

Presumption of Travel Time by a BPR Function That Considers The Vertical Inclination on The Road

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Abstract: In today's road maintenance, the traffic distribution in short periods of time such as in the morning or evening peak is necessary to determine. The aim of this study is to propose the link performance function (BPR function) that focuses on such short lengths of time and the improvement of the accuracy of the BPR function that considers the vertical inclination on the road. The traffic condition was measured in the morning and evening. The relationship of actual traffic with the vertical inclination on the road was clarified by using the probe car. In addition, the root mean square rate fell by 69% in comparison with the previous estimation method by using the BPR function that considered the vertical inclination on the road, and the accuracy of reproducibility.

Key Words: *BPR function, Travel speed, Vertical inclination, Road capacity*

1. INTRODUCTION

1.1 Background of research

The Japanese Islands are long and slender from the north to south, and the center part of the country has a mountain range. Therefore most of the population and property is concentrated in small areas of plain regions. Therefore, a lot of roads go through mountainous areas. The road network plan, which uses traffic distribution calculations, is applied to today's road traffic planning in such because of the geography of the area. When the traffic is distributed, the accuracy of the link performance function is extremely important to improve. In order to try to accurately improve the link performance function in the mountainous areas, the present study presumes the constant nature of the BPR function which frequently make use of traffic distribution calculations based on the traffic investigation data and the vertical inclination on the road. The location for the research is on the route 8 Yahata IC-Kiba IC($L=6.06\text{km}$) section of Ishikawa Prefecture Komatsu city shown in Figure 1, and the travel time is estimated from traffic and the travel speed investigation result at the morning and evening peak in the present study according to the vertical inclination.

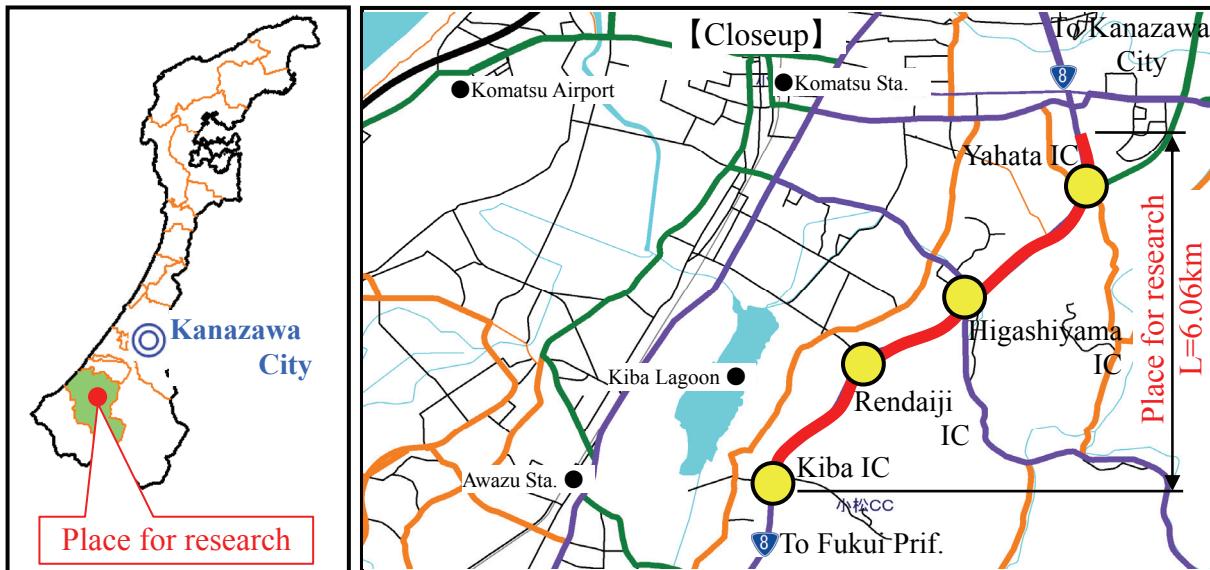


Figure 1 Location map of research

1.2 Arrangement of existing research

1.2.1 Research on bottleneck traffic capacity

A lot of research on the bottleneck traffic capacity has been conducted in the past and it continues to be a subject of interest for several studies today. Cho et al. said that the bottleneck traffic capacity (After it gets congested) is 2,200-2,700/h/2lane based on the traffic conditions of the Chuo and Tomei expressways. Ooguchi et al. investigates the influence of the sag part on the visibility according to a plane radius, the vertical curve length, and the inclination difference of the sag section. Furthermore it has been enumerated that the visibility decreases by the existence of the regular and long vertical curve. Yoshikawa et al. analyzed the relationship between the bottleneck traffic capacity and the road structure in the tentative two lane road section. Moreover when congestion occurs, traffic is influenced by the length of the vertical inclination on the downstream side of the bottleneck, and the processing traffic after congestion will possibly be highly influenced by the vertical inclination on the upstream side of the bottleneck. Yoshiike et al. made assumptions about the driver's car, which follows the models focused on the vertical inclination on the road by the CG of a driving simulator, and estimated the argument value of the inclination model based on this. Iwasaki et al. analyzed the traffic flow during and just before congestion occurs, and the road capacity under congestion decreases according to the lengths of the continuance time.

1.2.2 Research on parameter of link performance function

A lot of research on the constant presumption of the BPR function has been conducted. Mizokami et al. theoretically derives the BPR function of each day from the function of time BPR, and presumes $\alpha = 0.96$ and $\beta = 1.20$ and, proposes a practicable technique for setting the link cost function of the day to the actual road section according to the conversion coefficient in which the roadside condition is assumed to be a factor. Nishitani et al. collected and analyzed traffic and the average travel speed. Also they found the influence of the running time to be predominant when the congestion level is about 1.0 and, pointed out that the contribution rate of β rises as the congestion level rises. Yoshida et al. propose a method of giving the setting of the road segmentation that considers the roadside condition and delay time in the signal intersection besides the BPR function etc based on the road traffic census

data in 1995 and 1998. Moreover, the prediction accuracy is able to be improved by considering not only the possible traffic capacity of the single road part but also the capacity of an intersection in the urban area where the intersection density is high.

Table 1 shows the main, existing research example of the representative.

Table 1 Example of parameter of BPR function

	A	β	Free travel time (to)	Adoption road capacity
Kougami, Matsui et al	0.96	1.20	Reciprocal at restriction speed	Road capacity of the day
Nishitani, Asakura et al	0.6~1.0	1.5~3.0	to=80~98sec/km	
Matsui, Yamada	0.41~0.54	2.2~3.3	0.72~2.13 min/km	Road capacity of the day
Yoshida, Harada	0.10~0.74	1.1~3.7	35.1~92.1km/h	Road capacity of the time
Suzuki et al, Inoue et al	0.3~1.0	2.0~10	Function of restriction speed and signal intersection density	Road capacity of the day
Japan Society of Civil Engineers	0.48	2.82	Reciprocal at design speed	Road capacity of the day

1.2.3 Research on traffic distribution for the hourly traffic distribution for an entire day

To analyze a traffic jam in a section of a city during the morning and evening, it is improper to use a static traffic distribution for an entire day, and the traffic distribution for every hour is needed. Therefore, research on the hourly traffic distribution has been conducted. The research has shifted towards the development of a method for distributing traffic that uses the link performance function according to the time zone afterwards through the method for the proportional distribution and by dividing the link traffic. The OD traffic volume was adopted for the research on traffic according to the initial time zone.

Suzuki *et al.* proposed that the OD traffic volume according to the start time and to consider the time fluctuation by setting a suitable interval time as a distribution method according to the time zone, and moving these one by one timewise as some blocks. Fujita *et al.* considered the temporal continuity in the time zone mutually adjoined, proposes the model (OD revised statutes) and the model, which corrects the volume by the link traffic level in each route(link correction method) corrected at the link traffic level in each route and the OD traffic volume level. Fujita *et al.* afterwards proposed the link performance function that combines the congestion delay time function with the statistical, free running time function. Furthermore, they clarified the congestion phenomenon faithfully by improving the link correction method. Yoshida *et al.* examines a semi-dynamic apportion model according to the time zone, the type of vehicle based on the multiple user stochastic equilibrium model and the OD revised statutes.

Yagi *et al.* estimates the link cost function of the BPR and Davidson type by the maximum likelihood estimation method which uses the presumption of the link performance function to obtain the road traffic census data. Next they do traffic distribution according to time zone by using the road network data of the existing metropolitan area, and confirm the utility. Moreover, Ito *et al.* constructed the probabilistic user balance apportion model according to time zone to consider the large-sized car specifying it. Moreover, they verify the current state reproducibility, practicality, etc. through application to the Nagoya metropolitan area road

network. As a result, they demonstrated the high accuracy of the model, by which the large-sized car conversion coefficient is considered.

1.2.4 Research on the use of the probe investigation data

Since the traffic situation and action that changes hourly are recorded in the probe data, the probe data is often used to analyze these two properties. Nakagawa *et al.* measured the passing speed on the mountainous areas. They have pointed out a large difference in the time calculated from the actual case and the time that was calculated by assuming the passing speed of the mountainous areas used in the previous macro. Takahashi *et al.* measured the transport speed in the autumn and winter of Sapporo city by using the probe car, and they quantitatively analyzed the effect of the snowbank and the recovery of the travel speed after the roads have been snowplowed. Kitamura *et al.* measured the traffic situation of a trunk line and a minute street located downtown by the probe car, and they analyzed the reported large and small areas in the route, the correlation of the transit speed, and the influence on the transit speed when an interactive or a one-way road is reported. Sakai *et al.* proposed a method to predict the travel time that can correspond to the traffic situation, which changes hourly by using the processed probe data. Uesugi *et al.* examines the method of estimating the expected value and the decentralization of the travel time of the entire selected section from the fragmentary probe tracks for the selected section. They showed that when the mixing rate of the probe vehicle was low, the estimation approach that used fragmentary probe tracks is effective.

1.3 Meaning and purpose of present study

In today's road maintenance, there is a demand for qualitative road maintenance that attempts to ensure safety and reduce congestion, as well as the distribution and improvement of factors including the smoothness, convenience, movement, and traffic. Therefore, to calculate not only the designed daily volume (daily traffic volume) in which not only the road structure is decided but also the easing of congestion and the traffic demand management , the traffic distribution in a short period of time, such as in the morning or evening peak is necessary to create.

The following is an organized summary of existing studies:

- There is a need for the improvement of accuracy in traffic distribution because the link performance function that shows the relationship between the decrease of the road capacity and the decrease of the travel speed is not shown though the road capacity of the sag is analyzed in the bottleneck part.
- There is no parameter setting, which is the element of the vertical inclination on the road. Likewise, there is a need for a parameter setting that reflects the situation of the current state of the road though various research has been conducted for the parameter of the link performance function.
- In the congestion measures, and the link performance function , it is necessary to calculate the traffic distribution that corresponds in a short period.

Therefore, it is necessary to improve the accuracy of the BPR function as the vertical inclination to express the flow of traffic for a short time, which is needed for calculating the distributing traffic in time, and to reflect the reduction of speed on a steep section that realistically occurs in an actual traffic situation.

Therefore, the two following matters are examined in the present study:

- Proposal of the link performance function (BPR function) that focuses on a short period of time
- Improvement of the accuracy of the BPR function that considers the vertical inclination on the road

2. OUTLINE OF RESEARCH

2.1 Flow of research

The following is the procedure of this study:

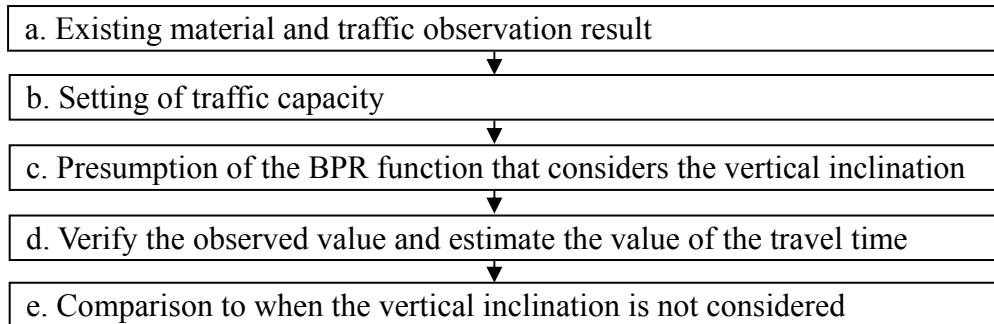


Figure 2 Flow chart of research

2.2 Arrangement of existing material and the traffic observation result

The typical cross-section in the route concerned is shown from the existing road plan material, the design condition, and the vertical inclination in Figure 3 and Table 2.

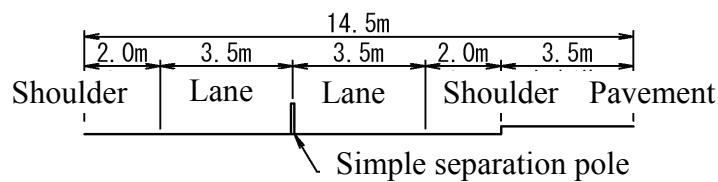


Figure 3 Imitative standard cross section

Table 2 Design condition and vertical linear on the road

Item		Content			
Division of road		The third kind and first class			
Design speed		V=80km/h			
Restriction speed		V=60km/h			
Inclination of the road					
Section	Inclination %	Length M	Section	Inclination %	Length m
1	3.50	560	11	-3.00	195
2	3.50	280	12	4.00	350
3	-3.97	400	13	2.03	360
4	-0.67	300	14	-2.47	640
5	4.00	300	15	1.60	320
6	-3.89	265	16	-1.80	420
7	-4.24	50	17	3.00	460
8	-3.79	100	18	-3.00	460
9	-4.12	50	19	1.30	500
10	-2.54	50	Total		6,060

And, the traffic census did the content shown in Table 3 on November 16, 2009(fine on Monday 7:00-9:00) and November 20, 2009(fine on Friday 17:00-19:00).

Table 3 Content of traffic census

Item	Content
Car size (Large or Small)	It totals it every ten minutes
Traffic observation according to direction	4place×2h×2days
Travel speed investigation by probe car	6times·direction/2h×4cars×2days

The investigation result chart November 16, 2009(Monday 8:30-8:40) is shown in Figure 4 as a case with the result of the traffic census.

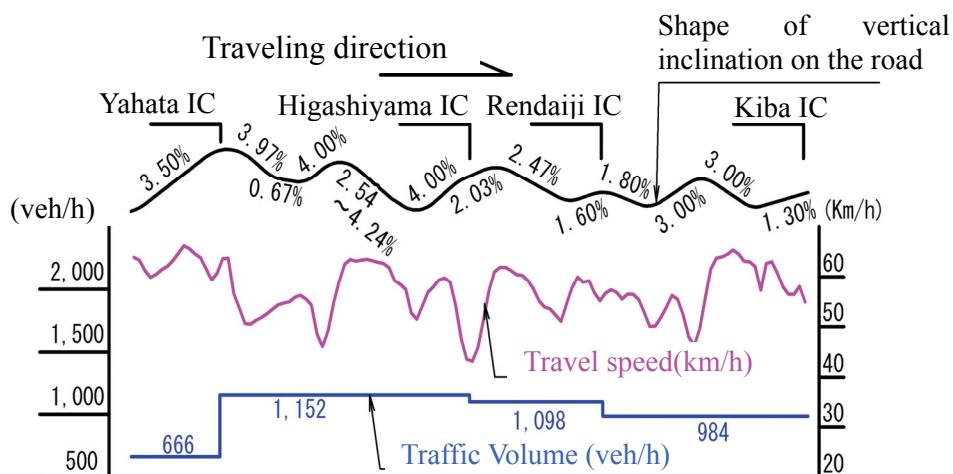


Figure 4 Investigation result chart November 16, 2009 (Monday 8:30-8:40)

In addition, the relationship between traffic and the travel speed is shown in Figure 5. Because the BPR function is a simple increasing function, the observed value of the congestion style part where the travel time overlaps for traffic due to congestion is assumed to be an examination of the subject.

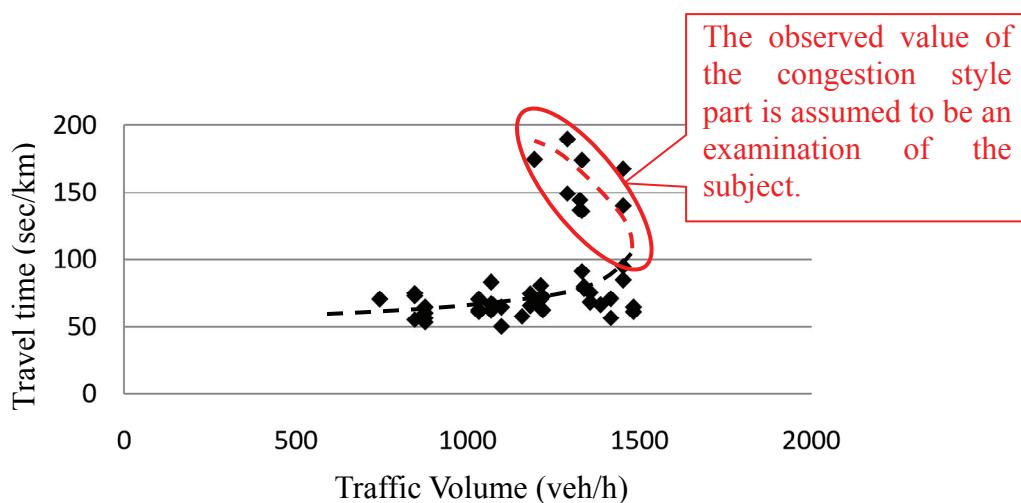


Figure 5 Relation between traffic and travel speed

2.3 Setting of traffic capacity

The road capacity was set as 1,540/h/lane from the value of the same direction in the 2006 road traffic census and the road structure is the same as the neighborhood observation point. Moreover, the road capacity is corrected based on the road capacity according to the vertical inclination by the formula shown in figure 6.

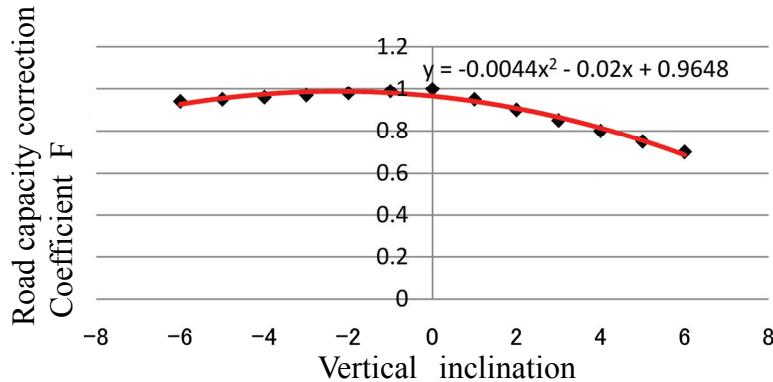


Figure 6 Relationship between the vertical inclination and road capacity correction coefficient

$$C = 1,540 \cdot F \quad (1)$$

$$F = -0.0044 \cdot I^2 - 0.02 \cdot I + 0.9648 \quad (2)$$

I : Vertical inclination (%)

F : Road capacity correction coefficient

2.4 Presumption of the BPR function that considers the vertical inclination

The BPR function that considers the vertical inclination is the following formula:(3).

$$t = t_o \left\{ 1 + \alpha \left(\frac{v}{C} \right)^\beta \right\} \quad (3)$$

t : Travel time (min)

t_o : Free travel time (min)

v : Traffic Volume (veh/h)

C : Road capacity (veh/h)

α and β : Constant

The results of the traffic volume and travel speed investigation result is totaled in the same vertical inclination section, and the combination of t_o, α, β , which requests the error of the square sum with the observed value is minimized. However, a presumption of the section extension from the subject is an observed value in 7-10 sections with 50m-100m to receive the influence of the back and forth short section.

2.4.1 Relativity of the constant (t_o, α, β) of the BPR function and vertical inclination

The constant of the BPR function and the relativity of the vertical inclination are thought to be as follows from the existing document.

- If the vertical inclination is relatively steep, it increases and if the vertical inclination is not steep then it decreases as t_o is the travel time when traffic is 0. Therefore, it is thought that this is highly related to the vertical inclination.
- α is an increasing rate of traffic below the capacity at the travel time. Therefore, it is thought that it influences the travel time according to the vertical inclination.

- β is a value in which the curved condition of the BPR function is shown, and the travel time increases rapidly compared with traffic more than the traffic capacity when β is large.

It is thought that β doesn't depend on the vertical inclination to cause the velocity lowering regardless of the vertical inclination when the traffic exceeds its capacity.

2.4.2 Approximation process of t_o, α, β

t_o, α, β were presumed according to the following procedures.

- Traffic and the travel speed observation data of the same inclination section are totaled according to the inbound-outbound line.(The data of the congestion style part is deducted.).
- t_{oi} substitutes the value one by one for 40-80 seconds every second.
- α_j substitutes the value of 0.01-3.00 one by one by 0.01 units.
- β_k substitutes the value of 0.01-10.00 one by one by 0.01 units.
- t_o, α_j, β_k are substituted, and the presumption travel time t_x is calculated.
- The combination of t_o, α, β which has the minimum error of the square sum between the presumption travel time t_x and where the observation travel time t_a is minimized, is calculated.

$$t_{xn} = t_{oi} \left\{ 1 + \alpha_j \left(\frac{v_n}{C} \right)^{\beta_k} \right\} \quad (4)$$

$$Z = \sum (t_{an} - t_{xn})^2 \Rightarrow \text{Min} \quad (5)$$

n: traffic and the number (48 data or less) of same inclination sections of travel speed observation data

t_{oi} : assumption freedom travel time (min)

v_n : nth observation traffic (veh/h)

C : Road capacity in a section concerned (veh/h).

α_j and β_k : Assumption constant

2.4.3 Estimated result of t_o, α, β

Figure 7-9 shows the relationship between t_o, α, β and the vertical inclination I obtained by the above-mentioned calculation. The number of the evaluation data is 30.

Though the vertical inclination, t_o and α have the correlation from Figures 7 and 8, neither the vertical inclination nor β are correlated from Figure 9. Since β doesn't depend on the vertical inclination, the value of the error of the square sum in all sections is minimized and is adopted. Therefore, t_o, α, β are presumed as follows.

$$t_o = 0.0002 \cdot I^3 - 0.0027 \cdot I^2 + 0.0155 \cdot I + 0.96 \quad (6)$$

$$\alpha = 0.0063 \cdot I^2 - 0.0142 \cdot I + 0.1596 \quad (7)$$

$$\beta = 0.94 \quad (8)$$

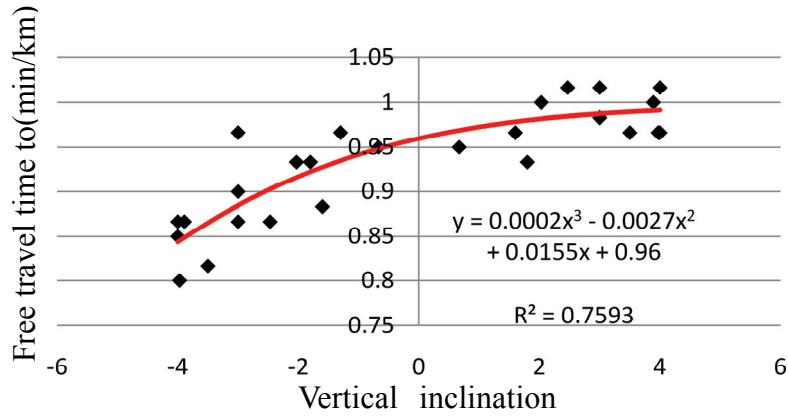


Figure 7 Relationship between the vertical inclination and free travel time

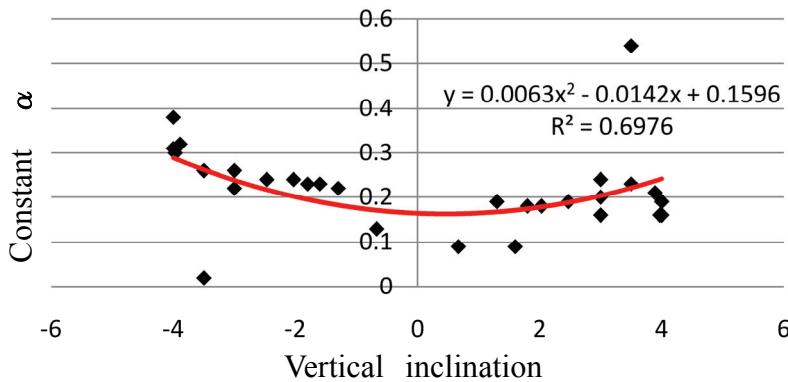


Figure 8 Relationship between the vertical inclination and α

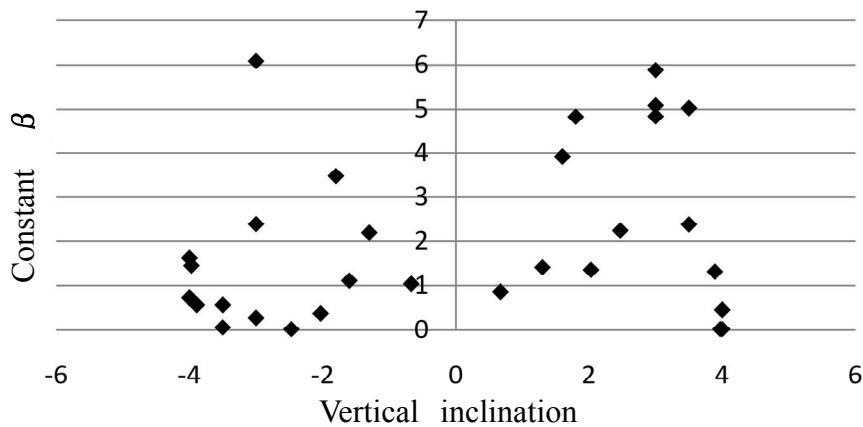


Figure 9 Relationship between the vertical inclination and β

2.5 Observed value at travel time and verification by estimation

The presumption travel time t_x and observation travel time t_a of each section are verified by using the presumed t_o, α, β . It verifies it according to 1,702 data (93.3% of the number of the all observational data) that excludes the congestion style data ($N=122$) from all of the observational data ($N=1,824$).

As a result of the verification, the correlation coefficient of the presumption travel time t_x and the observation travel time t_a was 0.904. In them, the correlation was very strong (Refer to Figure 10).

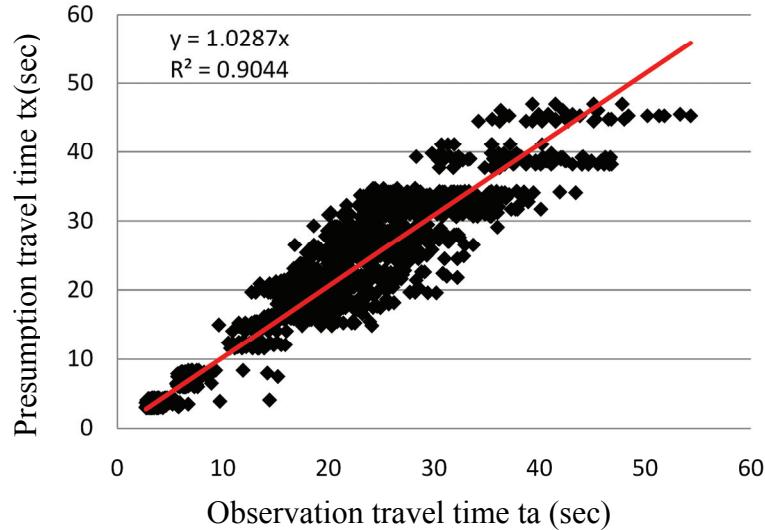


Figure 10 Correlation of observation travel time and presumption travel time

From Table 4, the root mean square error (RMSE) is 3.5 seconds and the root mean square rate (%RMS) is 17.6%, which is considered low.

Table 4 Verification result table

Item	Value
Number of data for evaluation	1,702 data
Mean value at observation travel time (t_a)	20.6 sec
Mean value at presumption travel time (t_x)	20.9 sec
Root Mean Square Error (RMSE)	3.5 sec
Root Mean Square rate (%RMS)	17.6%

2.6 Comparison of when the vertical inclination is not considered

In this study, the presumption travel time was calculated in consideration of the vertical inclination and we compare it to the case that doesn't consider the vertical inclination. The constants used in the comparative study are the values of the "Two lanes in the mountainous district", which presumed the function of time BPR used by Yoshida *et al.*.

Values of Yoshida *et al.*: $t_o = 1.471$ (min), $\alpha = 0.103$, $\beta = 3.7$

Table 5 Comparative study result

Item	This research results	Values of Yoshida <i>et al.</i>
Number of data for evaluation	1,702 data	
Sum of Error Square	21,222.52	220,253.61
Root Mean Square Error (RMSE)	3.5 sec	11.4 sec
Root Mean Square rate (%RMS)	17.6%	56.7%

From Table 5, this study's results are 90.4% less than the results that did not consider the vertical inclination (estimated result by the values of Yoshida *et al.*) sum of error square, and became the results of the root mean square error decreasing by 69.3%.

Thus, it is thought that the improvement of accuracy for estimating the travel time was attempted by considering the vertical inclination.

3. RESULT OF RESEARCH AND CONSIDERATION

In this study, the purpose was proposing the link performance function (BPR function) in a short period of time and improving the accuracy of the BPR function, which considered the vertical inclination. We estimate the t_o, α, β BPR function based on traffic and the road situation (vertical liner) in the morning and evening peak.

As a result, the correlation coefficient between the presumption travel time and observation travel time in the same inclination section is 0.904, which is very strong. The root mean square rate is 17.6% ,and it is very small. Moreover, it was confirmed that the root mean square rate decreased from not considering the vertical inclination by 69.0%. Therefore, it is thought that the accuracy is high.

However, to presume the travel time more generally and accurately, we have the following points.

3.1 Collection and analysis of data under various road conditions

In this section of the research, comparatively the road was wide, and its maximum vertical inclination was about 4%. Moreover, there was no traffic going in and out of the route, and a delay in the travel time from the signal was not found either.

However, because there are a lot of roads that are narrow and steep, it is necessary to presume a constant of the BPR function with high generality by collecting and analyzing many travel data related to steepness in various widths and vertical inclinations.

In addition, it is necessary to consider the situations of not only the width and the vertical inclination of the road but also urban areas and DID districts, as well as consider the delay because of intersection signals. For instance, the following expressions are thought.

$$t = t_o \left\{ 1 + a \left(\frac{v}{C} \right)^\beta \right\}$$

$$t_0 = t_1 + t_2 + t_3$$

t : travel time (min)

$t_1 \sim t_3$: free travel time to have considered the driving condition (road condition, roadside condition, and intersection signal condition in the width of the road and the vertical inclination, etc.) (min)

V: traffic Volume (veh/h)

C: Road capacity in which the driving condition was considered (veh/h)

t_c, α, β : Constant that considers the driving condition

3.2 Link performance function in congested and non congested traffic

The travel time is different even when traffic is the same depending on if it is congested or non congested. Therefore, it is important to change the calculation method that uses the link performance function when it is congested or non congested by catching the change in traffic by consecutively calculating the traffic distribution timewise.

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