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A Methodology for Travel Time Reliability Benefit Measurement Considering Travel Time Variability

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ABSTRACT: *While travel time reliability benefit is direct benefit in cost-benefit analysis of transportation, the previous procedure of assessing investment impact on transport facility could not capture reliability effect of the road investment in Korea. This paper suggests a quantitative method of reliability and reliability benefit measurement method to be included in benefit items. The quantitative method of travel time reliability is provided to forecast travel time variability considering specific statistics such as the free flow travel time, average travel time, standard deviation of travel time, coefficient variation. This study measures travel time reliability benefit through case studies using actual analyzed road network and describes relationship between travel time savings benefit and travel time reliability benefit to show possibility to apply it to cost-benefit analysis. The results provides strong evidence that travel time reliability benefit is an important factor to consider traveler's convenience because reduced travel time variation caused by a proposed road investment allows them to make better use of their own time and save the cost of their buffer time. The results of this study are expected to be positive effects on proposed transportation investments and policies..*
KEYWORDS *-Reliability, Travel time variability, Standard deviation of travel time, buffer time*

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I INTRODUCTION

Decision-making for transportation infrastructure validity is decided by carrying out economic analysis in feasibility study or preliminary feasibility study. Benefit is divided into direct benefit and indirect benefit when economic analysis is progressing. For instance, direct benefit, which is generated to users using transportation facilities directly, contains comfort benefit, in-time rate, stability benefit and savings in travel time, traffic accident rate and in vehicle operating costs.

Benefit of transportation, for example reliability, comfort, safety and effectiveness improvements are excluded from procedure of assessing investment impact on transport facility because it was difficult to quantify.

Indirect benefit is a ripple effect occurring to everyone, regardless of using facilities, when road project is putting into operation.

In terms of environmental cost savings benefit belonging to indirect benefit, research on quantifying a degree of pollution, atmospheric and others is accumulated, thereby applying to cost-benefit analysis.

Though travel time reliability benefit has a marked socioeconomic effect on users compare with comfort benefit and stability benefit, it is still considered a qualitative index because of having difficulty to quantifying.

In existing economic analysis, benefit from reduced travel time is calculated average travel time using all OD pair have same travel time by user equilibrium traffic assignment model. So travel time and standard deviation of each traveler is not considered.

But Travelers should not arrive at expected arrival time because of traffic congestion like unpredictable weather and accidents. Therefore, travelers contain spare time added to average travel time before departure to satisfy reliability for travel time variability. Statistical range, buffer time and tardy trip are prime concerns to quantify travel time reliability.

This paper quantifies travel time reliability through studying mainly on statistical range which is related to free-speed travel time, average travel time, standard deviation of travel time and coefficient variation.

In addition, benefit is calculated by applying real road network, and establishing methodology for calculating benefit with using reliability time value studied by RAND EUROPE [1].

Calculated travel times, travel times, reduce the value of punctuality benefits of convenience and comparative analysis of the economic analysis can be applied if after reviewing the issue and suggest improvements

As a result of this study, the economic benefit analysis of travel times, punctuality of convenience items, including additional items to be prudent investment of public transport policy development projects and to prioritize investments to contribute to the objectives of this study is that it can be.

The range of this study divides into method for quantifying reliability and developing calculation of benefit. The first half of the study contemplates method for quantifying reliability through considering existing study, and develops calculation using reliability time-value rate. The second half calculate reliability benefit through applying developed calculation to real road network, and analyze importance of reliability benefit through comparing with existing travel time savings benefit.

II REVIEW

1. Travel time reliability

Travelers are aware that traffic congestion is a matter of course in urban area. Because travelers are accustomed to congestion in this city, they consider buffer time add to average travel time. Travelers also consider specific delay to arrive on time. Most of the traveler remember travel time fluctuate rather than fixed for a year. Also, they think travel time is different day by day because of unexpected delay. So, freight forwarders, who have a close relationship between money and travel time, always consider variance of travel time. (FHWA : Federal Highway Administration [2]) A yearly traveler's travel time distribution is as below.

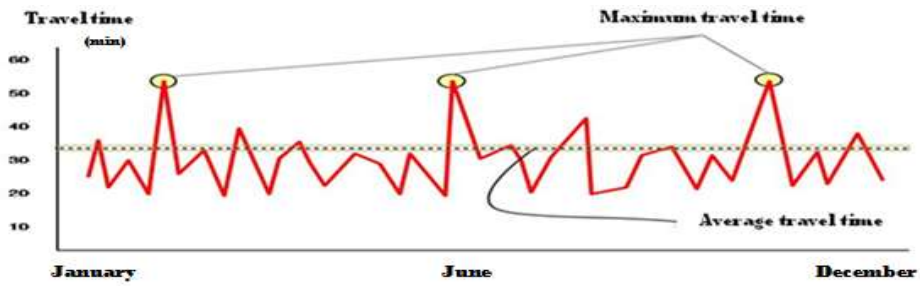

Fig 1. Travel time distribution concept

2. Buffer time

Traveler should be consider spare travel time to arrive on time. Buffer time means spare time adding to planning time when they schedule on time traffic. This spare time can explain about unpredicted delay. .

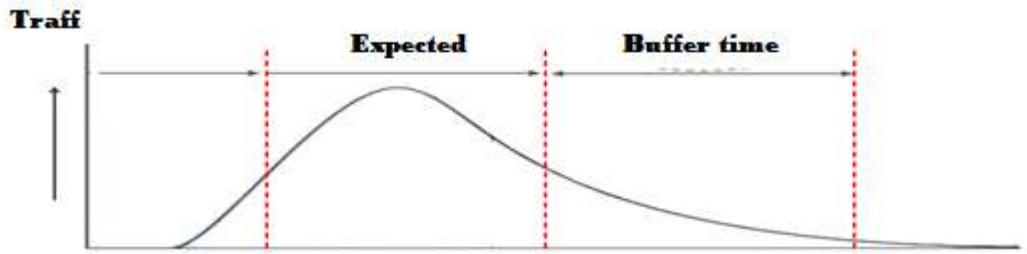

Fig 2. Travel time reliability concept

FHWA suggests rate of time for considering extra time to add to average travel time by using buffer time index. Buffer time index explains reliability go bad as its value increases. Definition of buffer time is well explained through in minutes per mile rather than average travel time. FHWA uses example for explaining buffer time index briefly. Example is as follows.

If average travel time is 20 minutes and buffer time index is 40%, extra buffer time is defined 8 minutes. Travelers should consider 29 minutes to arrive on time at least 95% travel time. This method easily calculates actual travel time. And its information includes weights of travel time according to each link. Buffer time index

is relatively similar to average travel time. Buffer time index equation is calculated by dividing buffer time by average travel time as below.

$$BI = \frac{PT - ATT}{ATT} \quad (2)$$

Where, BI is buffer time Index, PT is Planning Time, and ATT is Average Travel Time

3. Planning time

Planning time is a total travel time including buffer time, and planning time index means a total travel time for making plan including proper buffer time. Planning time represents morning and evening peak characteristic, and it has a higher value than travel time graph value. Travel time index is comprised in average value in travel condition. But empty space in planning time index and travel time index means buffer time index. Planning time index graph is as below.

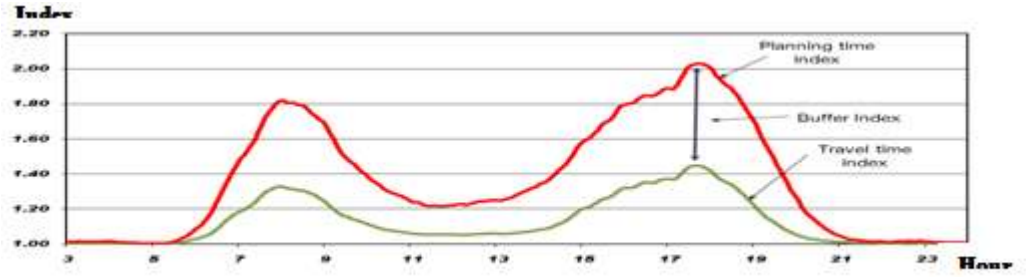

Fig 3. Travel time index

95% travel time is used with buffer time index. 85%, 90% even 99% travel time can be used according to level of reliability. For example, low percentage travel time is used when we calculates reliability for less important travel due to the nature of travel.

Practical problems can occur when planning time is estimated by using an existing OD. Therefore, OD for estimating planning time is needed to establish separately. Also, if method for calculating ratio of planning time to exist average travel time is suggested, it is judged that there is no problem for quantifying variance of travel time.

4. Value of Reliability

Lam and Small [3] suggests ratio of value of time to value of reliability to estimate value of reliability. Their study measures VOT and VOR at once through collecting actual travel behavior by using loop detector. Random utility function about value of reliability assumes travelers choose route 1 or 2, and it is as below.

$$U_{in} = V_i(t_{in}, v_{in}, c_{in}, x_n) + \varepsilon_{in} \quad (3)$$

Where, each of t, v and c represents travel time, variance of travel time and quantification of cost. x is a observable socioeconomic vector or other characteristics. And ε is a extreme value as distribution of random utility components. These assumptions guided by the path selection model are defined equation of value of travel time and reliability.

$$VOT_n = (\partial V / \partial t_n)/(\partial V / \partial c_n) \quad (4)$$

$$VOR_n = (\partial V / \partial v_n)/(\partial V / \partial c_n) \quad (5)$$

This ratio of reliability value to travel time value is calculated 1.39, and still studying on reliability is going on. Also, RAND EUROPE[1] operates SP research on travel time of passenger car in Netherland to estimate reliability. Value of travel time reliability is estimated as ratio of value of travel time by analysis standard deviation of travel time distribution, 80% travel time, 90% travel time, average travel time, and unpredicted delay. The ratio of reliability time value is estimated 1.3 times larger than travel time value.

This study investigated the SP travel times, travel time reliability value measured by the ratio does not exist, the measured value of reliability time ratio (1.39) from Terence C. Lam and Kenneth A. Small would not reflect more than the current traffic situation proposed by the RAND EUROPE[1] punctuality time value (1.3)

This study, ratio of reliability value measured by SP investigation does not exist. Terence C. Lam and Kenneth A. Small measured on the time value ratio (1.39) proposed by the RAND EUROPE[1] punctuality time value (1.3) than the currently considering the traffic situation would not have done it is considered. Therefore, this

paper tentatively uses the ratio of reliability value, which was suggested by RAND EUROPE[1], until it is suitable for Korea.

5. Standard deviation of travel time

It is needed to know variation of travel time distribution for calculating reliability benefit of transportation facility enterprise. Travel time is not fixed factor if there isn't particular event because it is distributed differently day after day in traffic congestion. Also, Travel time distribution appears distinctively when traffic congestion increase. So, many travelers have to aware buffer time to arrive destination on time. Traveler's equation of travel time deviation is required to utilize data in EMME/2, traffic assignment software. This paper suggests as (eq. 6) that standard deviation of travel time can be used to utilize cost-benefit analysis by analysis actual travel time and congestion in according to Stockholm's congestion fee policy.

$$\sigma = t\exp(-\alpha + \beta(\frac{t}{T}) - \gamma(\frac{t}{T})^3) \qquad (6)$$

σ is a standard deviation of travel time, t is average travel time of each link and parameter α equals -0.4, β equals 1.23 and γ equals -0.036.

Eliasson[4] reviews actual travel time distribution to modify existing standard deviation of travel time equation. The distribution of travel time when traffic congestion is low, the asymmetry appears as if the severity of traffic congestion, such as a normal distribution were analyzed appeared symmetrically., and symmetric like normal distribution when traffic congestion was high. When he passes the time variability analysis to analyze the situation, primarily because of traffic congestion, travel time distribution determines the symmetry was achieved and to modify the existing formula was. Modified formula was suggested in consideration of form of queue, length of link, type of road, and degree of congestion.

$$\sigma = const \times t^{12}\sqrt{\frac{t}{T} - 1} \qquad (7)$$

In regard to Const, it makes calculation easier replacing parameter of existing formula.Also, this formula shows travel time variability is 0 when degree of congestion is low, and it represents square of 1.7 when congestion is highest.

6. Travel time coefficient of variation

England's Department of Transportation revalues existing travel time variability by analysis travel time data collected in recent year to predict travel time variability in urban area. [5]This research suggests the equation of travel time variability factor, and analyses relation between travel time, degree of traffic congestion and length of link through single link analysis and multi link analysis in the ten cities of England.

$$CV_t = \alpha CI_t^B d^\delta \qquad (8)$$

Where, CV_t: Coefficient of variation of travel time slide t

CI_t : Congestion index of travel time slide t

d :Distance(km)

α : Constant/Scale Factor(0.16)

β : Elastic factor on congestion index(1.02)

δ : Elastic factor on distance(-0.39)

And $CI_t = t/T$

Where, t : Travel time

t : Free speed travel time

This study definitely confirms relation between β and length of link in variability factor formula, but it doesn't confirm relation between α and length of link. Department of Transportation of England will show definitely relation between two parameters by analysis length of link and influence of and in next research.

III DEVELOPING EQUATION FOR TRAVEL TIME RELIABILITY

This study reviews travel time indexes, time value, and variability. It is considered that there are not enough data of travel, plan, and buffer time in order to use travel time indexes in purpose of calculating equation for

travel time reliability. Therefore, we could get a travel time standard deviation formula regarding the travel time variability and with using that formula, it is developed the equation for travel time reliability.

1. Equation for calculating standard deviation of travel time

There are formulas about travel time variability. One is the equation of standard deviation of travel time showed by Eliasson in 2007 [6~7] and the other is the equation of coefficient of variations. In this paper, It is used the latter one in order to develop the formula of standard deviation of travel time of each link because there was a problem that defining a constant was not possible in the current level. Statistically, coefficient of variations is as following:

$$CV = \frac{\sqrt{\sigma^2}}{\overline{X}} \qquad (9)$$

Where, σ : Standard deviation

$\overline{X}$: Average.

In the formula 9, It is regarded the σ as the standard deviation of travel time of each link, $\overline{X}$ as the average of travel time of each link and substituted those in the formula 8 in order to develop the formula 10, which is the formula of standard deviation of travel time of each link to calculate the travel time reliability.

$$\alpha_l = 0.16 t_l d_l^{-0.39} \left(\frac{t_l}{T_l}\right)^{1.02} \qquad (10)$$

Where, α_l : Standard deviation of link l travel time

t_l : Average travel time of link l

T_l: Free speed travel time of link l

In the formula 10, α_l means travel time standard deviation of Link l, t_l means the average travel time of Link l, T_l means the travel time of Link l in free speed, and d_l means the length of Link lin Km.

2. Equation for travel time reliability

In this paper, it is defined that travel time reliability improves after enforcing traffic control devices with the decrease of the range of fluctuation of travel time. And the distribution of travel time of passengers is showed as a normal distribution and improves the reliability due to the reduction of travel time and the decrease of standard deviation.

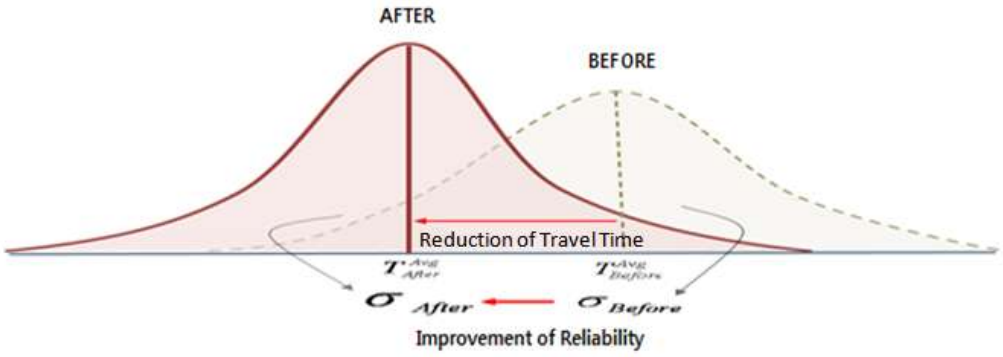

Fig4. The key map of calculating travel time reliability

In the picture 4, T_{before}^{avg} and T_{after}^{avg} mean the average of travel time before and after of the enforcement of traffic control devices α_{before} and α_{after} mean the standard deviation of travel time before and after of it.

The benefit of travel time reduction is calculated based on the link volume of traffic. In preliminary feasibility study, total travel time on the road is calculated with multiplication of link travel time and vehicle's quantity of the volume of traffic in a direct influence area resulted from allocating traffic. In order to calculate travel time reliability, calculating the change of cost of travel time variability with considering differences of

travel time standard deviations of link volume and calculating the benefit with considering the ratio of travel time reliability value need to be done. Fig. 11 is the equation for travel time reliability.

$$VORS = VOR_{before} - VOR_{after} \quad (11)$$

$$VOR = \left[\sum_{t} \sum_{k-1}^{3} TTV_{kl} \times p_k \times Q_{kl} \right] \times VORR \times 365$$

Where, TTV_{kl} : Standard deviation of link travel time by vehicle type

$VORR$: Reliability ratio of travel time value by vehicle type

p_k : Travel time value by vehicle type

Q_{kl} : Traffic volume by vehicle type of link l

k : Vehicle type(1 : auto, 2 : bus, 3 : truck)

IV. EQUATION FOR TRAVEL TIME RELIABILITY AND COMPARISON AND ANALYSIS

1. The result of analysis

In order to maintain consistency with existing studies, we used each OD and networks that were used from each study, and analyzed networks with EMME/2. Also, it is used existing travel time value to be consistent in economic feasibility.

Table 1. Benefit comparison in case of

Classification		2014year	2016year	2021year	2026year	2031year
Expressway	Reduce travel time benefits	114.9	145.9	178.4	216.6	255.4
	Reliability travel time benefit	16.9	22.0	27.5	34.4	42.4
	Ratio	14.7%	15.1%	15.4%	15.9%	16.6%
National Highway	Reduce travel time benefits	114.9	145.9	178.4	216.6	255.4
	Reliability travel time benefit	16.9	22.0	27.5	34.4	42.4
	Ratio	14.7%	15.1%	15.4%	15.9%	16.6%

West Coast Expressway and National highway

1.1 Extension of Expressway

It is compared the benefit of reduction of travel time in preliminary feasibility study of the extension of West Coast Expressway (AnsanI.C~Ilgic I.C) and the benefit of travel time reliability in this study. The benefit of travel time reliability based on travel time standard deviation is showed on table 1.

It is showed that the benefits of travel time reliability is calculated as 14% to 16% of the existing benefits of reduction of travel time reliability. This is because West Coast Expressway (AnsanI.C~Ilgic I.C) section is so crowded that travelers' reduction time of buffer time is huge. This is because of reduction of travel time and decrease of variability of travel time due to relief of the traffic jam by extension of roads.

1.2 Extension of National Highway

It is compared the benefit of reduction of travel time in validity re-verification study of the extension of National Highway 5 (Hwaone-Okpo) and the benefit of travel time reliability in this study. The benefit of travel time reliability based on travel time standard deviation is showed on table 1.

It is showed that the benefits of travel time reliability is calculated as 12% to 13% of the existing benefits of reduction of travel time reliability. This is because National Highway 5 (Hwaone-Okpo) section is less crowded than West Coast Expressway (AnsanI.C~Ilgic I.C) section that travelers' reduction time of buffer time is smaller. The extension of National Highway 5 (Hwaone-Okpo) improved travel time reliability since Fig. 10 shows the benefit of travel time reliability increases similar to increase of the benefit of travel time reduction. This is because of reduction of travel time and decrease of variability of travel time due to relief of the traffic jam by extension of roads.

2. Compare of the case study result

In this study, it is calculated the benefits of travel time reliability through analysis scenario and analyzed the features of the benefits of travel time reliability. It is analyzed that the benefits of travel time reliability are 14%~16% of the benefits of travel time reduction in the West Coast Expressway (AnsanI.C~Ilgic I.C) extension and 12%~13% in the National Highway 5 (Hwaone-Okpo) extension. Also, I showed the differences of benefits of travel time reliability among different roads by comparing expressway and national

highway. Even though West Coast Expressway is Continuous Flow, its ratio of the benefits of travel time reliability is higher than National Highway 5 as its traffic congestion is severe.

V. CONCLUSION

In this study, the result showed travel time standard deviations macroscopically from EMME/2, traffic allocating software, with using a formula that can calculate travel time standard deviations based on the theory of travel time variability. The benefit of travel time reliability, which means the reduction of travelers' travel time variability, is calculated by applying travel time standard deviations and time value of travel time reliability to existing equation of the benefits of travel time reduction.

In this study, It is used West Coast Expressway to preliminary feasibility study, National Highway 5 validity re-verification study, OD and networks in order to calculate the benefits of travel time reliability and analyzed the features of the benefits of travel time reliability with the comparison of the benefits of travel time reduction. It is analyzed that the benefits of travel time reliability is proportional to the benefits of travel time reduction. Also, the benefits of reliability have close relation to traffic congestion and the benefits are bigger in more congested roads.

In the result of this study, the benefits of travel time reliability have been analyzed to be produced from the reduction of free time resulted from travelers' travel time variability reduction. The benefits also were analyzed to be an important factor among benefit of investment of transportation facilities in comparison to the benefits of travel time reduction. Also, it is expected that there will be positive effects on establishing a prudent investment policy for development of transportation facilities by being able to calculate the benefits of travel time reliability through this study.

This study will be significant in terms of trying to calculate the benefits of travel time reliability that could have not been calculated, but since there were no substantial researches on travelers' travel time variability, it will be needed to be improved such as a formula of travel time standard deviations, parameters, or the values of travel time reliability. Also, since there have been no possible ways to calculate the benefits of travel time reliability for rails, the researches on travel time reliability, variability indexes, or the value of travel time reliability are needed to be produced in order to establish a formula for calculating proper benefits of travel time reliability.

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