

Analyzing Relationship between Weather and Variability of Travel Time of Bus

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Abstract: This paper aims to find out the relationship between the weather condition and the travel time of transit buses. It is assumed that travel time consists of ‘dwell time’ and ‘running time’. Grouping bus management system (BMS) data by weather and peak condition contributes to the calculation of the standard deviations and coefficients of variation (CV) of travel time and its elements for the segments of major median bus lanes. According to the analysis, running time is various in sunny days and dwell time in rainy days. CV of dwell time is larger in most cases and this shows which element is more easily affected by the weather condition. The results can help developing the bus operating system responding to the weather condition changing simultaneously.

Keywords: Median Bus Lane, Weather, Travel Time, Variability, Dwell Time, Running Time

1. INTRODUCTION

In 2004, new public transportation transfer policy was introduced that reduced the bus and metro fare dramatically, and Seoul metropolitan government spends a lot of budget subsidizing local transit bus companies. But it was not enough to change the modal share rate effectively. Furthermore, in spite of rising driving cost due to the oil price increasing, there are still many cars on the road in Seoul. This means owner drivers are not sensitive to the driving cost and supports the idea that relevant authorities should focus on policies such as the service quality of public transportation, not economic parts like indirect subsidies. According to the poll, people who do not ride public transportation complain about the inconveniences such as low reliability, uncomfortable transfer and longer travel time, not the fare.

Subway and bus are the most familiar modes to public and it can be proved by the modal share rate of Seoul (35.2% for subway and 27.8% for bus in 2009). The valuation basis of public transportation can be the travel time it takes, reliability, accessibility, convenience and other characteristics. Subway has high reliability because it has strict time schedule, but low accessibility due to high construction cost. On the other hand, bus line installation is easy and it results in high accessibility of bus. However, as its schedule is severely affected by on-road traffic situation, it cannot assure the accurate arrival time at bus stop. From this fact, attracting passenger car drivers to public transportation is possible by constructing more subway lines and stations for better accessibility or improving reliability of bus operation. Since former method has some problems such as incalculable costs and concern whether there is enough demand, it is reasonable to implement cheaper operational means like bus priority.

2. LITERATURE REVIEW

Kho *et al.* (2005) established some indices that evaluate the punctuality of bus operation. Focusing on the passenger waiting time at bus stop, indices included the difference between planned headway and real headway or the difference between planned arrival time and real arrival time. There should be a gap with this research because of different view. This paper is concerned about the travel time variation of certain sections.

Kang and Lee (2006) analyzed the effect of median arterial bus lane divided to change of number of users, vehicle speed and reliability. Also, they introduced various indices that can be used as indices evaluating reliability.

To check the transit bus line that has low reliability on users' stances, Oh *et al.* (2009) analyzed the reliability of 33 transit bus lines in Seoul on June 15th, 2005 during morning peak time using data envelopment analysis (DEA). Considering the headway error ratio per route and travel time error ratio per route, they established the reliability of route converted in a percentage. Finally, routes and sectors that were lack of reliability were distinguished.

Yang *et al.* (2011) calculated the benefit of reducing travel time of passengers by decreasing average waiting time that was used as a quantitative index of evaluating bus management system. They insisted that analyzing average waiting time should follow the comparison of scheduled headway and interval that the bus actually arrives at stop. It was suggested that using reliability index as the ground of judging how different these elements are. The square of coefficient of variation (CV) subtracted from 1 and converted into a percentage is the reliability index, "% reliability". This index used as a dependent variable in the reliability prediction model.

3. METHODOLOGY AND ASSUMPTION

3.1. Research Method and Range

In this research, bus travel time data was arranged by section and weather condition, and CV of them was calculated to observe the variability of travel time. This work helped look into how weather and time affect the variability. Furthermore, travel time is divided to dwell time and running time, and comparing their CV each other was possible. This process could reveal which one is more influential to variability of travel time.

Since it was impossible to conduct the research for the entire transit bus system of Seoul, some sample sections might be picked out. To minimize the error from the disturbance of external traffic flow, selecting median bus lanes was reasonable because the right-of-way of buses was guaranteed. The data was BMS data based on the arrival/departure records of transit buses at every stop in Seoul in April 2011. The data of G-Buses that are registered in Gyeonggi province and Metropolitan Buses that connects several cities in Seoul metropolitan area were not collected because of difference of BMS. From this, the bus lanes that are used by lots of G-buses and Metropolitan Buses could not be sampled. Next, it was advantageous to get enough data that entering and leaving transit bus line hardly changes along the sample section. By these 2 criteria, 8 sections were selected as samples. Table 1 shows their details and pictures captured from Google Maps (Figure 1 to 4) are attached. Gangnamdaero and Yongsanno had 2 sections of opposite direction with same length, but Cheonhodaero and Dongsomunno had different ones because of the imperfect installation of median bus lanes.

Table 1. Characteristic of sampled median bus lane sections in Seoul

Section Name	Start & End Point	Length (km)	No. of Stops	No. of Lines
Yongsanno NB	Garwol-dong ~ North Side of Hangangdaegyo(bridge)	3.34	5	13
Yongsanno SB				
Cheonhodaero WB	Children's Grand Park Back Gate (Achasan Stn.) ~ Sinseoldong Stn. & Seoul Folk Flea Market	6.44	10	3
Cheonhodaero EB	Dongdaemun-gu Office ~ Children's Grand Park Back Gate (Achasan Stn.)	4.99	7	
Dongsomunno NB	Samseongyo (Hanseong Univ. Stn.) ~ Wolgok New Town	2.67	4	11
Dongsomunno SB	Wolgok New Town ~Changgyeonggung	4.38	7	
Gangnamdaero NB	Sinnonhyeon Stn. ~ Korean Educational Development Institute	2.82	6	9
Gangnamdaero SB				8



Figure 1. Yongsanno

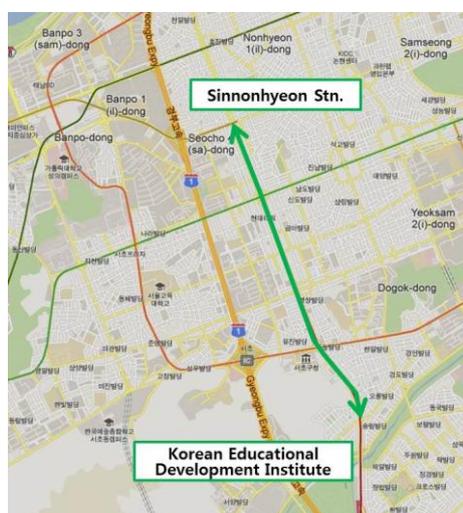


Figure 2. Gangnamdaero



Figure 3. Dongsomunno

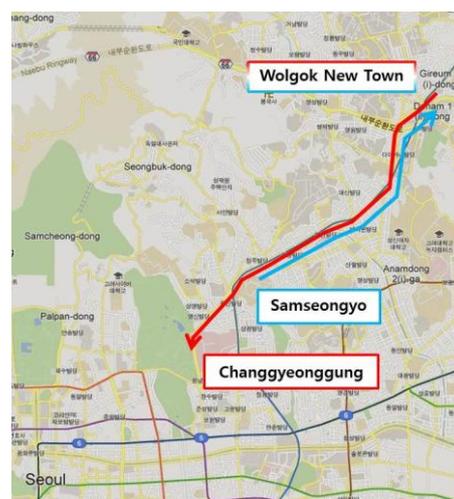


Figure 4. Cheonhodaero

3.2. Research Assumption and Factor Setting Up

There are so many factors that affects the travel time of transit bus, but weather (Day with or without rain) and time (Peak or Non-Peak time) were considered as influential factors and others are assumed that they were uniform in this research. To figure this out, data were

grouped to 4 cases like Table 2.

Table 2. Case division by weather and peak conditions

Conditions	Peak time	Non-Peak time
Day without rain	No-Rain-Peak (NRP)	No-Rain-Non-Peak (NRNP)
Day with rain	Rain-Peak (RP)	Rain-Non-Peak (RNP)

It was a simple task to gather past weather records from Korea Meteorological Administration (KMA) website because the database for them was provided. Peak time was 7:30~8:30 and Non-Peak time was 14:00~15:00 and these time periods came from the analysis of the travel patterns of transit bus by using BMS data.

By the way, travel time, which is the time that bus travels a certain section, t_{route} is consisted of running time, which is the time that bus moves among stops, t_{run} and dwell time, which is the time that bus stays at stops, t_{dwell} . The relationship among them can be expressed as Equation 1.

$$t_{route} = t_{run} + t_{dwell} \quad (1)$$

Former research analyzed the reliability including the variability of arrival time at stops compared to running time, based on the idea that users' satisfaction might be affected largely by arrival time. But, this paper focused not the users' satisfaction but variability of t_{route} , t_{run} , and t_{dwell} itself related to weather and peak conditions.

3.3. Coefficient of Variation (CV)

$$\text{Coefficient of Variation(CV)} = \frac{\sigma}{\mu} \quad (2)$$

where,

σ : standard deviation (S.D.)
 μ : mean

As Equation 2, CV is the standard deviation divided by mean. The smaller its value, the closer the data distributed near the mean. It is useful index because it is possible to compare data that comes from different kind or has different unit.

Because the necessity for checking index relative to mean rises, CV is used as a criterion of dispersion, not standard deviation. For example, section A that has 40 minutes of travel time and 5 minutes of standard deviation has less variation than section B that has 10 minutes of travel time and 3 minutes of standard deviation. Also, using CV is proper method that comparing among sample sections from different positions. Therefore, it is convincing that CV has advantages over standard deviation to analyze the variability.

4. RESEARCH RESULTS

4.1. External Condition Change

Table 3, 4, and 5 contains the mean, standard deviation and CV of bus travel time upon changes of weather and peak condition.

Table 3. Basic statistics for travel time in different weather condition on each section

Section	No-Rain			Rain			Difference of CV
	Mean	S.D.	CV	Mean	S.D.	CV	
Yongsanno NB	548.1	66.4	0.121	548.4	81.6	0.149	0.028
Yongsanno SB	606.9	47.4	0.078	607.4	46.4	0.076	0.002
Cheonhodaero WB	994.5	103.6	0.104	990.0	105.3	0.106	0.002
Cheonhodaero EB	777.1	72.3	0.093	782.9	65.8	0.084	0.009
Dongsomunno NB	479.6	64.6	0.135	499.0	63.3	0.127	0.008
Dongsomunno SB	966.8	123.9	0.128	961.2	154.0	0.160	0.032
Gangnamdaero NB	922.7	71.8	0.078	922.9	66.3	0.072	0.006
Gangnamdaero SB	1287.6	269.2	0.209	1204.1	209.8	0.174	0.035

Table 4. Basic statistics for travel time in different peak condition on each section

Section	No-Rain			Rain			Difference of CV
	Mean	S.D.	CV	Mean	S.D.	CV	
Yongsanno NB	561.8	75.3	0.134	524.9	62.6	0.119	0.015
Yongsanno SB	607.3	47.5	0.078	606.6	46.0	0.076	0.002
Cheonhodaero WB	1018.1	99.6	0.098	952.1	98.5	0.103	0.005
Cheonhodaero EB	781.6	71.7	0.092	775.9	66.4	0.086	0.006
Dongsomunno NB	475.7	66.6	0.140	507.2	56.3	0.111	0.029
Dongsomunno SB	1041.8	86.4	0.083	802.6	59.8	0.075	0.008
Gangnamdaero NB	940.8	69.7	0.074	889.8	56.1	0.063	0.011
Gangnamdaero SB	1368.7	229.3	0.168	1029.1	79.5	0.077	0.091

Table 5. CVs of travel time for 32 cases

Section	Yongsanno		Cheonhodaero		Dongsomunno		Gangnamdaero	
	NB	SB	NB	SB	NB	SB	NB	SB
NRP	0.119	0.079	0.099	0.098	0.141	0.077	0.08	0.178
NRNP	0.117	0.077	0.105	0.082	0.112	0.069	0.061	0.079
NP	0.155	0.077	0.095	0.078	0.136	0.086	0.06	0.14
RNP	0.121	0.074	0.103	0.09	0.107	0.079	0.065	0.076

4.2. Comparing Dwell Time and Running Time

Table 6 and 7 indicates the CV of dwell time and running time for 32 cases (2 weather conditions, 2 peak conditions and 8 sections).

Table 6. CVs for dwell time and running time on Yongsanno and Cheonhodaero

Cases	Yongsanno NB		Yongsanno SB		Cheondaero NB		Cheondaero SB	
	t_{dwell}	t_{run}	t_{dwell}	t_{run}	t_{dwell}	t_{run}	t_{dwell}	t_{run}
NRP	0.216	0.216	0.185	0.163	0.216	0.128	0.176	0.151
RP	0.253	0.021	0.178	0.169	0.175	0.129	0.219	0.157
NRNP	0.209	0.201	0.178	0.156	0.202	0.128	0.217	0.150
RNP	0.233	0.191	0.158	0.152	0.196	0.110	0.250	0.156

Table 7. CVs for dwell time and running time on Dongsomunno and Gangnamdaero

Cases	Dongsomunno NB		Dongsomunno SB		Gangnamdaero NB		Gangnamdaero SB	
	t_{dwell}	t_{run}	t_{dwell}	t_{run}	t_{dwell}	t_{run}	t_{dwell}	t_{run}
NRP	0.216	0.230	0.139	0.128	0.233	0.184	0.211	0.267
RP	0.221	0.210	0.146	0.138	0.268	0.190	0.197	0.210
NRNP	0.185	0.174	0.161	0.131	0.228	0.176	0.204	0.161
RNP	0.187	0.167	0.146	0.135	0.219	0.162	0.201	0.147

5. ANALYZING RESULTS

5.1. External Condition Change

Table 8. Conditions that recorded highest CV on each section

	Weather condition		Peak condition	
	No-Rain	Rain	Peak	Non-Peak
Section	Yongsanno SB	Yongsanno NB	Yongsanno NB	Cheonhodaero WB
	Cheonhodaero EB	Cheonhodaero WB	Yongsanno SB	
	Dongsomunno NB	Dongsomunno SB	Cheonhodaero EB	
	Gangnamdaero NB		Dongsomunno NB	
	Gangnamdaero SB		Dongsomunno SB	
			Gangnamdaero NB	
			Gangnamdaero SB	

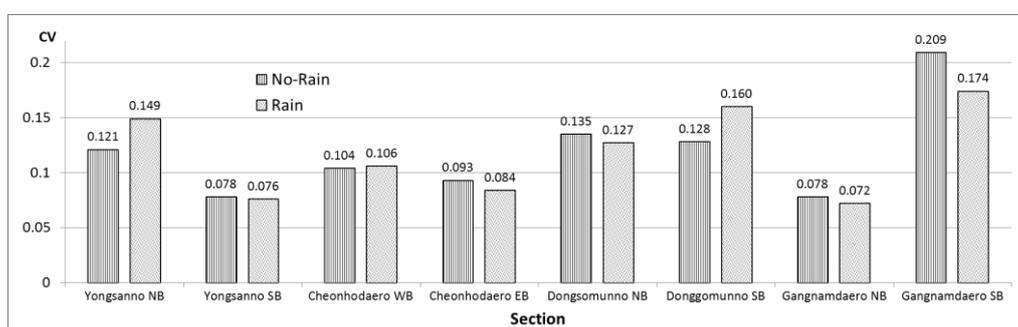


Figure 5. CV of travel time on sections at different weather condition

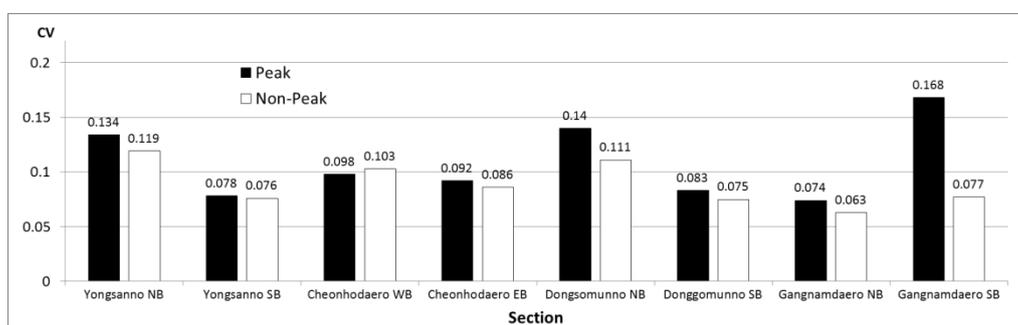


Figure 6. CV of travel time on sections at different peak condition

Table 8 is the result of analysis that compared CV of weather or peak condition on each section when the other condition is fixed. For weather condition, 5 sections have larger CV in No-Rain days and 3 sections in Rain days. For peak condition, only 1 section has larger CV in Non-Peak times. Figure 5 is the graph indicates the difference between weather conditions and Figure 6 between peak conditions. The mean difference of graph is 0.015 for weather and 0.021 for peak. From this result, it can be found that peak condition affects the variability more than weather condition does.

More detailed separation of conditions is shown in Table 5 considered 4 cases (NRP, NRNP, RP, and RNP). In Table 9, every section is connected with the external condition that has the largest CV. The number of sections belongs to each conditions are 5 sections for NRP, 2 for RP, and 1 for NRNP. This reflects the result of Table 8 that No-Rain and Peak condition affects the CV more. It is the most persuasive estimation that the most sections are included to NRP among cases because the largest demand occurs in NRP. In other words, CV is affected by the number of people getting on and off at stops.

The largest CV was 0.178 on Gangnamdaero SB at NRP and the smallest was 0.079 on Yongsanno SB at NRP. Especially, Gangnamdaero was the second shortest section but had the largest mean 1390.2 and standard deviation 247.0. This led to the conclusion that some improvement must be done on Gangnamdaero SB first if the authority can afford to do it.

Table 9. Maximum CV and its condition on each section

Section	Condition that indicates the largest CV	CV	Note
Yongsanno NB	Rain / Peak	0.155	
Yongsanno SB	No-Rain / Peak	0.079	
Cheonhodaero WB	No-Rain / Non-Peak	0.103	5 NRP
Cheonhodaero EB	No-Rain / Peak	0.098	2 RP
Dongsomunno NB	No-Rain / Peak	0.141	1 NRNP
Dongsomunno SB	Rain / Peak	0.086	
Gangnamdaero NB	No-Rain / Peak	0.080	
Gangnamdaero SB	No-Rain / Peak	0.178	

5.2. Comparing Dwell Time and Running Time

CV of dwell time and running time was calculated for 4 cases on 8 sections. CV of running time was larger only at Yongsanno NB NRP, Dongsomunno NB NRP, Gangnamdaero SB NRP and RP, and that of dwell time in 87.5% of 32 cases. It is evident that management of dwell time is more important than that of running time to reduce the variability of travel time.

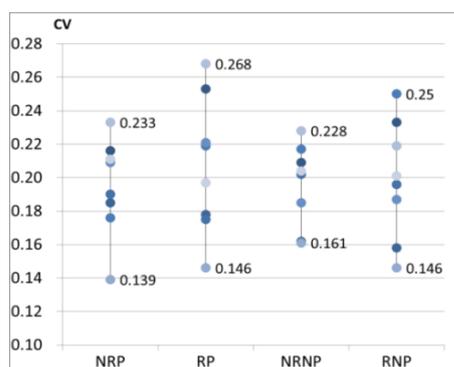


Figure 7. Distribution of CV of dwell time

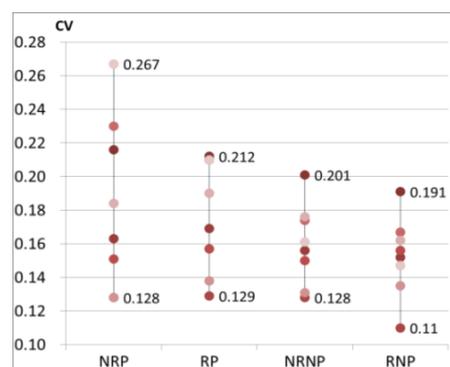


Figure 8. Distribution of CV of running time

By the way, change of CV of dwell time and running time are expressed in Figure 7 and 8 by changing the weather and peak condition. The numbers in the graph mean the maximum and minimum value. For running time, it is the largest at NRP and the smallest at NRNP. On the other hand, CV of dwell time had the most diverse value at RP and least at NRNP.

Table 10 contains the basic statistics of CV calculated at each 32 cases including range. Regardless of peak condition, the mean and standard deviation of CV were larger on No-Rain days than on Rain days. This supports the assertion that the variability of running time increases on No-Rain days and it can be explained by the limitation of driving environment. On Rain days, drivers must be careful because of some obstacles such as short sight distance and lower deceleration rate, but the environment would change on No-Rain days. They can drive in their own habit and these behaviors result in the high variability of running time.

Similarly approaching, the CV of dwell time had the largest differences at RP and smallest at NRNP. According to Table 14, mean of CV on Rain days is larger than that on No-Rain days regardless of peak condition. This means that the variability of dwell time increases on Rain days. This can be explained by the estimation that passengers need more time for getting on and off the bus at stops on Rain days.

Table 10. Basic statistics of CV of dwell and running time under each case

Cases	Running Time			Dwell Time		
	Range	Mean	S.D.	Range	Mean	S.D.
NRP	0.128 ~ 0.267	0.183	0.05	0.139 ~ 0.233	0.195	0.029
NP	0.129 ~ 0.212	0.177	0.034	0.146 ~ 0.268	0.207	0.041
NRNP	0.128 ~ 0.201	0.160	0.024	0.161 ~ 0.228	0.196	0.025
RNP	0.110 ~ 0.191	0.153	0.024	0.146 ~ 0.250	0.199	0.035

6. CONCLUSION AND FUTURE RESEARCH

If the CV of dwell time is large, it means that dwell time is unstable and changes a lot. It is same for the running time. From considered 32 cases, CV of dwell time was larger than that of running time in 28 cases. The guess inferred from this result is that most of the variability of bus travel time may come from the dwelling process at stops and decision makers should pay attention at stabilizing dwell time if they want lower variability of bus travel time. Particularly, running time is variable on No-Rain days and dwell time on Rain days. It is helpful for securing the reliability to establish the changeable operation plan focusing the elements of bus travel time according to weather condition.

There is a limitation that this research considered the dwell time and running time as simple values. In reality, they are not the simple values but the variables that must be explained by the complex model. For instance, the number of the signalized intersection and crosswalks, the width of bus door or the bus berth capacity may affects the running time and dwell time. In the future research, these elements can be considered as mathematical model that contains various factors as written above so that the quantitative analysis can be done. Then, it may results in optimum improvements of the reliability of bus travel time.

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