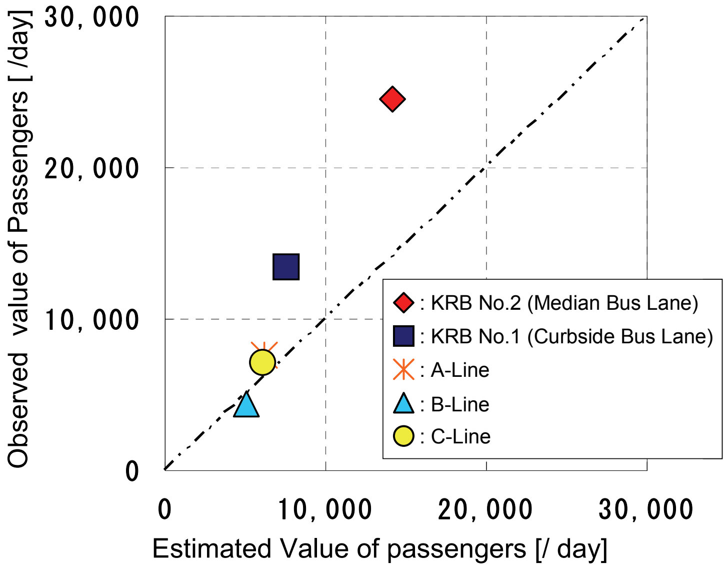

Figure-7 Relationship between the estimated value and observed value in 2004

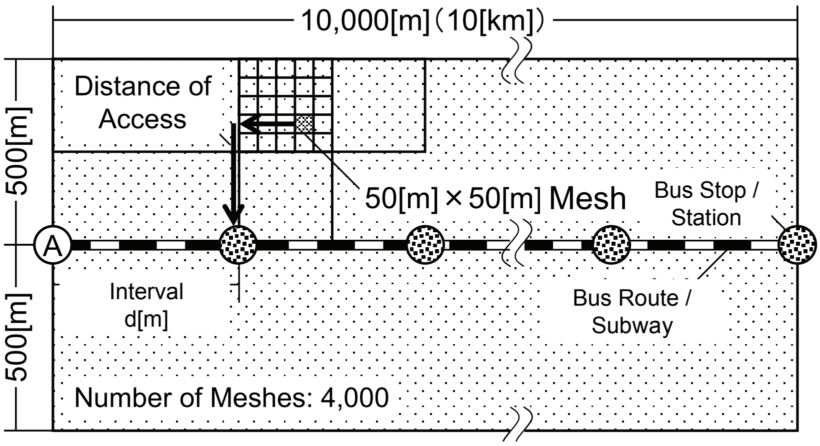

Figure-8 Virtual belt-shaped area to analyze access/egress time

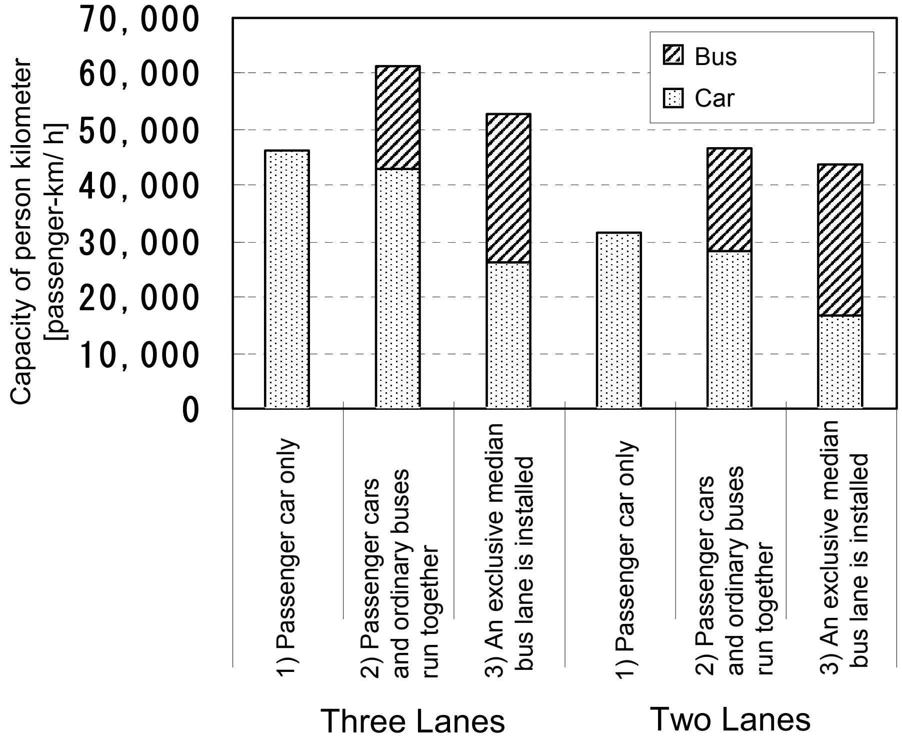

Figure-9 Results for the capacity of person kilometer change calculations

Table-1 Examples of BRT System (Median bus lane)

	city	population (million)	opening year	Separated/ Non-Separated
Brazil	Curitiba	1.6	1973	Separated
Columbia	Bogota	6.8	2000	Separated
China	Beijing	13	2005	Separated
China	Kunming	3.7	1999	Non-Separated
China	Hang Zhou	6.4	2006	Non-Separated
Ecuador	Quito	1.6	1995	Separated
Indonesia	Jakarta	11	2004	Separated
Japan	Nagoya	2.2	1985	Non-Separated
Korea	Seoul	9.9	2004	Non-Separated
Mexico	Mexico City	18	2005	Separated
Taiwan	Taipei	2.6	2001	Non-Separated

Table-2 Service Level characteristics of Key Route Bus (No.2)

Routes	Operation Speed	Alighting Time	Peak Volume of Buses
3	20km/h	30min	33 /h

Routes

- Sakae – Hikiyama
- Nagoya Central Station – Hikarigaoka / Idaka Shako

  (Above two Routes are operated by Transportation Bureau of City of Nagoya)
- Nagoya Central Station – Shiken-ya etc.(East Area from Hikiyama)

  (Above one Route is operated by Meitetsu Bus Co,.Ltd)

Table-3 Delays from the scheduled time

(per kilometer)	Ordinary route bus (A)	Curbside bus lane (B)	Median bus lane (C)	Improvement [%] 1-{C/A}	Improvement [%] 1-{C/B}
Average delay time per km(sec/km)	35.8	52.1	16.3	54.4%	68.7%
Standard deviation of Delay Time per km [sec/km]	22.6	26.4	16.8	25.7%	36.4%

Table-4 Parameter Estimation Results

		Coefficient	t-value
Population in the catchment area	b_1	0.00812	7.3
Number of students in the catchment area	b_2	0.439	2.56
Average distance of bus service	b_3	244	2.34
Log (Number of annual bus services per population in the catchment area)	b_4	4814	11.7
Constant term	b_0	-1754	-1.79
Number of samples		46	
R^2		0.872	

Table-5 Access/egress time delay analysis

Mode	Assumed value				Calculated value	
	Interval of bus stops / stations d [m]	Waiting time at signals t_b[min]	Operation speed V_d[km/h]	Standart deviation of delay time t_e[s/km]	Average access time to bus stops or stations t_e[min]	Average total trip to point A t[min]
1)Ordinary bus	300	0.00 or 0.88	13	23	4.50	33.2
2)Median bus lane	600	0.88	19	17	5.89	26.9
3)Subway	1200	1.50	33	0	8.31	20.2

Table-6 Reduction of the environmental load effect

Estimated Mode / Value	Operation speed [km/h]	Fuel consumption [km/L]	CO_2 emission [ton-CO_2/year]	NO_2 emission [ton-NO_2/year]
Median bus lane	19	3.58	1,520	11.2
Curbside bus lane	16	3.35	1,620	12.0
Ordinary bus	13	3.10	1,750	13.0

Table-7 Population, changes along the Key Route Bus

Population	1980	1990	2000
(1) Within 500m zone	81,930	84,073	81,108
(2) 500-1000m zone	111,936	109,774	104,064
(3) Others	169,084	186,172	184,259

Change rate of population	1980-1990	1990-2000
(1)500m zone	+2,62	-3.53
(2)500-1000m zone	-1.93	-5.20
(3Others	+10.1	-1.03