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A DEVELOPMENT OF PUNCTUALITY INDEX FOR BUS OPERATION

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Abstract: Punctuality of bus operation can be defined as "timely operation of buses according to their operation schedules." It is often considered as one of the important measures of bus operation reliability in evaluating bus operation performance from the viewpoint of bus users. Passenger waiting times are severely influenced by the punctuality of bus operations. However, there exist many situations that predetermined schedules cannot be met. In these cases, other definitions of punctuality should be given. This paper is to develop punctuality indexes of bus operation based on various bus operating situations. Bus operation data sampled from Seoul bus system were analyzed to calculate punctuality indexes for a number of bus routes. Then, bus operation punctuality was characterized by various operating conditions. Several interesting results were obtained and explained.

Key Words: Punctuality Index, Reliability, Service Measure, Transit Preferential Treatments, BMS (Bus operation Management System)

1. INTRODUCTION

Bus service level from the viewpoint of users can be evaluated with various measures. Unfortunately, most of them are qualitative and not measurable. Reliability is one of them. It is a very compound concept and can be described by several factors. Among which, punctuality of bus operation is a one of the quantitative measures of reliability. It can be defined as "timely operation of buses according to their operation schedules."

Punctuality has not been able to be obtained due to the lack of detailed data of bus operations, especially bus arrival times to each bus stop. Seoul Metropolitan City reshaped its bus route network and launched the BMS (Bus operation Management System) to improve the efficiency and level-of-service of bus operations for about 5,000 buses of 221 bus lines in June 2004. The purpose of this reform is to alleviate the traffic congestion problem of Seoul by revitalizing the bus ridership that has decreased since the operation of subways.

However, thanks to the introduction of BMS, detailed bus operation data became to be

available, such as bus arrival times at each bus stop for all the operations dispatched. From these data, punctuality of bus operation can be measured numerically. In BMS, buses are equipped with GPS receiver and send location and time data of bus operation via wireless data communication network.

TCQSM (Transit Capacity and Quality of Service Manual-2nd Edition, Transportation Research Board, Washington DC, 2003) suggests that the punctuality of bus operation, as a quantifiable measure of reliability, consists of on-time performance and the regularity of headway between successive bus vehicles. The manual states that on-time performance is the most widely used reliability measure that users can relate to. However, when vehicles run at frequent intervals, headway adherence becomes important to passengers, especially when vehicles arrive in bunches, causing overcrowding on the lead vehicle and longer waits than expected for the vehicles. In addition, buses in Seoul Metropolitan City run on headway base without exact time schedules of bus arrivals to bus stops. In this case, punctuality of bus operation can be defined as "evenness of headways between successive bus vehicles." Therefore, punctuality of bus arrivals should be defined in various ways according to operating situations.

The purpose of this paper is to define punctuality indexes for various bus operation environments, to gather bus operation data of Seoul bus system, and to analyze bus operation punctuality for various bus routes with different conditions of bus operation.

2. BASIC CONCEPTS

Table 1 shows various measures to evaluate quality of bus service suggested in TCQSM.

Table 1. Quality of Service Framework

	Service Measures		
	Transit Stops	Route Segments/Corridors	System
Availability	Frequency	Hours of service	Service coverage
Comfort & Convenience	Passenger load	Reliability - on-time performance - headway adherence	Transit-auto travel time

Source: Transit Capacity and Quality of Service Manual-2nd Edition, Transportation Research Board, Washington DC, 2003.

These measures are closely dependent upon each other. Among which, reliability is one of the most important measures in determining bus service level from the viewpoint of users as well as operators. The frequency, hours of service and service coverage that indicate the availability of bus service are not adequate indexes to represent service quality of bus operation in Seoul, because the headways of bus routes in Seoul are mostly short and most of the buses operate during more than 20 hours a day and are covering wide area. Therefore, each bus route does not have the salient points of difference in service availability.

On the other hand, passenger load factor and reliability that represent comfort and convenience of the service level of a bus route vary significantly, so they may be appropriate for evaluating service level of bus operation. The reliability can be evaluated by the data collected by BMS, while the estimation of the passenger load factor requires the data on passenger loading and unloading at each stop.

TCQSM suggests that the reliability can be evaluated by on-time performance and headway adherence. Headway adherence means the consistency or evenness of the interval between successive bus vehicles, number of missed trips and number of pass-ups and so on. Herein, it is assumed that every bus has its' own scheduled arrival times to all bus stops. However, number of missed operations and pass-ups can be considered as inadequate indexes when bus headways are very short, like in Seoul. Therefore, on-time performance and headway adherence remain appropriate in evaluating reliability of the bus operation.

However, when vehicles run frequently with short headways (e.g. 3~10 minutes), the meaning of the punctuality to their exact scheduled arrival times lessens because for short headways passengers are not aware of exact arrival times. Instead, they arrive at bus stops rather uniformly ignoring exact schedules. Furthermore, in very congested cities, scheduled dispatch headways are hardly maintained because of the shortage of bus fleet due to delayed bus operations. In these cases, evenly timed arrival of buses rather than exact schedule adhesion becomes more important in terms of the passenger waiting time. Consequently, punctuality of bus arrivals needs to be defined in various ways according to different operating situations.

In this paper, the punctuality is defined an umbrella concept that contains on-time performance and headway adherence and three kinds of punctuality indexes for a scheduled headway are suggested according to the definition of punctuality.

- Punctuality Indexes of a bus stop for a bus route

  - P1: Index indicating the magnitude of time gap between actual arrival time and scheduled arrival time (adherence)
  - P2: Index indicating the magnitude of time gap between actual headway and scheduled headway (regularity)
  - P3: Index indicating the magnitude of time gap between average headway of a day and each headway of successive buses (evenness)

Table 2. Punctuality Indexes

	P1	P2	P3
Punctuality Index	$P_1 = \frac{S_1^{\,2}}{h_t^{\,2}}$	$P_2 = \frac{S_2^{\,2}}{h_t^{\,2}}$	$P_3 = \frac{S_3^{\,2}}{(\bar{h})^2}$
Variables	$S_1^{\,2} = \frac{1}{I}\sum_{i=1}^{I}(t_i - \tau_i)^2$	$S_2^{\,2} = \frac{1}{I-1}\sum_{i=2}^{I}(h_i - h_t)^2$	$S_3^{\,2} = \frac{1}{I-1}\sum_{i=2}^{I}(h_i - \bar{h})^2$
	h_t : Scheduled headways I : Number of operations t_i : Actual arrival time of i-th bus operation τ_i : Scheduled arrival time of i-th bus operation $h_i = t_i - t_{i-1}$ $(i = 2,...,I)$: Actual headway of i-th bus operation $\bar{h} = \frac{1}{I-1}\sum_{i=2}^{I}(t_i - t_{i-1})$: Average actual headway of successive bus operations		

P1 is similar to the on-time performance suggested in TCQSM. But, P1 is the concept of variance that is not contained in on-time performance. P2 is a square of coefficient of variation that is the measure to estimate headway adherence suggested in TCQSM. P3 is a new index that is developed in this paper to consider the condition that the number of actual operations differs from that of scheduled number of operations.

P1 and P2 cannot be used if there is not a scheduled timetable and/or number of operations. The reason is that the actual arrival times should be compared with the scheduled arrival time and/or number of operations. In Seoul, most bus companies set up the times of only the first and last operating buses and, during the operation hours, dispatch buses according to scheduled headways only as far as buses to be dispatched are available. Strictly speaking, only P3 can be used as a punctuality index.

The punctuality index P3 of a bus route can be calculated by averaging punctuality indexes of bus stops of the route and the punctuality of bus-company also can be calculated by averaging the punctuality indexes of bus routes of the company.

If passengers arrive at the bus stops uniformly, the expected average waiting time of passengers considering the punctuality index is,

$$E\{W\} = \frac{1}{2}\bar{h}\left[1 + \left(\frac{S}{\bar{h}}\right)^2\right] = \frac{1}{2}\bar{h}\,(1+P) \tag{1}$$

The punctuality index is a factor that determines the expected average waiting time of passengers and is a statistically representative index to indicate the variation against the average.

$$P = \left(\frac{S}{\bar{h}}\right)^2 = (Coefficient\ of\ Variation)^2 \tag{2}$$

If all buses arrive at bus stops on time, the punctuality index P is zero and the expected average waiting time of passengers is a half of the average headway, which is the minimum value of expected average waiting time of passengers. It means that the larger the P value is, the less regular the headway is.

Table 3. Punctuality Index and Expected Average Waiting Time of Passengers

Punctuality Index	Expected average waiting time of passengers	Arrival type
P = 0	$E\{W\} = \frac{1}{2}\bar{h}$ (Minimum mean waiting time)	All buses arrive on time
P = 1	$E\{W\} = \bar{h}$ (The worst case practically)	Complete random arrival

If the distribution of bus arrival times is random, i.e. negative exponential distribution, the punctuality P of the bus stop becomes 1. In general, for any arrival time distribution, random arrival is known to be practically a maximum. Therefore, in case of bus arrival times it can be argued that P=1 is a maximum practically, the worst case.

Generally, passengers and peoples recognize that the punctuality is high if buses arrive at evenly. But P, which is the variation of the arrival time headways, is low if bus arrival time headways are even. So to consult the convenience of passengers and peoples, it is desirable to converse P into percentage value.
Punctuality index, P can be conversed into percentage value as follows.

$$P\% = [\text{Percentage value of Punctuality index P}] = (1 - P) \times 100 \quad (3)$$

3. DATA

In Seoul, four streets are facilitated with exclusive median bus-lanes; Cheonho, Dobong-Mia, Susaek-Seongsan and Gangnam streets, and about 5,000 buses among 7,868 buses are equipped with GPS receivers. The BMS center collects bus operation data, including bus ID, route ID, bus stop ID and arrival / departure time on stops, from GPS receivers equipped on buses.

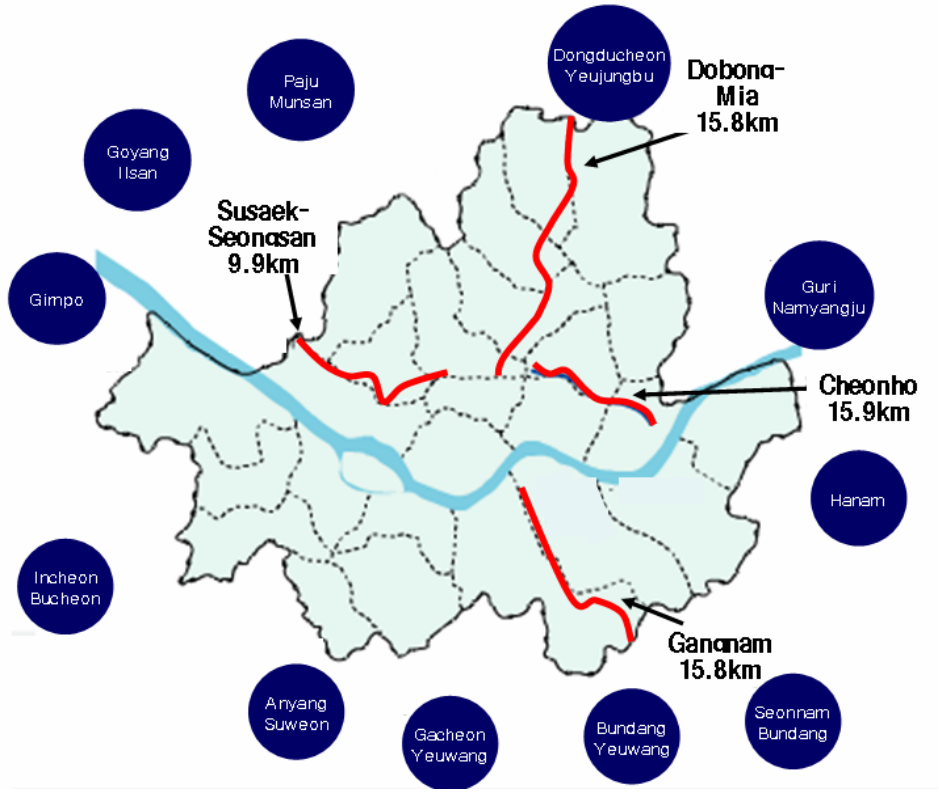

Figure 1. Exclusive median bus-lanes

Bus operation data of 22 routes, which operate on exclusive median bus-lane partly, were analyzed. The bus operation data were arrival times on bus stops during 5 days, from August 5 to August 9, 2004.

Table 5 shows the information of each bus route. The average length of the routes is about 45km and the number of bus stops is 73 on average. The distance between stops is from 5m to 9,137m long, 629m long on average. The average number of bus stops on exclusive median bus-lanes is 14, which is about 19% of the whole bus stops.

The buses equipped with GPS receivers send the data to BMS center. The data consists of bus ID, routes ID, bus stop ID and arrival/departure times on stops. The BMS center collects the real-time data received from buses, manage the bus operations of 221 routes, and analyze the operations of bus routes with statistical data.

A matrix of bus operations is filled in with bus operation data. The smoothing method is used to fill up blanks, missed data of bus operations in the matrix.

Table 4. Matrix of bus operations

	Descriptions
Arrival times	$\{a_{ij\,r}\}$: real arrival times at bus stops $\{a_{ij\,s}\}$: scheduled arrival times at bus stops
Variables	i : 1, ·····, I j : 1, ·····, J I: Number of operations (actually can be less than this) J: Number of stops

Table 5. Routes information

	Route Number	Route Length (m)	Stops	Distance of stops (m)			Exclusive Bus lane	
				Mean	Max.	Min.	Stops	Ratio (%)
Gangnam	400	33,253	40	831	3,578	300	17	42.5
	402	42,632	65	656	7,745	148	10	15.4
	420	37,365	64	584	2,432	118	8	12.5
Dobong-Mia	101	27,479	53	518	1,525	134	18	34.0
	102	30,398	59	515	1,510	120	13	22.0
	107	56,778	99	574	2,203	5	36	36.4
	141	54,050	86	628	4,603	92	24	27.9
	142	49,310	55	897	4,336	207	30	54.5
	151	47,303	73	648	9,137	70	14	19.2
	160	70,337	114	617	4,255	121	34	29.8
Susaek-Seongsan	163	60,514	109	555	4,173	98	7	6.4
	170	46,355	102	454	1,682	76	4	3.9
	171	40,397	62	652	2,410	107	7	11.3
	172	44,440	78	570	2,148	42	6	7.7
	272	45,899	87	528	2,431	153	10	11.5
	606	36,091	46	785	4,012	251	10	21.7
	700	28,709	48	598	2,199	167	24	50.0
	750	43,949	76	578	2,199	5	22	28.9
Cheonho	130	49,523	71	698	6,519	77	4	5.6
	145	43,432	78	557	1,927	150	2	2.6
	300	40,591	55	738	7,203	120	5	9.1
	370	59,212	89	665	7,203	120	4	4.5
Average		44,910	73	629	9,137 (Max.)	5 (Min.)	14.0	19.2

Table 6. Summary of Bus Operations

	Route Number	Hours of Service (mean)	Headway (mean)	Route travel time			Passenger (Pax/day)
				Mean	Max.	Min.	
Gangnam	400	20:06:38	17:19	1:29:15	2:33:24	0:56:16	5,249
	402	21:38:20	06:16	2:13:52	2:48:44	1:34:22	27,444
	420	21:03:26	09:08	2:00:02	2:59:09	1:17:07	15,270
Dobong-Mia	101	20:33:37	10:13	1:48:58	2:32:22	1:04:56	9,720
	102	21:08:29	11:59	1:52:00	2:55:20	1:09:59	7,744
	107	21:16:15	11:51	2:34:31	3:16:56	1:56:38	12,878
	141	21:02:35	08:02	2:53:33	3:39:56	2:06:43	17,610
	142	21:18:00	07:53	3:06:39	4:00:23	2:05:45	17,788
	151	21:11:53	07:58	2:55:27	4:09:13	1:47:07	25,401
	160	21:18:19	11:13	4:01:02	5:50:36	2:33:14	19,967
Susaek-Seongsan	163	21:16:23	08:31	3:14:06	4:40:34	1:59:21	12,078
	170	21:07:19	09:15	2:51:37	4:05:47	1:42:16	21,759
	171	20:43:17	07:45	2:53:56	3:41:16	1:33:57	19,164
	172	21:19:21	09:41	2:24:55	3:18:34	1:38:31	16,058
	272	20:32:19	06:08	2:19:54	3:03:08	1:37:39	30,641
	606	20:11:24	12:55	1:27:43	2:11:54	1:04:50	16,384
	700	19:15:25	12:38	1:17:42	1:53:36	0:52:33	3,390
	750	20:52:53	08:22	2:04:17	2:31:01	1:29:42	8,124
Cheonho	130	20:37:10	08:56	3:14:30	4:57:52	2:03:17	17,223
	145	20:51:26	09:03	2:10:46	3:05:13	1:24:52	10,204
	300	20:35:56	06:14	1:54:55	2:28:15	1:22:28	14,129
	370	21:12:04	09:16	3:08:08	3:48:30	2:18:26	12,958
Average		20:52:23	09:34	2:27:10	5:50:36 (Max.)	0:52:33 (Min.)	15,508

Table 6 shows the results of bus operations of during the 5 days, from August 5 to 9, 2004. The hours of service of the 22 routes is about 21 hours on average and the average headway of the routes is less than 10 minutes. The route travel time is about from 52 minutes to 6 hours long, about 2.5 hours on average.

4. PUNCTUALITY INDEX CALCULATION

The punctuality index P3 of each bus stop is computed with bus operation matrices and presented graphically in Figure 2. It was found that the punctuality index of each bus stop decreases as the bus move farther from the starting point.

The bold spots in the graphs mean the stops on exclusive median bus-lane. The variation of punctuality indexes of the stops on exclusive median bus-lane did not show a distinct difference. For some routes, if the distance between successive bus stops is comparatively long, the decrease of punctuality index is large. But, there is not a statistically significant relation between decrease of punctuality index and distance between stops, so that is not a

common phenomenon.

The punctuality index of the starting stop is mostly about 80% and that of the last stop is very variable from 20% to 80% in accordance with routes and days.

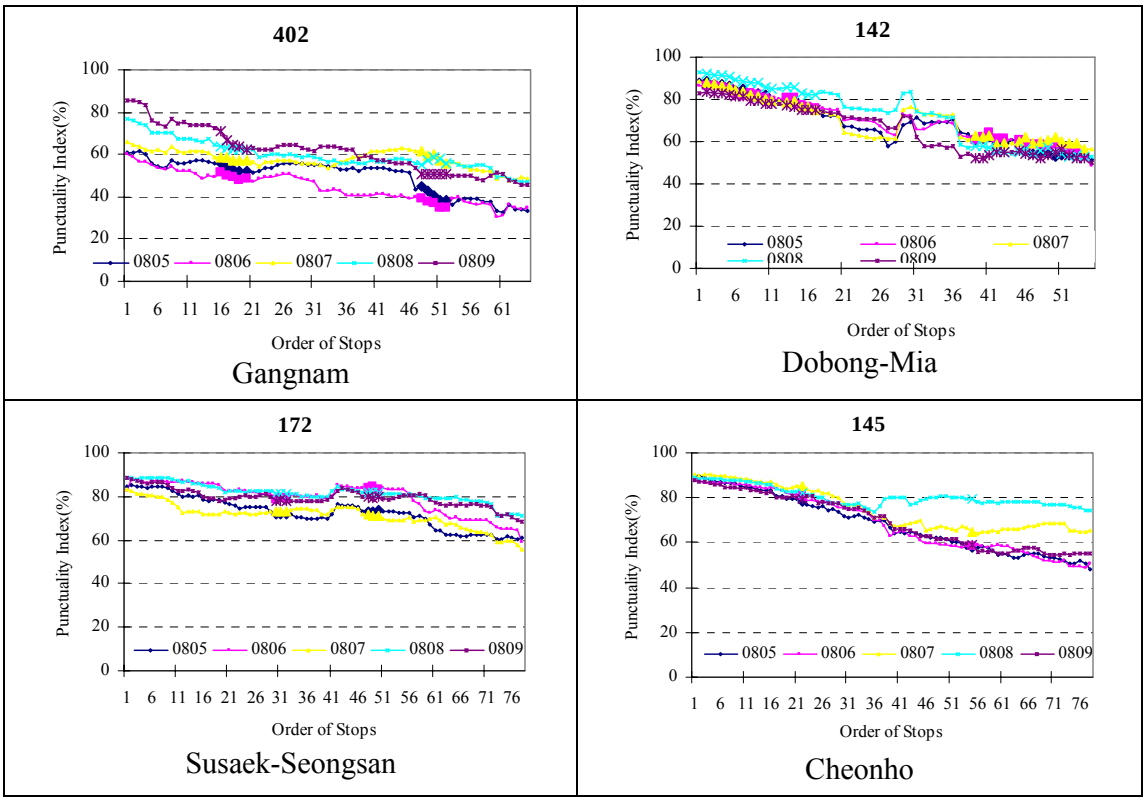

Figure 2. Examples of Punctuality Indexes of Each Bus Stop

Table 7 shows the average punctuality indexes of the bus routes for different days. The punctuality index ranges from 44.5 to 81.7% with 64.8% on average. The maximums of the mean and variance of punctuality index were obtained in Aug. 9.

Table 7. Summary of Punctuality Indexes of Bus Routes (%)

	Route Number	Aug. 5	Aug. 6	Aug. 7	Aug. 8	Aug. 9	Average
Gangnam	400	58.6	63.7	68.4	62.0	65.7	63.7
	402	45.0	44.5	57.8	59.8	61.8	54.7
	420	45.0	63.5	55.4	50.6	51.7	53.2
Dobong-Mia	101	67.7	67.0	72.8	75.5	68.1	70.2
	102	75.6	76.7	72.0	76.8	76.0	75.4
	107	73.8	63.3	55.7	66.3	66.0	65.0
	141	54.6	73.5	60.5	74.0	67.0	65.9
	142	68.7	69.7	69.9	72.6	66.2	69.4
	151	65.3	66.7	67.5	68.7	63.8	66.4
	160	60.3	61.6	62.6	58.0	52.1	58.9

Table 7. Summary of Punctuality Indexes of Bus Routes (%) (continued)

	Route Number	Aug. 5	Aug. 6	Aug. 7	Aug. 8	Aug. 9	Average
Seongsan	170	66.9	62.7	67.6	53.8	57.0	61.6
	171	52.6	56.8	60.0	69.5	62.0	60.2
	172	72.6	79.5	71.3	81.7	79.4	76.9
	272	59.0	60.8	67.7	78.5	63.2	65.8
	606	68.0	74.6	72.0	77.4	72.6	72.3
	700	79.2	74.3	73.4	73.0	52.0	70.4
	750	55.8	54.1	66.9	79.4	70.6	65.4
Cheonho	130	57.8	58.3	56.7	60.8	55.0	57.7
	145	68.2	68.5	74.9	80.5	69.3	72.3
	300	56.0	53.8	61.7	51.9	62.1	57.1
	370	76.9	79.3	79.4	81.4	80.0	79.4
Average		63.1	65.1	66.4	68.6	64.5	65.6
Max.		79.2	79.5	79.4	81.7	80.0	79.4
Min.		45.0	44.5	55.4	50.6	51.7	53.2
Variance		92.8	80.7	45.5	104.8	68.8	52.6

5. CHARACTERISTICS OF PUNCTUALITY INDEXES

Throughout the analysis, it was found that the punctuality of bus operation is affected by many factors including;

- Traffic conditions
- Road conditions
- Route length and number of stops
- Evenness of passenger demand
- Transit preferential treatments
- Operations control strategies
- Vehicle and staff availability
- Differences in operator driving skills

A lot of data are required to construct a model explaining the punctuality of bus operation because it is affected by many factors complicatedly. The punctuality estimation model could not be developed due to insufficient data. Instead, the relations between punctuality of bus operation and some effective factors are examined.

■ Effects of traffic conditions

The result of t-test (paired two sample for means, 5% significance level) shows the punctuality of August 8, Sunday, is statistically higher than that of the other days except August 7, Saturday. The punctuality of August 7 is not significantly different from that of August 8, because 5-work-day policy made work trips decreased on Saturday. It is consistent with common sense that traffic congestion aggravates the punctuality of bus operation.

Table 8. T-test: Paired Two Sample for Means

	Aug. 8 (SUN)	Aug. 5 (THU)	Aug. 6 (FRI)	Aug. 7 (SAT)	Aug. 9 (MON)
Mean	68.61	63.14	65.10	66.35	64.48
Variance	104.80	92.83	80.67	45.49	68.77
Observations	22	22	22	22	22
Pearson correlation		0.531	0.592	0.668	0.753
Hypothesized mean difference		0	0	0	0
d.f.		21	21	21	21
t stat.		2.661	1.880	**1.391**	2.862
P (T ≤ t) one-tail		0.007	0.037	**0.089**	0.005
t critical one-tail		1.721	1.721	**1.721**	1.721

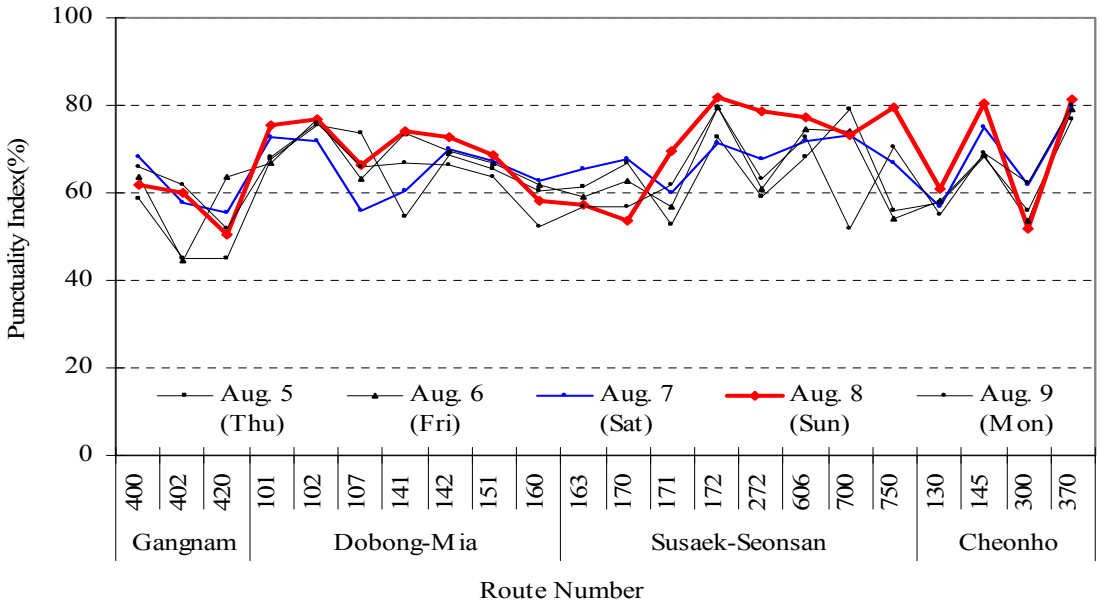

Figure 3. Daily Difference of Punctuality

■ Effects of bus occupancy

The effects of passenger occupancy could not be considered because necessary data was not available. Only daily number of passenger of each route was available. Generally, it seems like that the more the passengers were, the lower the punctuality index was.

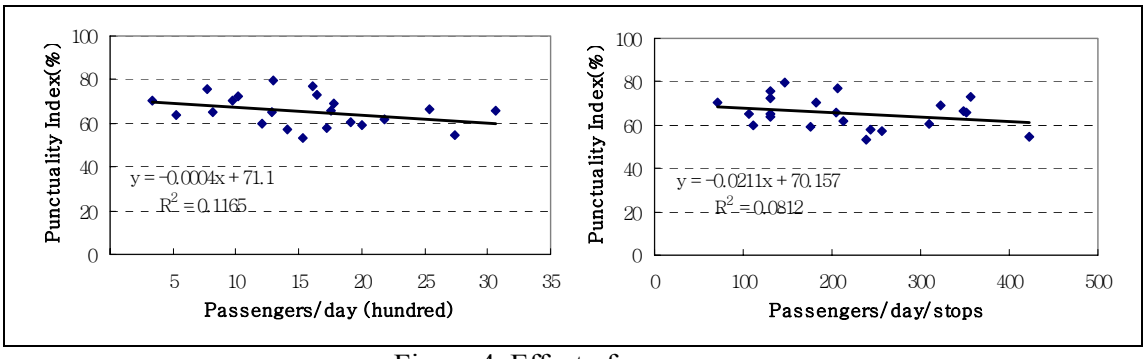

Figure 4. Effect of occupancy

■ Effects of route length and number of stops

The punctuality of bus operation decreases with the route length and number of stops. The longer the route travel time, which is strongly related with route length, is, the lower the punctuality index is. Moreover, the larger the coefficient of variation of route travel times is, the lower the punctuality index is. In other words, the larger the variation of traffic conditions is, the lower the punctuality of bus operation is.

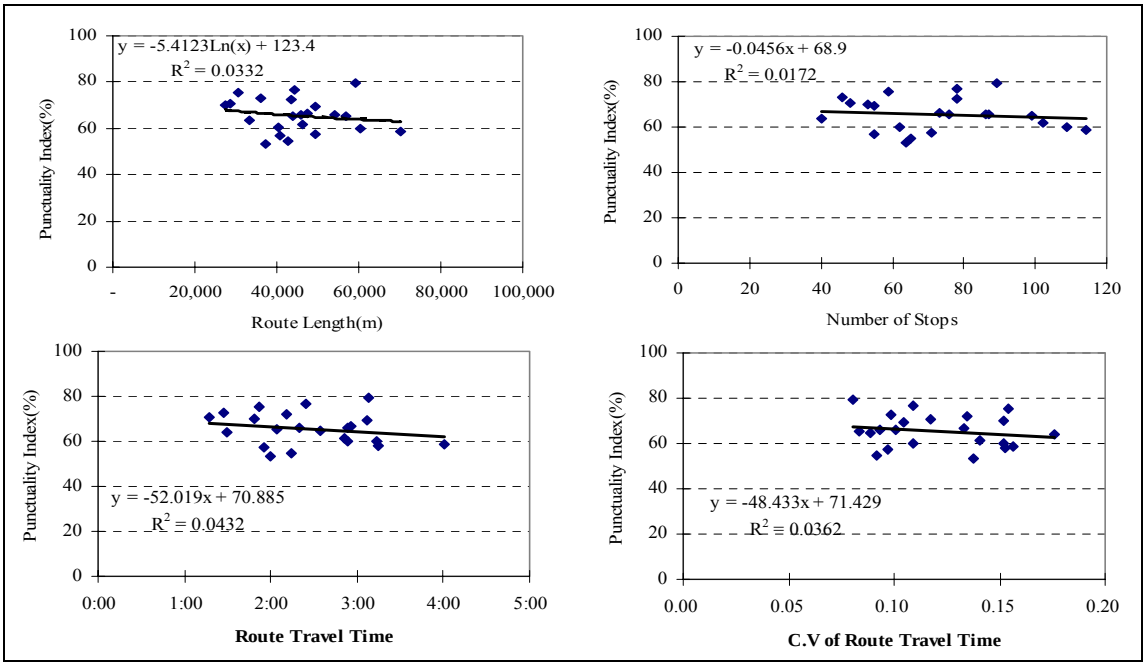

Figure 5. Punctuality Indexes vs. the Route Length, Number of Stops and Route Travel Time

■ Effects of transit preferential treatments

In order to evaluate the effect of exclusive median bus-lane, a before-and-after test is required to be performed. However, there was not any data collected before exclusive median bus-lane constructed. Instead, the variation of punctuality index was examined according to the ratios of the length and number of stops operating on exclusive median bus-lane to the whole route length and total number of stops.

As a result, the punctuality index seems to slightly increase with the ratio of stops on exclusive median bus-lane but it was not salient. Therefore, it could not be verified the effect of exclusive median bus-lane.

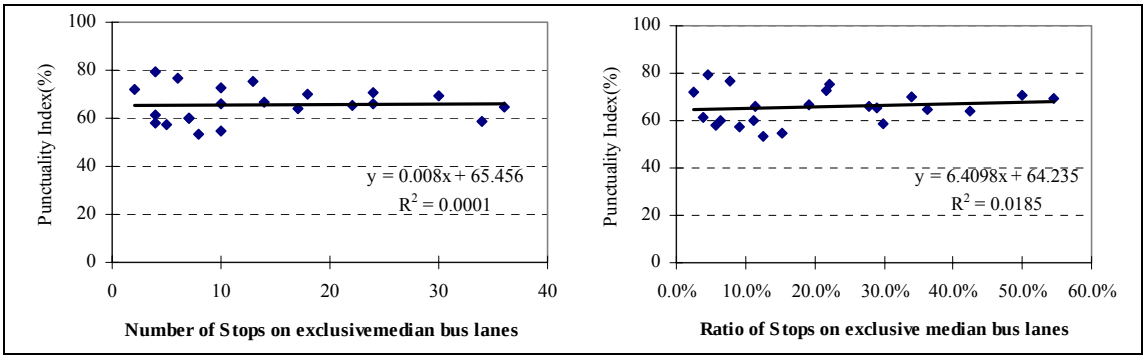

Figure 6. Effect of the Transit Preferential Treatments