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Estimating Loss of the Latent and Manifest Performance of Roads in the Mobility Function

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Abstract

In recent years, discussions on the study of performance-oriented design and the forming of hierarchical road networks are increasing in Japan. Therefore, it is important to understand and evaluate the performance of roads in the mobility function. Thus, this paper tried to formulate the latent performance of road which is determined by road structure and traffic management without traffic volume, and the manifest performance which is revealed by the traffic volume by using the travel speed under the assumption that the sum of the mobility function MOE and the access function MOE is constant. By formulation, it is understood that speed reduction is greatly influenced by signalized intersection density as loss of latent performance and degree of saturation and the access function MOE as loss of manifest performance. Assuming speed limits to be the performance target, the loss of the latent and manifest performance were calculated from the difference between performance target and the estimated travel speed.

Keywords: Mobility function, Latent perfomance, Manifest performance, The FY2015 road traffic census ;

1. Introduction

In recent years, discussions on the study of performance-oriented design and the forming of hierarchical road networks are increasing in Japan (Nakamura et al (2005), Nakamura and Oguchi (2011)). Especially, how to set the performance of mobility functions is an important theme, and performance can be evaluated by clarifying target setting. In addition, it can be said that it also leads to construction of functional hierarchical road networks. Therefore, it is important to understand and evaluate the performance of roads in the mobility function.

In order to set the performance of the road, it is necessary to clarify the mobility functions of the road. The mobility functions of the road are largely divided into the traffic function and the access function. The traffic function

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emphasizes quick transportability to the destination, and often evaluates the performance using the travel speed (e.g. HCM (2016)). It is also shown in the analysis by Kozuka et al. (2012) that the travel speed decreases due to the degree of saturation, the density of signalized intersections, etc. Although it is general, by observing the travel speed when the traffic volume is sufficiently small, it is possible to understand the actual condition of the basic performance which the road originally possesses.

The access function is a function for a vehicle to stop by or stop at a facility along the roadside. A clear evaluation index has not been set yet and some studies (e.g. Hayakawa and Nakamura 2009) are expressed by travel speed due to the speed reduction at the time of access.

Regarding the access function, HCM (2016) shows the calculation method for base free flow speed. And base free-flow speed adjustment factors are also included for some of the access functions such as access point density, percent with on-street parking, etc. However, these indices are not fully explainable for access function. The access Management Manual (2014) suggests a basic idea of access management for various roads. But it still can not decide how to evaluate the access function MOE and the relationship between the traffic function and the access function.

Therefore, this paper focuses on the travel speed which is one of the leading performance indices representing the traffic function. The authors tried to understand the actual condition of the road's basic mobility performance by formulating the travel speed based on the assumption that performance indices of both traffic function and access function can be represented directly or indirectly by travel speed. In addition, the authors estimate the performance of the road not considering the traffic demand (latent performance) and the performance of the road considering the traffic demand (manifest performance), and calculate the loss amount of each performance from the comparison of the performance target and the performance of the actual road.

2. Mobility functions and hypothesis of the latent and manifest performance

This chapter shows hypothesis of mobility functions and defines latent and manifest performance. Fig.1. shows the hypothesis of mobility functions and the schematic diagram of the latent and manifest performance.

2.1. Hypothesis of the relationship between traffic function and access function

The traffic function and the access function are in a trade-off relationship, and the situation as shown in Fig. 1. (a) is said to be ideal for a functional hierarchical road network. In this research, assuming that the sum of the performance of the traffic function and the performance of the access function is constant, this relationship can be expressed as Eq. 1.

$$MOE_t + MOE_a = Const. \tag{1}$$

where, MOE_t and MOE_a are measure of effectiveness of traffic function and measure of effectiveness of access function, respectively.

The performance index (MOE: Measure of effectiveness) of the traffic function can be expressed using the travel speed as described above, but the performance index of the access function is not clearly set. Roads with high access functions are similar to road environments that degrade traffic functions such as high intersection density, easy access to other roads, and many roadside facilities. Therefore it can be assumed that travel speed is low on roads where the performance of the access function is high. Assuming that the performance of the access function can be represented by the travel speed as well as the performance index of the traffic function, it can be expressed as in Eq. 2.

$$Travel\ speed[km/h] = \beta \times MOE_a + \varepsilon \tag{2}$$

where, *Travel speed* is the 12h daytime travel speed (km/h), β is a parameter for converting the access function MOE into the unit of speed and ε is the constant term of representing the traffic function MOE (km/h).

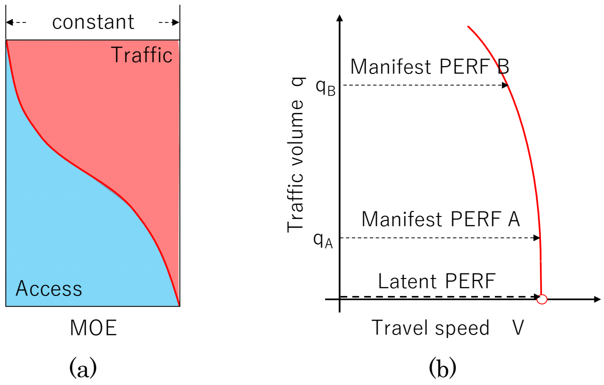


Fig. 1. (a) Hypothesis of mobility functions; (b) Schematic diagram of the latent and manifest performance.

2.2. Definition of the latent and manifest performance

Latent performance is defined as the travel speed when only one vehicle travels along a road (red circle in Fig. 1. (b)). In other words, in the section where the traffic volume is extremely small, such as a bypass at midnight, traffic interruption and the like are not experienced, so the latent performance of the road is demonstrated. However, on actual roads in Japan, in addition to the fact that main traffic is obstructed by signalized intersections being installed in multiple places and entering and leaving from roadside facilities, road structures such as gradient, road width provide an environment in which the latent performance of the road cannot be fully demonstrated (blue circle in Fig. 2.). In this paper, latent loss is defined as the amount of potential degradation of such roads.

The manifest performance can be defined as decreasing mainly as traffic volume (degree of saturation) increases for a road (red line in Fig. 1. (b)). The manifest performance is thought to cause a decrease in the travel speed as the traffic volume increases, and the amount of decrease due to this manifest performance is defined as a manifest loss (blue broken line in Fig. 2.). Therefore, by adding the term of the latent performance and the loss of the manifest performance described by Eq. 2, the travel speed on the actual road can be expressed by Eq. 3.

$$Travel\ speed[km/h] = \beta \times MOE_a + \gamma \times L + \varepsilon \tag{3}$$

where, L is the function of loss for the latent and manifest performance and γ is a parameter for converting the loss into the unit of speed.

In order to model travel speed on the basis of Eq. 3, chapter 4 shows how to understand the access function and the influencing factors of the loss.

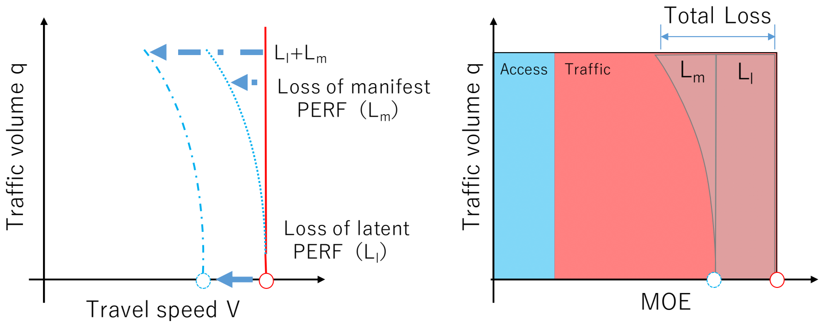


Fig. 2. Basic idea of loss of the latent and manifest performance

3. Analysis of the performance of different influencing factors

3.1. Data collection and aggregation

In this paper, the following analysis was conducted using Japan's FY 2015 Road Traffic Census data. Indexes are defined as follows.

- *12h daytime travel speed (km/h)* : The data for the Fall of FY2015 are counted, and the average travel speed for the 12h daytime travel speed [km/h] is calculated from the average travel speed in the daytime from 7:00 to 19:00.
- *Degree of saturation* : The ratio of traffic volume to capacity in the basic section.

$$Degree\ of\ saturation = \frac{Traffic\ volume[veh/12h]}{Capacity[veh/12h]} \tag{4}$$

- *Road type* : There are 7 kinds of road types; 1.National expressway, 2.Urban expressway, 3.Ordinary road, 4. Major regional road (prefecture road), 5.Major regional road (city road), 6.Ordinary prefectural road and 7.others.
- *(signalized) Intersection density(/km)* : Number of (signalized) intersections per km in road condition survey unit section.

$$(signalized)\ Intersection\ density = \frac{Number\ of\ (signalized)\ intersections}{Investigation\ unit\ interval\ extension[km]} \tag{5}$$

- *Type of median strip* : There are 8 types of median strip; 5 kinds of physical separation, 1 type of simple separation and 2 kinds without structure. In this paper, physical separation and simple separation are classified as "separation", without structure as "non-separation".
- *Access control* : There are 4 kinds of access control; full access control, partial access control, no access point due to physiographic factor and access free.
- *Route state* : There are 5 types of route state; Densely Inhabited District (DID) & commercial area, DID (except commercial area), other urban district, flatland district and mountainous district.
- *Speed limit(km/h)* : The maximum speed displayed by road signs. For the roads not designated for the maximum speed, the maximum speed specified by the Enforcement Order of the Road Traffic Law was taken.

Using these data, factors influencing latent and manifest performance are analyzed. In addition, it is also assumed that the degree of influence of loss differs between the area where the road is hierarchized and the area where it is not. Therefore, in this paper, two regions of Hokkaido and Aichi were analyzed.

3.2. Influencing factors of the latent performance

To understand the factors affecting the deterioration of the latent performance, the 12h daytime travel speed was compared by speed limit, road type and signalized intersection density (Fig. 3.). In the box-and-whisker diagram shown here, a value that is 1.5 or more times as long as the length of the box (between the 1st and the 3rd quartiles) is taken as an outlier, and the maximum value and the minimum value are calculated. In addition, irregular data in sections such as Interchange/Junction merging and railroad crossings were excluded from analysis.

- *Speed limit*

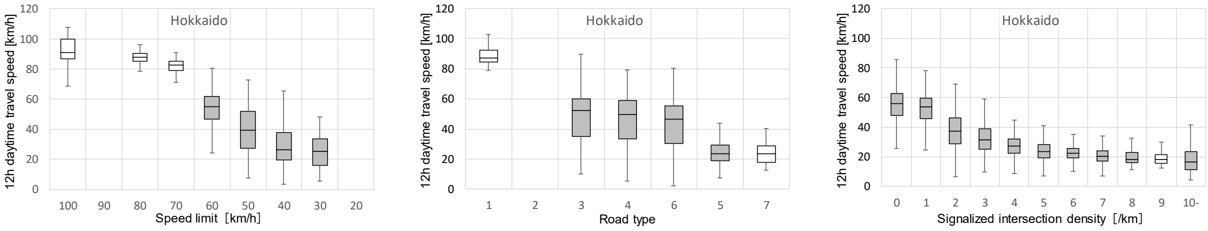
  In Hokkaido, as the speed limit decreases, the travel speed also decreases step by step. However, in Aichi, the travel speed became almost constant over the regulated speed of 60 to 30 km/h. According to the result of Hokkaido the speed hierarchy changes according to the speed limit, which is a factor of lowering latent performance. In addition, since gradual speed change was confirmed by analysis result of speed limit, it can be said that the hierarchy of the road is clear in Hokkaido compared to Aichi.
- *Road type*

According to the results of analysis based on the road type, in both Hokkaido and Aichi, the travel speed is almost flat with ordinary road and major prefecture road (3,4,6), which is not hierarchical. However, in Hokkaido it is about 50 km/h, while in Aichi Prefecture it is about 30 km/h, which is a larger deviation than Hokkaido. In the index of road type, there are only two speed grades on the other road and roads beyond that, it can not be said that this is a declining factor of latent performance.

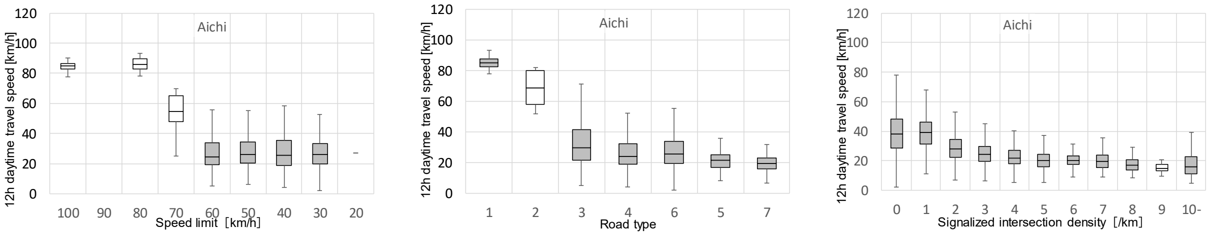
- *Signalized intersection density*

The values of the signalized intersection density were rounded up and analyzed in 11 stages of 0 to 9 and 10 or more. In both Hokkaido and Aichi, it can be seen that the travel speed decreases as the signalized intersection density increases. Therefore, it can be seen that the signalized intersection point density is also a factor of lowering the latent performance.

Based on the analysis results of the above three indices, the regulation speed and the signal intersection density are used as models for lowering the latent performance and used for the modeling.



(a) Hokkaido & Speed limit (b) Hokkaido & Road type (c) Hokkaido & sig intersection density



(d) Aichi & Speed limit (e) Aichi & Road type (f) Aichi & sig intersection density

※Outliers are hidden and white color boxes express less than 50 samples

Fig. 3. Results of influence on the latent performance.

3.3. Influencing factors of the manifest performance

Analysis is carried out focusing on the access function MOE and the degree of saturation as the influencing factors of the declining manifest performance.

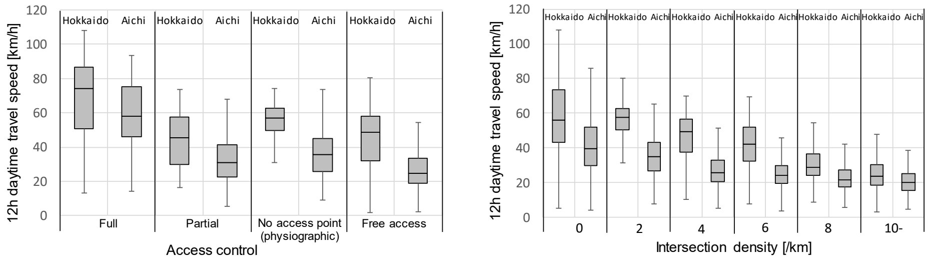
- *Access function MOE*

In this paper, it is assumed that the access function MOE consists of two kinds of "road access function MOE" and "roadside access function MOE". Road access function MOE represents movement from the subject road to another road, and uses "Access control" indicating the access restriction situation and "Intersection density" capable of expressing the access opportunity. The roadside access function MOE represents the movement from the subject road to the roadside facility, and the "Typical route state" that can express the number of facilities and the "Median strip" which can express the restriction on the roadside access.

The relationship between road access function MOE and travel speed is shown in Fig. 4. (a), (b). The road access function MOE tended to decrease in speed as access opportunities increased, such as "partial access control" and "Free access" of access control (Fig. 4. (a)). The intersection density (Fig. 4. (b)) shows that the higher the density, the lower the travel speed, which is affected by entering and exiting vehicles, turning vehicles etc.

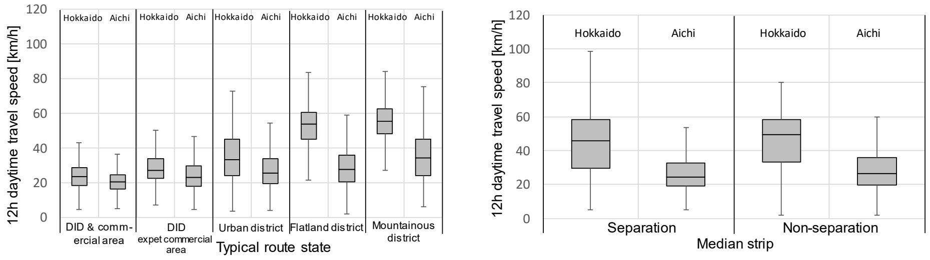
The relationship between roadside access function MOE and travel speed is shown in Fig. 4. (c), (d). The typical route state (Fig. 4. (c)), the travel speed of DID is lower than that of other districts. This is considered to be due to the fact that DID has more locations of roadside facilities and is affected by entering and exiting vehicles. In addition, although it was assumed that the travel speed would be higher if the median strip was installed, there was no significant difference from the non-separation cases (Fig. 4. (d)). This may be due to the fact that only a part of the section is set up with the median strip, and there are few roadside facilities, and there is little entering and exiting without a median strip.

From the above, the influence on the travel speed was confirmed by the access function MOE excluding the median strip.



(a) Access control

(b) Intersection density



(c) Typical route state

(d) Median strip

※Outliers are hidden

Fig. 4. Relationship between the access function MOE and travel speed.

・*Degree of saturation (V/C)*

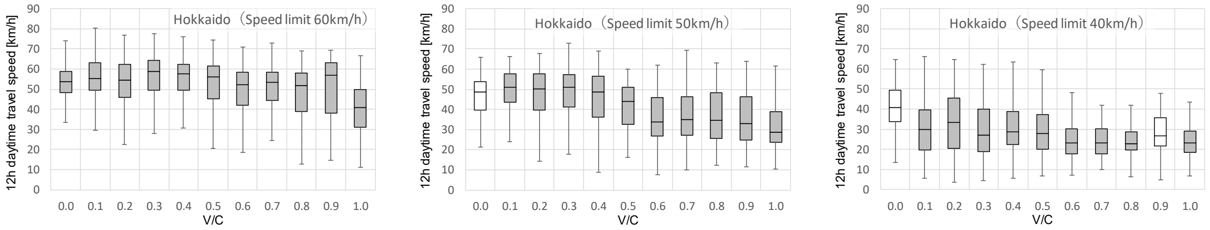
Changes in the 12h daytime travel speed according to V/C are shown in Fig. 5.

In order to understand the influence on the travel speed by the degree of saturation (V/C), the influence on the travel speed by V/C was confirmed for the speed limit and the access function MOE. In Hokkaido, the travel speed decreases as V/C increases, but in Aichi it is almost flat. Also, focusing on the result of speed limit 50 km/h, in Hokkaido, the median value is about 50 km/h at approximately V/C = 0.3, whereas in Aichi it is about 23 km/h at the same V/C condition, which is much lower than the speed limit. This is because Aichi has lower latent performance than Hokkaido and that it is likely to be influenced by entering vehicles even if V/C is low, such as roadside access vehicles etc. Especially in Hokkaido the speed reduction due to the increase in V/C was confirmed, so V/C as an influencing factor of manifest loss will be added to the model.

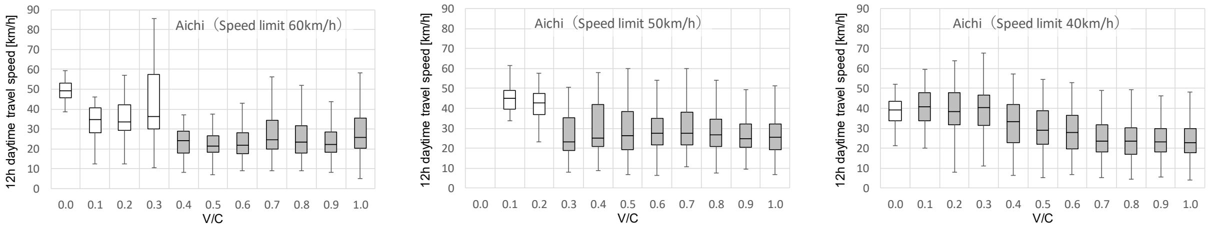
Analysis of V/C and access function MOE focused only on conditions susceptible to V/C. Specifically, They are: the access control is Access free, the intersection density is 10 or more, the typical route state is DID and the median strip is non-separation data. Fig. 6 shows the relationship between V/C and access function MOE. As for the access control, as the V/C becomes larger, it is understood that the travel speed gradually decreases. However, the intersection density was nearly flat, even if V/C increased. This is because the intersection density is correlated with the signalized intersection density, and it is conceivable that it is difficult to be influenced by V/C. For the median strip, it can be seen that the speed gradually decreases as V/C increases. However, the typical route state is almost flat, even if V/C increases. This is because the signalized intersection density is very high in DID, so it is greatly affected by the signalized intersection point, and there is a possibility that the influence of V/C becomes very small.

From the above, in the access function MOE, it was confirmed that the decrease in the traveling speed by V/C became clearer for free access and non-separation. However, in the case of V/C = 0.0, the intersection density and the typical route state are slightly larger than other values though the number of samples is small in both Hokkaido and Aichi, which is considered to be influenced by V/C. Therefore, the four access function MOEs are added to the model as influencing factors of the manifest loss.

However, especially in Aichi there is no difference between V/C = 0.5 and V/C = 1.0. Therefore, when V/C = 0.0, the access function MOE is assumed to have no influence on the reduction of the travel speed and a model is developed.



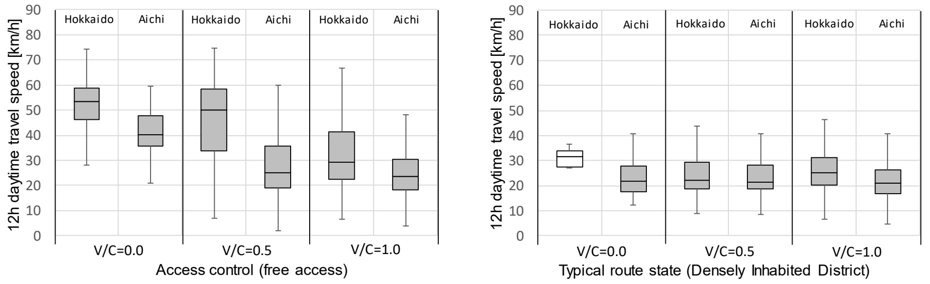
(a) Hokkaido & 60km/h (b) Hokkaido & 50km/h (c) Hokkaido & 40km/h



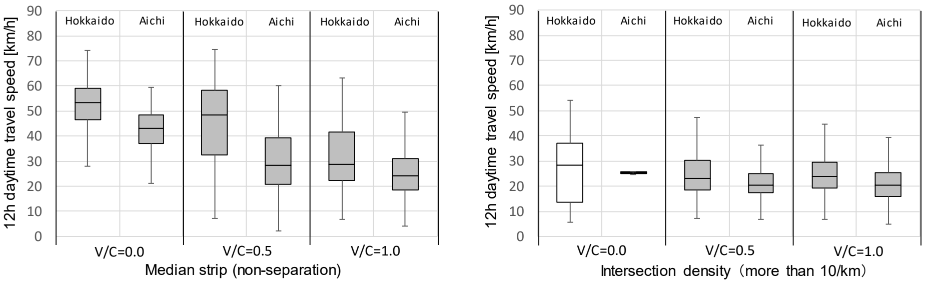
(d) Aichi & 60km/h (e) Aichi & 50km/h (f) Aichi & 40km/h

※Outliers are hidden and white color boxes express less than 50 samples

Fig. 5. Relationship between V/C and travel speed in the traffic function MOE.



(a) Access control & V/C (b) Typical route state & V/C



(c) Median strip & V/C (d) Intersection density & V/C

※Outliers are hidden and white color boxes express less than 50 samples

Fig. 6. Relationship between V/C and travel speed in the access function MOE.

4. Modeling travel speed and calculation of the loss of the latent and manifest performance

4.1. Modeling 12h daytime travel speed

Based on the Eq. 3 shown in Chapter 2 and the results of the influential factors on the latent and manifest performance in chapter 3, 12h daytime travel speed is modeled. Especially, in the case of V/C = 0.0, with only the subject vehicle, assuming that there are no other roadside vehicles, Eq. 6 is obtained.

$$Travel\ speed[km/h] = \sum_{i=1}^{m}\{\beta_i \times (MOE_{ai} \times D_{V/C})\} + \sum_{j=1}^{n}(\gamma_{lj} \times L_{lj}) + \sum_{k=1}^{l}(\gamma_{tk} \times L_{tk}) + \varepsilon \qquad (6)$$

where, $D_{V/C}$ is the dummy value of V/C (at V/C=0.0, this value become 0), m, n and l are the number of the access function MOE, the number of the loss function of the access function MOE and the number of the loss function of the traffic function MOE, respectively.

As shown in Table 1, 12h daytime travel time is modeled by using latent loss, manifest loss and access function MOE. V/C values more than 1.0 were set to 1.0.

In this paper, it is assumed that all functions are linear from the result of Chapter 3, and they are obtained by multiple linear regression analysis. The explanatory variables and results given in the multiple regression analysis are shown in Table 1.

In both Hokkaido and Aichi, except for dummy of access control, there was a similar trend, almost all explanatory variables became negative, and the result was as expected. Except for the flat area dummies in Hokkaido, the absolute value of the t value of all the variables was larger than the limit value of the 10% level (two-sided test). Among the latent performance variables, there is a big difference in the speed limit dummy coefficient. The difference between the speed limit of 60 km/h and less than or equal to 30 km/h is about 15 in Hokkaido, whereas it is about 5 in Aichi, which indicates that the difference in hierarchy appears. In V/C which is the variable of manifest loss, the coefficient is larger in Aichi. As shown in Fig. 4, Aichi tends to be more influenced by V/C.

In the access function MOE, the absolute value of the coefficient increased in the DID district of the dummy of the route state. This can express the decrease in the travel speed in the area where there are many roadside accesses. Furthermore, the absolute value of the coefficients became smaller toward flatland district, and the same tendency as the analysis result of Fig. 3. (a) was obtained. However, the coefficient of dummy of access control in Hokkaido became positive, resulting in the opposite result to the assumption.

Table 1. Multiple regression analysis-coefficient (t-value).

Explanatory variable			Hokkaido	Aichi
ε : constant			87.7(66.2)	87.2(73.6)
Loss of latent PERF	Signalized intersection density[/km]		-1.56(-17.6)	-1.36(-24.8)
	Dummy of speed limit	・60km/h	-34.6(-25.1)	-32.1(-25.0)
		・50km/h	-38.3(-27.3)	-33.1(-25.4)
		・40km/h	-43.1(-30.0)	-34.8(-26.6)
		・less than 30km/h	-49.8 (-26.4)	-37.2(-26.9)
Loss of manifest PERF	V/C (V/C≥1.0 as V/C=1.0)		-3.91(-8.05)	-5.47(-13.4)
Road access function※	Dummy of access control	・Partial access control	4.14(2.81)	-8.43(-9.80)
		・No access point (physiographic)	6.03(4.79)	-6.83(-7.21)
		・Free access	4.81(8.11)	-12.2(-18.4)
	Intersection density[/km]		-0.66(-17.3)	-0.28(-8.86)
Roadside access function※	Dummy of route state	・DID & commercial area	-8.74(-13.3)	-6.95(-15.6)
		・DID (except commercial area)	-9.25(-15.0)	-6.20(-15.8)
		・Urban district	-7.20(-14.4)	-4.81(-13.2)
		・Flatland district	-0.45(-1.33)	-3.43(-11.1)
	Dummy of Median strip (Separation:0, Non-separation:1)		-0.51(-1.68)	-0.47(-1.70)
R^2 : multiple coefficient of determination			0.56	0.45
Sample size			9.01×10^3	8.63×10^3

※when V/C=0.0, $D_{V/C}$ becomes 0, therefore all MOE of access function also become 0.

4.2. *Calculation of the loss of the latent and manifest performance*

In accordance with the conditions in Table 2, using the results of multiple regression analysis, the estimated value of 12h daytime travel speed is calculated, and loss amount of latent and manifest performance are obtained from the difference between performance target and estimated value. Here, for the sake of convenience, the speed limit is assumed as the performance target of the road. The average signalized intersection density and intersection density are obtained by each region, route state and speed limit.

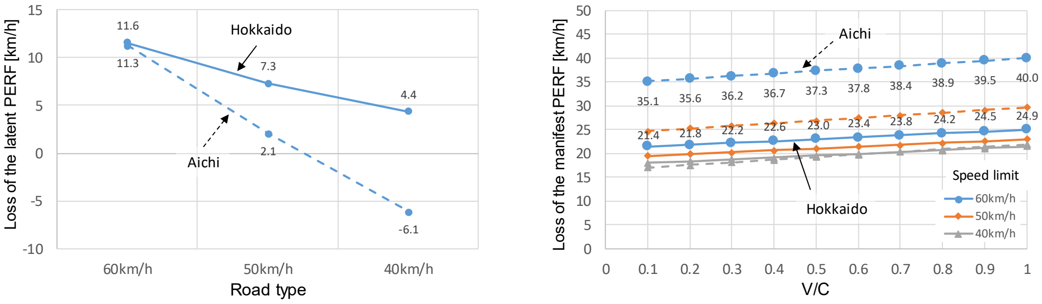
Fig. 7. (a) shows the calculation results of latent losses. Although the latent loss is less in Aichi than in Hokkaido, the estimated value exceeds the performance target at the speed limit of 40 km/h. This is because the coefficient of the dummy of speed limit in Aichi is small as described above. As a cause of this, it is suggested that Aichi may possibly have loophole traffic avoiding congested roads (travel with speed exceeding speed limit). Also, the signalized intersection density has an influence in Aichi. the signalized intersection density does not change regardless of the speed limit, so it is considered that the influence on the estimation value is small.

Fig. 7. (b) shows the calculation result of the manifest losses. In both Hokkaido and Aichi, the tendency is that the loss amount increases as V/C increases. The data label shown in the figure is of speed limit of 60 km/h, and when V/C increases from 0.1 to 1.0, the increase in the loss amount in Aichi is about 1.5 times that in Hokkaido. This is because Aichi has a high sensitivity to the manifest loss to V/C and is in a state susceptible to V/C influence. In addition, it can be confirmed from the comparison between Fig. 7. (a) and Fig. 7. (b) that the manifest performance is largely

degraded by the influence of the access function MOE. Especially in Aichi, its effect is bigger than that in Hokkaido, causing a speed reduction of about 24 km/h.

Table 2. Calculation condition.

Parameter		Road type（Speed limit）		
		60km/h	50km/h	40km/h
Average signalized intersection density (DID& commercial area)	Hokkaido	2.99	4.32	5.74
	Aichi	4.76	4.55	4.67
Average intersection density (DID& commercial area)	Hokkaido	7.57	11.08	13.28
	Aichi	12.94	8.81	10.54
V/C		0.0~1.0		
Dummy of Median strip		1（Non-separation）		
Dummy of access control		Free access		
Dummy of route state		DID & commercial area		
Dummy of speed limit		60km/h	50km/h	40km/h



(a) (b)

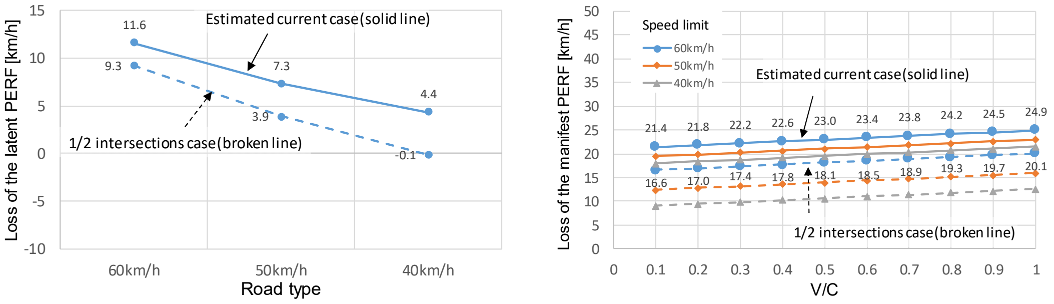
Fig. 7. (a) Estimation result of loss of the latent performance; (b) Estimation result of loss of the manifest performance.

4.3. Sensitivity analysis

Sensitivity analysis of the loss by the case where the number of signal crossing points and the number of intersections were decreased was carried out based on the model equation. Fig. 8. shows the result when the signalized intersection density and intersection density for each speed limit in Hokkaido are halved. By decreasing the number of intersections by half, the latent and manifest performance are improved. Also, the lower the speed limit, the greater its impact.

Fig. 9. shows the result when the signalized intersection density and intersection density for each regulated speed in Aichi are halved. By decreasing the number of intersections by half, the latent and manifest performance are improved. In particular, about 20 km / h improvement is seen for the amount of manifest loss, which is about 5 times larger than Hokkaido in Fig. 8. This is influenced by the high signalized intersection density of the current state in Aichi.

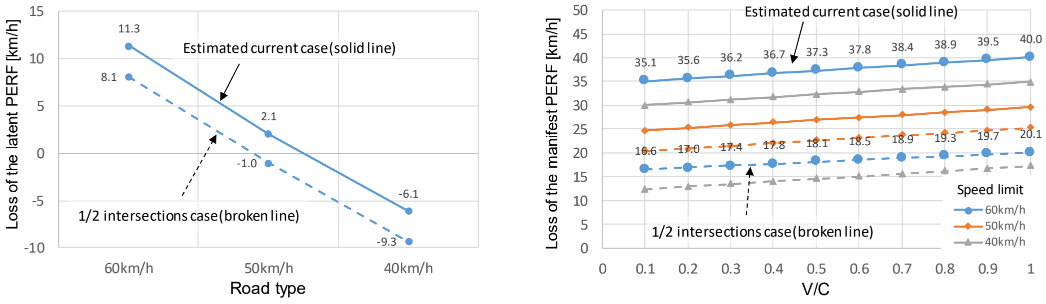
In this paper, sensitivity analysis is performed with signalized intersection density and intersection density halved. but a case of changing access function MOE will also be implemented in the future.



(a) Estimation result of loss of the latent performance

(b) Estimation result of loss of the manifest performance

Fig. 8. Result of sensitivity analysis in Hokkaido.



(a) Estimation result of loss of the latent performance

(b) Estimation result of loss of the manifest performance

Fig. 9. Result of sensitivity analysis in Aichi.

5. Conclusions

In this paper, travel speed was formulated with the loss factor of traffic function MOE based on the assumption that the access function MOE is a factor of reduction of the travel speed. It became possible to estimate the latent and manifest performance in each road type, and the loss amount of each performance on the actual road is calculated with respect to the performance target (the speed limit in this research) by using the estimation formula.

From the result of comparison in two areas with different degrees of hierarchy of roads, it was shown that the loss of manifest performance in the high degree of hierarchy area is smaller than in one with a lower degree of hierarchy. In particular, the signalized intersection density has a large influence on the reduction of the latent performance, and it is required to reduce the signalized intersection density on the high hierarchy road. Additionally, access control indicates that reduction in travel speed can be suppressed by entry and exit restrictions, and it is considered that target performance can be realized by measures such as grade separation and entrance restriction.

This paper is just a trial calculation assuming that the access function MOE is a factor of reduction of the travel speed and it is necessary to carefully discuss the influence of the access function MOE on the performance of the traffic function in the future. Furthermore, analysis was performed assuming the speed limit as a performance target, but it should be noted that the speed limit does not necessarily match the performance target or hierarchy.

In addition, there are many items that consider the number of connecting roads and street parking vehicles etc. as explanatory variables of the performance index of the access function, and it is necessary to continue the discussion considering them.

Furthermore, a linear relationship is assumed between the travel speed and the influencing factors, but the influence of V/C may change exponentially, so further investigation is necessary in the future.

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